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Soil Factors Behind Inground Decay of Timber Poles: Testing and Interpretation of Results

Anisur Rahman and Gopinath Chattopadhyay

***Abstract*—Inground decay is a major problem associated with the reliability and safety of timber poles. In modeling inground decay for effective maintenance strategies for timber poles, it is important to identify soil factors that are influential to the inground decay. This paper investigates some of the important influential soil factors and testing methods for those factors.**

***Index Terms*—Inground decay, maintenance, soil factors, timber poles.**

I. Introduction

TIMBER POLES are used in the electricity supply and telecommunications in many parts of the world.

The function of timber pole is to support the overhead lines and the conductors. Because of their high strength per unit weight, low cost, excellent durability (service life varies generally from 25 to 50 years or even more [1]), timber poles are popular throughout the world. Studies on timber pole management and simulation of replacement of poles for power delivery could be found in [2] and [3]. In Australia, more than 5.3 million timber poles are being used by the utility sector. This represents an investment of around AU$12 billion with replacement costs variously stated to be anything from AU$1500–2500 per pole [4].

Reliability of timber pole is important because breakdown or failure of any one or more of these poles can cause a huge loss to electricity supply organizations. These losses may be revenue loss, loss of property or even loss of life. Reliability and safety of these components depends on multiple factors such as age, loads on poles, durability of timber material and environmental factors such as climatic condition (cyclic wetting and drying, snowfall, humidity and temperature of the surrounding environment are the cause of most of the above ground decay), soil characteristics (moisture and clay contents, pH value and chemical composition are causing most of the inground decay). In Australia, a substantial number of failures of these poles are due to the decrease in peripheral dimensions at or below ground level and loss of strength due to inground decay. Rotting of fibers (at or below ground level) from center to outward, or outward to centre, due to fungal and insect (termite) attack is a significant problem in the south eastern coastal areas [5]. The factors causing inground decay of poles must be taken into account when evaluating new or in-service poles.

The strength of a timber pole can be retained to a certain extent by introducing effective maintenance strategies and managing the influential factors [5]. In order to do so, it is important to first identify the influential soil factors causing inground decay, quantify these wherever possible and develop relationship models to predict inground decay. Although the climate has significant effect on the above ground decay of timber poles, in this paper we focus our attention only on the soil factors causing inground decay of timber poles since only limited research work has so far carried out in this area.

This paper identifies soil variables influential to the inground decay of timber poles and develops mechanism for measuring these variables. Section II investigates possible influential soil factors; Section III discusses the procedure for soil sampling; Section IV deals with the development of different testing methods. In Section V, failure of timber poles according to Australian Standard is defined. Section VI analyses soil data to develop relationship models of soil variables for inground decay; contribution and scope for future research is discussed in Section VII.

II. Investigation and Identification of Influential Soil Factors

The following soil factors were identified after several discussions with industries based on their initial findings of failure rate due to inground decay.

Moisture Content: High moisture content in the soil increases the probability of biological attack. It is significant where the moisture content is more than 20%. In clayey soils, the moisture and chemicals are trapped inside the soil and cause algae, moss, and mould to grow which attack the timber, thereby causing faster deterioration. On the other hand, by virtue of their permeability, cohesion-less sandy soils allow drainage and reduce moisture content. Fiber saturation occurs when moisture content reaches around 30% [6].

Bulk Density: The mass of a unit volume of soil, generally expressed in $\mathrm{g/cm^3}$. The volume includes both solids and pores. Thus, soils that are light and porous will have low bulk densities, while heavy or compact soils will have high bulk densities.

pH Value: Presence of excessive acidity or alkalinity of groundwater in soils can be quantified by the pH value of the ground water.

Salinity: Presence of chloride, sulfate, carbonates or magnesium salts in soil are the indication of salinity. High salinity can cause decay of the timber [7]. A buildup of salts can also be threat to the foundation.

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Temperature: The strength of timber pole is inversely proportional to the temperature of the surrounding soil. An increase in temperature will result in decreased strength of the pole. Seasonal changes also influence cyclic stresses on the pole.

Climate: Climate has influence on soil condition and properties since the moisture content and temperature of soils changes with climate.

Electrical Conductivity: Electrical conductivity can be used to determine the soluble salts in the extract and hence soil salinity.

Chemical Composition: The presence of kaolin, quartz, and other chemicals may have an effect on inground decay.

Effectiveness of Preservatives: Poles in the U.S. and most of the countries are treated now a days with preservatives to provide a protective shell to resist from fungi and insects. However, this protection diminishes over time, permitting degradation of the outer surface, typically by the action of the soft rot, and also degradation of the internal cells. According to Australian Standard AS 2209-1994, hardwood poles are preferred in Australia because of their natural strength. In Australia, 14 different eucalypts have been used. The Australian Standard allows durable Class 1 and 2 species to be used for poles that are not full length preservative treated.

III. Soil Sampling

Power supply timber poles are spread over a wide range of areas and soil conditions and compositions vary from place to place. Foliente *et al.* [8] have grouped Australian land into four inground decay hazard zones. A (lowest decay hazard rate), B, C, and D (highest decay hazard rate) on the basis of intensity of decay of timber due to ground condition. Their studies showed that eastern coastal areas of Queensland and NSW in Australia have the high decay hazard rate. For this study the soil data of different suburbs in Brisbane and the failure rates of timber poles were collected. Suburbs in Brisbane with high replacement rate such as Wynnum, Lota and Manly and Caboolture, and suburbs with less replacement rate such as Chelmer and Holland Park were selected. The soil samples were collected around poles that have failed.

A. Equipment and Instruments Used in Sampling and Testing

Fig. 1 presents some of the essential equipment and instruments used for traditional soil sampling and testing. A brief description of these equipment and instruments is given as follows:

- 50- or 76-mm hand auger with an extension rod, sample bags, and 30 m tape for soil sample collection;
- sample extruder, weigh balance, scale and ruler (Fig. 1);
- electronic tester for measuring PH value, salinity and conductivity—A TPS WP-81 electronic Ph–Cod-salinity meter;
- compact gauge for soil compactness;
- moisture can and oven with temperature control to determine moisture content;
- volumetric flask, 250 ml or 500 ml, vacuum pump and aspirators for supplying vacuum, mortar and pestle, balance (0.1 g), de-aired, temperature-stabilized water for determination of specific gravity of soil;
- X-ray spectroscopy.

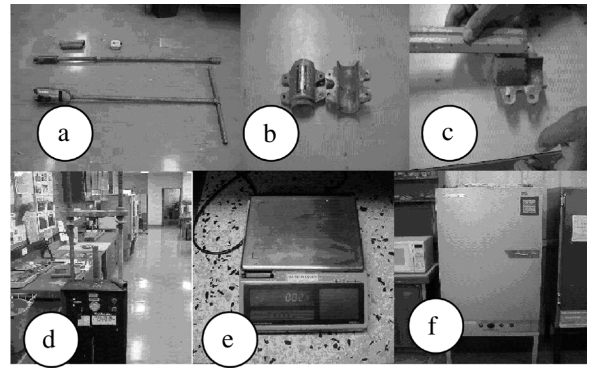

Fig. 1. Equipment and instruments used for traditional soil sampling and testing. (a) Hand augar and sample extractor with accessories. (b) Sample mould. (c) Sample extruder. (d) Nata weigh balance. (e) Drying oven.

B. Sample Collection

- Australian standards [9] specify the selection of sites at random.
- Boundaries of test areas from failed pole data were determined and recorded.
- Length (X) and width (Y) of the area and number of sites to be sampled were decided.
- For each site a random number was selected to multiply it with the length of the area to obtain a longitudinal distance from the start point.
- Another random number was used to obtain a lateral distance from the datum edge.
- The intersection of the above two steps defined the location of the site. Three random numbers were selected to decide sample points for each recently replaced pole within this area. Samples were taken from 0.6 m below the ground and within 1–1.5 m range from the pole.

Samples were obtained by using a soil sampler tube (see Fig. 2 for sampling procedure) and immediately covering it with a layer of wax in order to protect it from the external interference [10]. As satisfactory storage to maintain natural properties of soil samples is difficult, it is recommended to inspect and test the samples at the sites or immediately after their arrival at the laboratory. But when the sample sites are far away from the testing laboratory or further studies are needed, then storage is essential. Each collected sample should have a label with a tag for identification, location of sampling, sampling date and type of soil.

IV. Soil Testing

Both "On the site" and "Off the site" (in the laboratories) tests were carried out to analyze each sample's physical and chemical properties that are important to identify the influential soil factors and their severity.

A. On the Site Testing

For pH value, conductivity and salinity of the sample testing: a WP 81-pH, salinity and conductivity meter TPS (Fig. 3) was used. Solutions were prepared by mixing one part by vol. of soil and five parts by volume of distilled water. pH of soil is measured by dipping the probe of the electronic pH tester into

Fig. 2. Procedures for sample collection and measuring the depth of drill. (a). Drilling with the augar. (b) Sample extraction.

Fig. 3. WP 81-pH, salinity, and conductivity meter.

the prepared solution. Similarly, conductivity and salinity are determined by using specified probes.

B. Laboratory Testing

1) Moisture Content: The percentages of moisture content was estimated by subtracting the final weight of the sample after being dried from the initial weight and dividing it by the initial weight and then multiplying by 100 as given as follows:

$$\% \text{ of moisture content} = \frac{m_i - m_f}{m_i} \times 100$$

where m_i and m_f are the initial and final wt. of the sample.

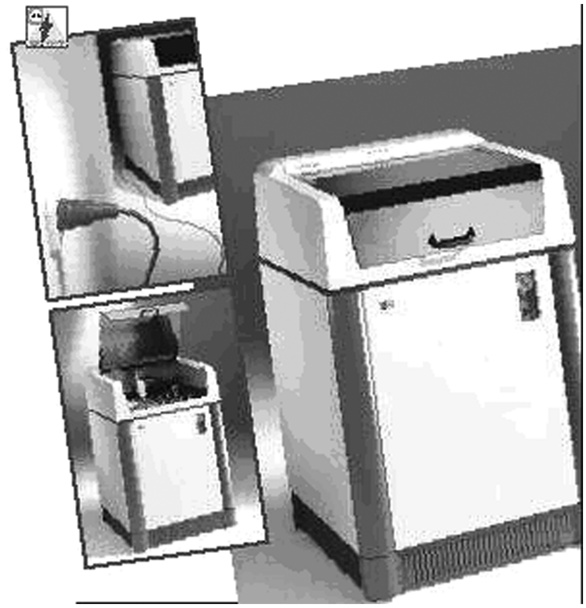

Fig. 4. S4 explorer X-ray Defractometer (Bruker AXS, Inc.).

2) Soil Compactness: Estimated by determining the bulk density. Bulk density (ρ) is given by

$$\rho = \frac{m}{V}$$

where

$$V = \frac{\pi d^2 h}{4}$$

where m, V, d, and h are the mass, volume, diameter, and height of the cylindrical sample, respectively.

3) Chemical Composition: Soil samples were analyzed by X-Ray Powder Diffractometry (see Fig. 4) at the chemical laboratory.

Clay analysis:

- Soil samples were put in a container and distilled water was added to make a solution.
- The mixture is fractionized by using ultrasonic equipment (Branson Sonics) to break up the clay in the soil.
- The mixture is then left for settlement for 10 to 15 min for analyzing the clay content of the particular location.

Chemical analysis:

- The samples are powdered to less than 100 μm using a swing mill.
- 2.7 g of soil are used to mix with 0.3 g. of corundum. The corundum is used to determine the percentages of mineral compositions for the test.
- The mixture is then further broken down to 5 μ in the crushing lab.
- The final samples are then poured into a beaker and placed in the oven for about 16 h to dry it. The dried powdered sample from the beaker is then used for analysis.
- When dried, it is put on an X-ray defractometer (see Fig. 4) for chemical composition analysis.

V. Timber Pole Failure

According to the Australian Standard for timber pole specification, AS 2209-1994, the design life of a timber pole is

TABLE I
SUMMARY OF SOIL TEST RESULT

Suburbs	Moisture Content %	Bulk Density g/cm^3	PH value	Conductivity µS	Salinity ppM	Failure rate /year
Chelmer	10.88	2.66	6.01	101.91	51.93	0.027
Holland Park	11.58	2.45	6.12	54.07	26.55	0.031
Wynnum, Lotta, and Manly	13.5	1.86	5.88	108.03	86.73	0.037
Caboolture	16.73	1.764	5.143	123.91	56.67	0.046

TABLE II
SUMMARY OF CHEMICAL ANALYSIS

Suburbs	Failure rate	% Quartz	% Kaolin	% Albite	Amorphous
Caboolture	0.046	48.32	35.998	11.64	0.366
Wynnum, Lota and	0.037	41.82	24.38		
Holland Park	0.031	50.85	30.92		
Chelmer	0.027	57.14	30.15	23.67	6.60

the period over which a timber pole is required to perform its designated functions. The design life for timber poles from AS 1720.2-1990 Clause 4.17 is up to 50 years for untreated timber of durability class 1. This life of a pole may be shortened due to decay causing strength degradation, which mostly occurs within a region extending about 460 mm above and 460 mm below the ground line. This decay of wood materials is extensive in the presence of oxygen and moisture, as this condition enables metabolic activity and growth of aerobic micro-organisms, such as bacteria, fungi, and insects. Biological decay can extend where the moisture content is more than 20% [6]. An in-service pole is said to be failed or discarded when it failed to conform to the minimum requirements of AS 2209-1994 due to decay above or below ground level. In addition, pole failure may also be due to reasons other than decay, for example, storms, motor accidents, road realignment and loads due to pole mounted equipment. In this research, we only consider the pole failures due to inground decay. The pole failure data used here were collected from the electricity supply and distribution company at Brisbane, Australia. These are taken from the pole replacement data due to poles fallen over and identified weak during inspection.

VI. Results of Soil Test

A summary of the test result are presented in Table I (for physical properties) and Table II (chemical analysis). These data were then analyzed with the failure data of the respective suburbs to determine the effects of identified soil factors on the failure or decay process of timber pole.

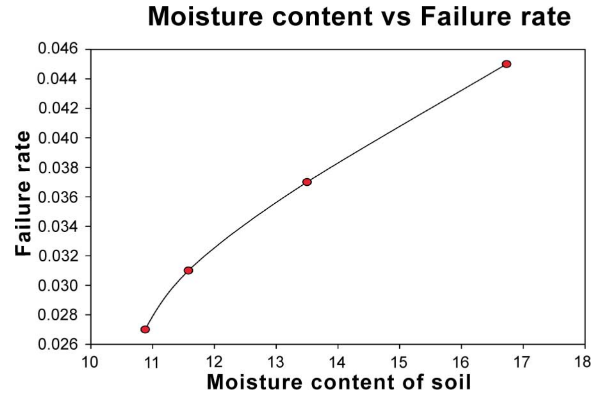

Fig. 5. Relationship of the moisture content of soil with the pole failure rate.

A. Data Analysis

Table I represents the mean value of each of the physical properties of soil for suburbs of Brisbane

1) Moisture Content: The percentage of moisture content in the soil depends on the rain falls, humidity, and temperature of the air and drainage. Meteorological conditions of the sampling site are recorded during sample collection. As the climate changes over seasons, it was necessary to do soil sampling in different seasons. Table I shows that the moisture content of the soil around the poles in Wynnum, Lotta, and Manly suburbs ranged from 5% to 20% with mean moisture content 13.5%. Similarly, the average moisture contents of Caboolture, Holland Park and Chelmer were found to be 16.73%, 11.58%, and 10.88%, respectively. The average service life of timber in Caboolture, Wynnum, Holland Park, and Chelmer are 22, 27, 32, and 37 years, respectively. Estimated failure rates of these suburbs are 0.045, 0.037, 0.031, and 0.027, respectively. A relationship model of failure rate with soil moisture content is presented in Fig. 5.

Fig. 5 shows that the moisture content of the surrounding soil has an influence over the timber pole failure due to the inground decay process. The failure rate increases with the moisture content of the soil.

Moisture is a problem for the stiffness of rail tracts and road bases. Geocomposite is used in the subbase of the rail track to drain out water from the soil. High flow triplanar geocomposite is engineered for long term drainage of water from the base soil. Similar techniques can be used in draining out water from the soil surrounding the timber poles in clayey soil.

2) pH Value: The pH values of the collected samples were found to be between 4 and 7 with a mean of 5.88, in Wynnum, Lota, and Mansfield suburbs which indicates a slightly acidic soil. The average pH value of soil samples collected from Caboolture, Holland Park, and Chelmer were 5.143, 6.12 and 6.01, respectively, which is also slightly acidic. The effect of acidity or alkalinity of soil on the failure rate of timber pole is analyzed and presented in the Fig. 6.

Fig. 6 exhibits that the decay or failure rate of a timber pole is related to the acidity of the surrounding soil. The failure rate increases slightly with the increase of soil acidity. This is consistent with the findings of Charman and Murphy [11] that the soil acidity problem appears to have occurred when the pH value

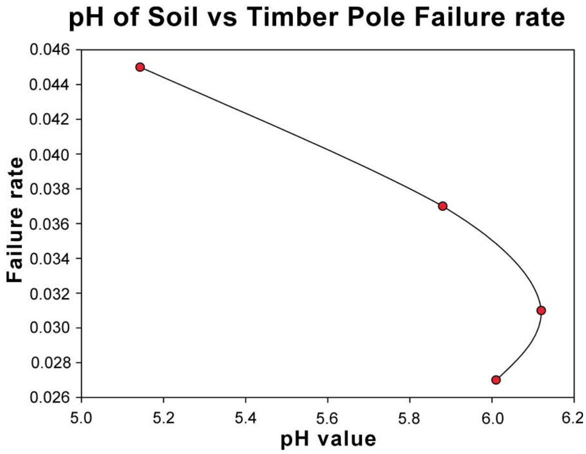

Fig. 6. pH of soil versus timber pole failure rate.

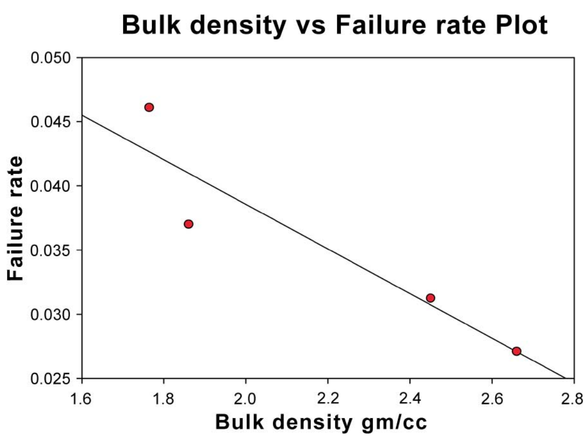

Fig. 7. Relationship model of bulk density and timber pole failure rate.

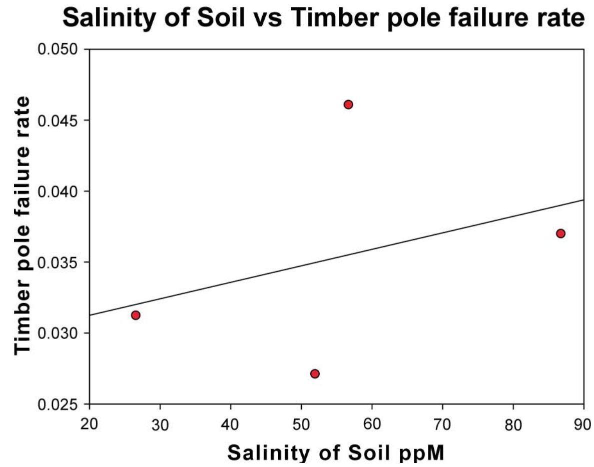

Fig. 8. Relationship model of salinity and timber pole failure rate.

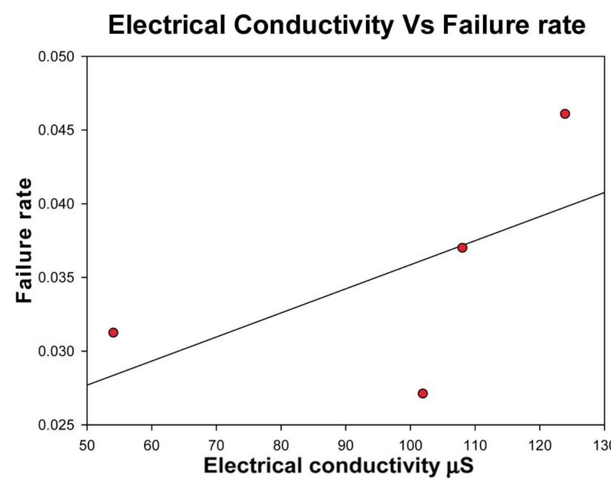

Fig. 9. Relationship model of electrical conductivity and timber pole failure rate.

falls below 5.5 and at pH value less than 5.5, the soil can be toxic to the timber component and can affect the buried portion of the timber material.

Liming (application of “Fluid Lime” or “Liquid Lime”) could be a probable solution to reduce harmful acidic conditions which develop in soils around the timber poles in the identified acid hazard areas. Generally applying lime is the most practical way of reversing soil acidification. Monitoring pH of the soil around the pole is recommended every 3 to 5 years, or more frequently if problems develop. If pH continues to decline below 6.0, lime additions may be needed.

3) Bulk Density: Bulk density of the samples collected from Wynnum, Lota and Mansfield were in the range 1.5 to 2.1 $\mathrm{g/cm^3}$ with mean of 1.86 $\mathrm{g/cm^3}$. It is consistent with Charman and Murphy’s findings. The mean of bulk density of soil in other selected suburbs Caboolture, Holland Park, and Chelmer are recorded 1.764 $\mathrm{g/cm^3}$, 2.54 $\mathrm{g/cm^3}$, and 2.66 $\mathrm{g/cm^3}$ respectively. These values indicate a clear trend of decreasing of failure rate with the increase of bulk density. The trend is shown in Fig. 7.

Analysis shows that the bulk density of soil has some effects on the failure rate of timber poles. It has an effect on drainage and is related to moisture trapped during the hot season. Soil compaction changes pore space size, distribution, and soil strength. As the pore space is decreased within a soil, the bulk density is increased. High soil compaction results in high bulk density where soil particles are pressed together, reducing pore space, and heavily compacted soils contain few large pores and water traps inside the soil surrounding the pole. A periodic compaction of soil around the pole can play an important role in increasing the bulk density.

4) Salinity: The mean salinity of coastal suburbs Wynnum, Lota and Mansfield are found 86.73 ppM and the mean salinity of another coastal suburb Caboolture is recorded as 56.67 ppM. The mean salinity of Chelmer and Holland Park are as 51.93 and 26.55 ppM, respectively. Fig. 8 shows a relationship of salinity of soil with failure rate of timber poles. The figure shows that there is an increased trend of failure rate of timber poles due to inground decay with the increase of salinity of soil.

Flue gas desulfurization (FGD) gypsum is being tested in the Lockyer Valley (Queensland) to reclaim Australian salinic and sodic soils. This could be explored for problems with soil salinity.

5) Effect of Electrical Conductivity on the Failure/Decay: The mean electrical conductivities of the collected samples are 101.91 μS in Chelmer, 54.07 μS in Holland park, 108.03 μS in Wynnum and 123.91 μS in Caboolture. From Fig. 9 it is seen

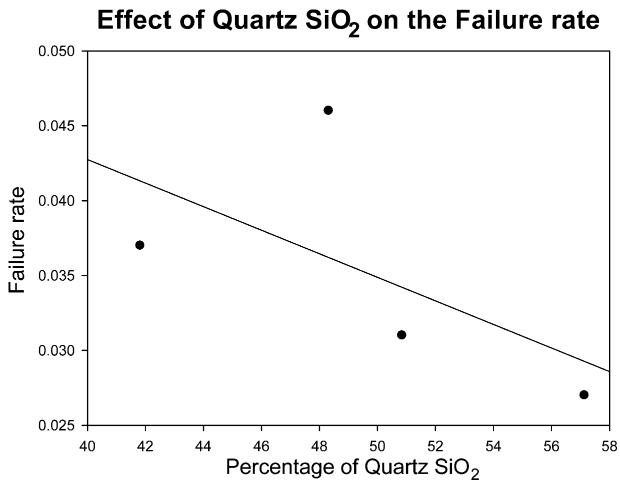

Fig. 10. Relationship model of quartz and timber pole failure rate.

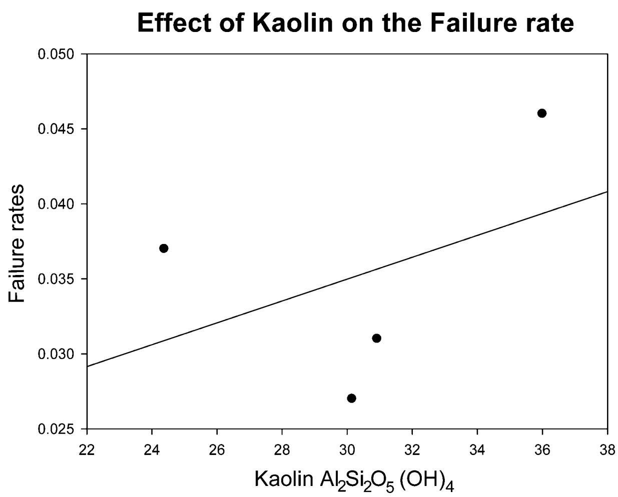

Fig. 11. Relationship model of Kaolin and timber pole failure rate.

that the failure rate of timber pole increases with the increase of electrical conductivity. The relationship model of electrical conductivity and timber pole failure rate can be seen in Fig. 9.

6) Chemical Analysis Result: Table II exhibits the summary of chemical tests. The mean value of major chemicals and failure rate of each of the suburbs are shown.

From Table II we see that Quartz (SiO2) and Kaolin (Al2Si2O5(OH)4) are the two common ingredients present in collected samples.

The average percentage by weight of quartz against failure rate is analyzed in Fig. 10. This showed some relationship between failure rate of timber pole and the amount of quartz content. Failure rate decreases with the increase of quartz content of the surrounding soil. We know that the sandy soil. Because the high percentages of quartz content allows the soil to drain water and keeps the soil less moist. This helps in preventing the biological attack. This, in turn, allows a better decay condition of timber materials.

The main factor of clay is the presence of Kaolin and Table II and Fig. 11 show that Kaolin accelerates the inground decay process. Because of its non-permeable property, Kaolin allows more water to trap inside the soil that causes algae, moss, and mould to grow and attack the in ground timber component, and results in increased deterioration. The effect of Albite ((Na,Ca)Al(SiAl)308) and Amorphous on the decay/failure rate is not clear.

VII. Conclusion

Inground decay is a major problem with timber poles widely used in electricity and telecommunication industry. Soil factors influential to inground decay were identified after analysis of failure data from electricity supply industries. Higher failure rate was observed in areas with clayey soils.

Sampling of soils from the identified areas and subsequent analysis increased the understanding of decaying process of the inground portion of timber poles. Testing methods for identification of influential soil factors were developed.

The moisture content, pH value (acidity/alkalinity), bulk density, salinity and electrical conductivity showed influence over inground decay of timber pole. It is also found that the chemical composition of soil such as presence of Kaolin or Quartz has some influence on the decaying process. This is due to the fact that Kaolin allows more water to be trapped inside the soil. This causes algae, moss and mould to grow and attack the inground portion of timber poles. Findings of this research resulted in recommendation of different installation specifications to improve drainage system in clayey soil areas. Other methods for corrective measures include soil compaction and liming of soil where needed.

Findings from this investigation can be useful in deciding inspection intervals, maintenance actions and replacement decisions of timber poles, bridge footings and house stumps and railway sleepers based on factors which include soil conditions.

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