Research article

Time Defendability of Ground Resistance Properties and Its Application of Vitric Tuff on the Development of Ground Enhancement Material

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ABSTRACT Ground repair material is an essential part of the grounding system as a lightning rod to reduce the risk of lightning activity. Grounding repair materials consist of conductive and superconductive materials, commonly known as Ground Enhancement Materials (GEM). GEM has a low resistivity, very effectively supporting lightning shock energy to earth. Vitric tuff, a pyroclastic rock, is composed of an aluminosilicate (phyllosilicate) mineral group developed as a grounding improvement material. The primary purpose of this study was to determine the decrease in resistivity of vitric tuff in its development as a GEM. The research method consisted of field observations and laboratory experiments (treatment with chemical-physical activation and formulation with additives). The results showed that moisture content, SiO_2/Al_2O_3 ratio (quartz and feldspar mineral/albite), clay mineral, crystal quality (impurities), carbon, and salt were influenced by vitric tuff resistivity. With the vitric tuff formulation and additives, the resistivity reduction is above 99%. Based on experiments, the best formulation of GEM made from tuff is 65% activated vitric tuff, 27% activated charcoal, 6% NaCl, and 2% Cement Material Cellulose. The formula produces a resistivity value of 0.0124 Ω-m, which is stable with time and meets GEM requirements ($\rho \leq 0.20$ Ω-m).

INTRODUCTION

One of the natural phenomena commonly found in tropical countries, such as Indonesia, Malaysia, Ecuador, and several other countries, is high lightning activity, reaching more than 32 strikes per km2/year (Asrina and Ramlee, 2018; Vaisala, 2020). The strong La Nina phenomenon also affects clouds and precipitation to increase lightning intensity (Ghosh et al., 2019). The high activity of lightning can cause danger, so lightning protection is needed (Azmi et al., 2019; Bakar et al., 2020). Lightning protection aims to protect and reduce the risk of harm to living things, buildings, electricity, electronic equipment, telecommunications, and lightning activity.

On the outside building, the lightning protection system consists of three main parts, air termination, down conductor, and grounding system (Halim et al., 2019). An effective grounding system requires a low resistance path. However, natural soils have a typical high resistivity of 30 – 3000 Ω-m, On the other hand, the required material resistivity value for the grounding system is 1 – 10 Ω-m (Badan Standardisasi Nasional, 2000). The high resistivity can inhibits the rate of spread of lightning energy to the earth, so it has a risk of danger. Additional material (backfill material) with high conductivity is required to accelerate the spread of high-voltage lightning energy. The conductivity number (σ) is one per resistivity (ρ) (Heaney, 2003). Thus, the resistivity must be made as small as possible so that maximum conductivity is obtained. Factors that affect soil resistivity include moisture content, with optimal decline occurring at concentrations above 30% and generally influenced by materials with high adsorption power (Azmi et al., 2019; Bakar et al., 2020; IEEE Standards Association, 2012; Martin et al., 2019; Wan Ahmad et al., 2018). To make the material more porous, increase the adsorption power, including thermal, hydrothermal, and solution treatment (Jozefaciuk and Bowanko, 2002; Kurniasari et al., 2011; Lu et al., 2009; Martin et al., 2019). The resistivity is influenced more by sodium chloride (NaCl) rather than sodium thiosulfate ($Na_2S_2O_3$). Optimal results occur at 6-13% (Agustinus et al., 2010; Ahmad et al., 2010). In addition, the resistivity is also influenced by the electrolyte and soil temperature (IEEE Standards Association, 2012).

Natural grounding repair materials include Na-bentonite and zeolite (Bakar et al., 2020; Shuhada et al., 2016). Vermiculite, pearlite (Lai et al., 2017), gypsum, and Marcionite (Mohd Tadza et al., 2019). These raw materials have not shown optimal performance, so several blending engineering technologies have been developed with additives, multi blending, and activation treatments (chemistry and physics) (Agustinus et al., 2010; Opara et al., 2014; Agustinus, 2018; Martin et al., 2019; Bakar et al., 2020). Other ingredients as additives include charcoal and salt (Ahmad et al., 2020), coconut husk (Halim et al., 2019), fly ash, and wood ash (Wan Ahmad et al., 2018). These materials are needed by various industries and affect prices that potentially become a problem for the sustainability in a long term (Febianti, 2014).

Based on the resistivity value, grounding repair material is divided into conductive and super-conductive materials. They are commonly called Ground Enhancement Materials (GEM). In Indonesia, GEM is widely used, but until now, it is still imported. GEM is a superconducting material with low resistivity ≤ of 0.20 Ω-m so that it is swift and more effective in transmitting high voltages such as lightning into the earth. GEM also has a low sulfur content of < 2% and is non-corrosive (depending on the type of electrode rod), and has good resistance to time (Erico, 2018). GEM has the main component of silica (Si), alumina (Al), and carbon (C) (Agustinus et al., 2010).

Silica and alumina are commonly found in aluminosilicate-based mineral groups (phyllosilicates), including vitric tuff. Tuff is a pyroclastic rock resulting from volcanic eruptions composed of rock, crystal, and glass fragments. Based on the mineralogical composition, vitric tuff is a tuff rock that is dominated by glass fragments (>50%) (Schmid, 1981). It undergoes precipitation and compaction and has excellent fluid retention (porosity) ± 25% (Jian et al., 2016). Indonesia has more than 30% of the world's active volcanoes. Based on the historical eruptions, there are type A volcanoes (79) erupting since 1600 and type B volcanoes (29) exploding before 1600 (Pratomo, 2006). Tuff is estimated to be abundant up to billions of tons and spread throughout the region following the distribution of volcanoes (Verdiana et al., 2014; Winarti and Gendoet, 2015), with a relatively easy acquisition. In addition, tuff is also a group of rocks that have not been widely used (marginal), so it has a high added value.

This paper discusses the development of vitric tuff as a Ground Enhancement Material (GEM) with the leading indicator resistivity 0.20 Ω-m, which is stable over time. This study aims to determine the characteristics of the raw materials, obtain the process technology, and better understand the phenomenon of decreasing ground resistivity.

Sample Location and Geology

Observations and sampling were carried out at the outcrop of the Cikamuning area, Tasikmalaya Regency, West Java Province. Regionally, the sampling location included in the Geological Map Sheet Karangnunggal Tasikmalaya (Figure 1).

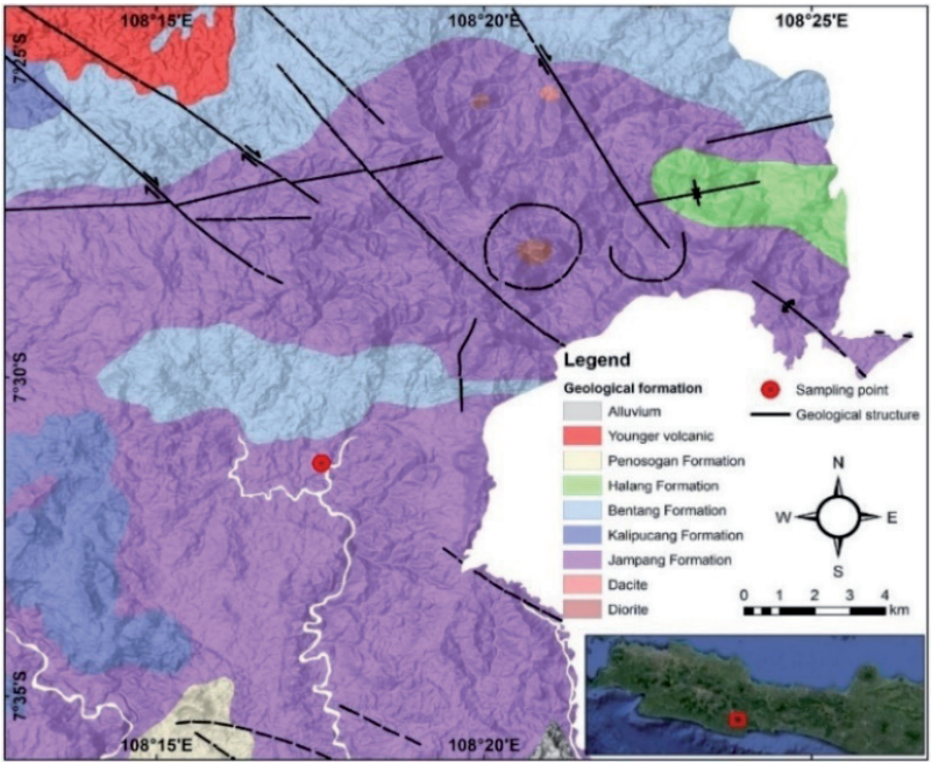

Figure 1. Geological Map of Tasikmalaya (modification from Supriatna et al., 1992)

The subduction of the India-Australia plate beneath the Eurasia plate throughout the Late Oligocene to Early Miocene resulted in Jampang and Genteng Formation volcanic rocks and epiclastic rocks. The Late Miocene to Pliocene experienced orogenesis accompanied by volcanic activity and produced volcanic deposits. They were compounding lithology: Jampang Formation (Tomj), Genteng Member Jampang Formation (Tmjg), Kalipucang Formation (Tmkl), Pamutuan Formation (Tmpa), and Alluvium Deposits (Qal) (Supriatna et al., 1992). The research location is included in the Jampang Formation (Tomj), consisting of breccia of various materials and tuff (coarse to fine) with insertion of lava (Verdiana et al., 2014).

METHODS

Materials

The raw materials used in this research consist of main ingredients and additives. The primary raw material is vitric tuff, while the additive consists of charcoal and sodium chloride (NaCl). Cement Material Cellulose (CMC) is used as a binder to adjust the shape of the powder. Vitric tuff samples taken from rock outcrops in the field were ± 20 kg.

Preparations

The selected samples as raw materials are then prepared for laboratory activities carried out in the integrated laboratory of theResearch Center for Geotechnology, including preparation, chemical-physical activation, formulation and homogenization with additives, and testing/analysis. The preparation activities consisted of thin section preparation, drying and grinding, and chemical preparation/dilution on vitric tuff samples. Preparation of thin incisions for mineral observation using petrographic methods cut 24 x 24 mm in size with a thickness of ± 0.02 mm. For mineral analysis using X-ray diffraction methods, chemical analysis, and resistivity, the samples were oven-dried for 12 hours at 70°C. Then, they were grounded using agate mortarfor bulk analysis of X-ray Diffraction and chemical analysis. Furthermore, vitric tuff was grounded using a Crusher and Ball Mill to 100 mesh for resistivity measurements.

Chemical-Physical Activation Treatment

Mineral engineering in this study is to modify vitric tuff. The treatment uses chemical and physical activation methods, and the aim is to remove impurities, open a wider pore surface and increase absorption. The activation method applied is alkaline chemistry with 1 M sodium hydroxide (NaOH) solution as an activator, through immersion for 24 hours followed by washing and filtering. Then, physical treatment through calcination at a temperature of 100°C for 3 hours (modification Kurniasari et al., 2011; modification Agustinus et al., 2010)

Formulation and Homogenization with Additives

Formulation and homogenization were carried out on vitric tuff treatment and additives (activated charcoal and NaCl). Starting with the experimental design of the formula, homogenization to resistivity measurements. Observed variations are designed into 4-four procedures (Agustinus et al., 2010), as shown in Table 1. The formulation of activated vitric tuff as the main ingredient is 55% – 85% and activated charcoal 7% – 37%, mutually substituted for 92% of the total composition. Then use 6% NaCl additives (modification IEEE Standards Association, 2012; Agustinus et al., 2010), and CMC as a binder 2%. The resistivity measurement results are compared with the standard GEM product. The best formulation is determined based on the resistivity value ≤ of 0.2 Ω-m with stable resistance to time (Erico, 2018), and the percentage of use of additives is low.

Table 1. Design of vitric tuff composition with additives

	Formula Composition (%)				
Experiment Design		Activated vitric tuff	Activated charcoal	NaCl	CMC
Formula	A	55	37	6	2
	B	65	27	6	2
	C	75	17	6	2
	D	85	07	6	2

Source: Modification Agustinus et al. (2010)

Data Collection and Laboratory Analysis

Analysis was carried out on vitric tuff raw material, activated, and after formulation with additives. Petrographic analysis was carried out on tuff using a Nikon eclipse 50 iPol polarizing microscopes with a magnification of 5 – 50x, and the aim was to identify minerals and determine rock types. X-ray diffraction analysis was conducted using Shimadzu 7000 equipped with International Center for Diffraction Data (ICDD) PDF 4+ Mineral 2018, with x-ray tube Cu (1,54060 Å), and scan range 2 Theta 5 – 80 degrees. Chemical analysis using Atomic Absorption Spectrometry (AAS) Shimadzu AA-7000. Resistivity measurements using a four-pin Soil box method (Mohd Tadza et al., 2019; Zhou et al., 2015) was carried out on the test sample with 36% water and repeated three times for approximately 50 hours. XRD (bulk analysis), AAS, and resistivity analyzes were carried out on the raw material and activated samples. The configuration of the Resistivity Meter is shown in Figure 2 (International Electrotechnical Commission, 2018). The resistivity value is determined

$$\rho = \frac{R \, x \, A}{a} \qquad (1)$$

based on the following equation approach (International Electrotechnical Commission, 2018).

where ρ is the resistivity of the material (Ω-m), R = measured resistance (Ω), A = cross-sectional area (m^2), and a = inner electrode distance (m).

Predictivity of resistivity value against time-based on linear regression analysis. The equation for Simple Linear Regression or SLR (Sugiyono, 2006).

$$y = a + b.x \qquad (2)$$

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2} \qquad (3)$$

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \qquad (4)$$

y is the resistivity, x = time, a = constant indicating the magnitude of the value of y if $x = 0$, and b = the magnitude of the change in y.

The correlation between resistivity values with time is following equation (Sugiyono, 2006).

$$r_{xy} = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{(n(\sum x^2) - (\sum x)^2)(n(\sum y^2) - (\sum y)^2}} \qquad (5)$$

where *r* is correlation, *n* = amount of data, *x* = time, and *y* = resistivity.
Correlation classification = 0.90 – 1.00 (very high), 0.70 – 0.90 (high), 0.40 – 0.70 (moderate), 0.20 – 0.40 (low), and 0 .00 – 0.20 (very low).

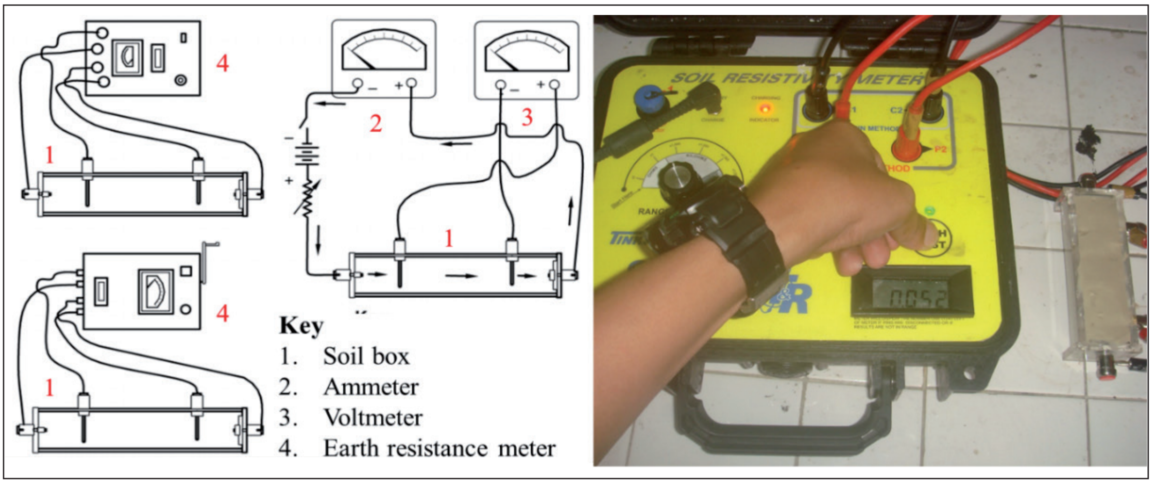

Figure 2. Configuration of the 4-electrode soil box method of resistivity meter equipment

RESULTS AND DISCUSSION

Characteristics

Megascopically, the tuff found has a compact physical characteristics, white to brownish-gray color, fine grain size (ash) d < 2 mm, and slightly weathered and oxidized (Figure 3). Then based on petrographic analysis, it has characteristics composed and dominated by the volcanic glass as the groundmass. Other minerals are feldspar, clay minerals, quartz, and opaque minerals.

Figure 3. Photo of tuff outcrops in the field

The mineral composition of tuff is volcanic glass (Gv – 60%), feldspar (Fls – 20%), clay mineral groups (Cy – 10%), quartz (Qz – 5%), and opaque minerals (Op – 5%). Based on the composition of the constituent minerals and the classification of the rock, it is a type of vitric tuff (Schmid, 1981). The petrography results are shown in Figure 4. Furthermore, the results of XRD analysis showed a crystalline form, regular mineral structure, with the main mineral compositions: quartz, albite, and clay minerals (Figure 5). The quartz (SiO_2) and feldspar indicate that vitric tuff has conductive/electrical properties. Alumina (Al) and silica (Si) from feldspar and other silicate minerals are basic materials that are widely used as conductors, semiconductors, and insulators (Nwachukwu and Lawal, 2018).

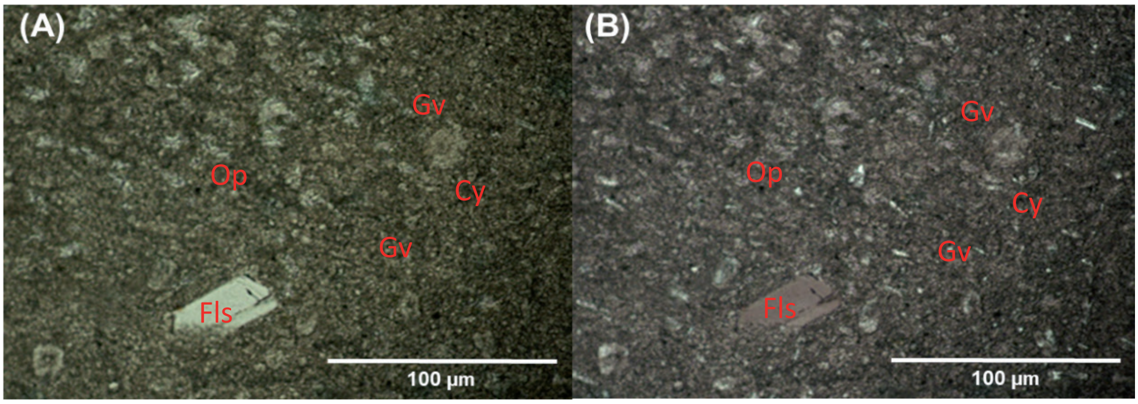

Figure 4. Thin-section petrography of vitric tuff samples (A) Niccol parallel, and (B) Niccol crossed. Volcanic glass - Gv, Felspar - Fls, Clay minerals - Cy, Opaque minerals – Op

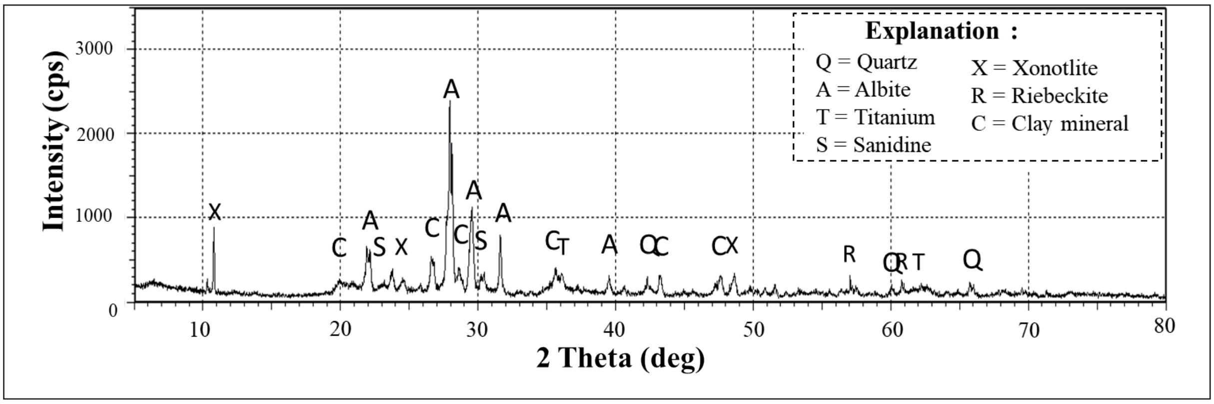

Figure 5. Vitric tuff (raw material) XRD diffractogram

The AAS vitric tuff analysis results showed that the main chemical composition was silica (Si), found in SiO_2 at 52.32% and alumina (Al_2O_3) at 16.57%. Other compositions are impurities in the form of oxides, including Fe, Mn, Mg, Ca, Na, K. In natural conditions, vitric tuff has a SiO_2/Al_2O_3 ratio of 3.13. SiO_2/Al_2O_3 ratio is an indicator of cation exchangeability. The lower the ratio value indicates the better capacity. The dominant cation exchange occurs in Mg, Ca, Na, K ions. Cation exchange capacity is an essential factor affecting the absorption of a material (Ackley et al., 2003; Gruszkiewicz et al., 2005). The higher the cation exchangeability, the better the adsorption capacity of a material. When bentonite is a grounding repair material, vitric tuff has a lower SiO_2/Al_2O_3 ratio than bentonite. The exchangeability value indicates that vitric tuff has the potential to be used as a grounding repair material. The chemical composition of raw material from vitric tuff is shown in Table 2.

Table 2. Changes in the chemical composition of vitric tuff

	Oxide	% wt	Oxide	% wt	Explanation
Raw material	SiO_2	52,32	CaO	2,30	Ratio SiO_2/Al_2O_3 = 3,13
	Al_2O_3	16,57	Na_2O	2,39	
	TiO_2	1,49	K_2O	1,15	
	Fe_2O_3	4,63	P_2O_5	5,67	
	MnO	0,09	LOI	10,17	
	MgO	2,77			
Activated	SiO_2	47,82	CaO	2,25	Ratio SiO_2/Al_2O_3 =2,60
	Al_2O_3	21,77	Na_2O	2,77	
	TiO_2	1,59	K_2O	1,37	
	Fe_2O_3	2,01	P_2O_5	5,65	
	MnO	0,07	LOI	11,94	
	MgO	2,17			

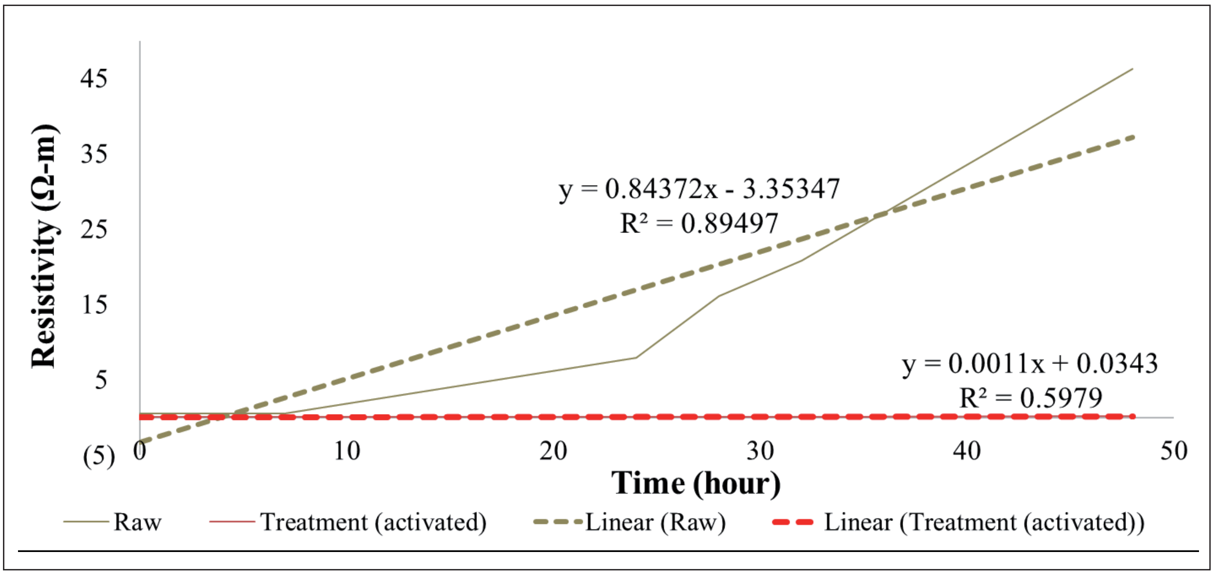

Figure 6. The pattern of resistivity development due to chemical-physical activation

Resistivity measurement using Soil Resistivity Meter, in its application, it is necessary to add water. The measurement results of vitric tuff raw material obtained that the resistivity is unstable and tends to increase with time with an average of 7.896 Ω-m (correlation coefficient or high r 0.95), as shown in the ash line Figure 6. In the first 7 hours, the resistivity was quite low, which was relatively stable with time, then it increased in the 24th hour and so on when the sample started to dry. This condition indicates that the vitric tuff resistivity is influenced by moisture content. The higher the resistivity, the lower the resistivity (Azmi et al., 2019; IEEE Standards Association, 2012).

Vitric tuff belongs to the swamp to wet sand types group with moderate resistivity reaching 105 Ω-m (Badan Standardisasi Nasional, 2000; Wiyono et al., 2017). However, the required grounding resistivity is not more than 5 Ω-m for areas with very high resistivity, a maximum of 10 Ω-m (Badan Standardisasi Nasional, 2000). The value shows that raw material from vitric tuff cannot be directly used as a grounding repair material and requires treatment.

Effect of Treatment (Chemical-Physical Activation)

Based on the observations, activated vitric tuff tends to dry more slowly than the raw material. The measurement results before and after activation showed a significant decrease in resistivity from an average of 7.896 Ω-m to 0.049 Ω-m, which was relatively stable and tended to increase with time. Redline shows the result of a decrease in the resistivity of the activation effect in Figure 6. The decreasing percentage of activated vitric tuff resistivity in the first 7 hours was 91.053%, then increased and remained stable at the 24th hour, reaching 99.459%. The development of a stable percentage indicates that the vitric tuff properties have been optimal; the average resistivity decrease is 94.055%. The resistivity of activated vitric tuff in dry conditions reached 6,242 Ω-m. the value shows that activated vitric tuff with resistivity indicator meets the requirements of a conductive grounding repair material, but not yet for the GEM category, so further treatment is needed.

XRD analysis shows a decrease in resistivity followed by an increase in the intensity of albite minerals and a reduction in quartz due to activation (Figure 7). The rise in albite minerals is thought to occur due to the exchange of cations (Al, Na) from albite minerals, clay minerals, and sanidine. Then, a decrease in the intensity of quartz minerals occurs due to the dissolution of silica and other impurities in the form of oxides. The mineral intensity and cation exchange are represented in the results of chemical analysis, with an increase in the chemical composition of Al_2O_3, Na_2O, and K_2O and a decrease in SiO_2 and Fe_2O_3 (Table 2). The dissolution of impurities increases the relatively pure minerals to obtain more optimal tuff properties (Sembiring et al., 2010). The increase in Al_2O_3 affects the SiO_2/Al_2O_3 ratio from 3.13 to 2.6. The decrease in the SiO_2/Al_2O_3 ratio indicates an increase in the cation exchangeability so that the electrical field or the vitric conductivity of the tuff increases (Kurniasari et al., 2011).

Based on observations, XRD, AAS, and resistivity analysis showed that the decrease in vitric tuff resistivity was influenced by moisture content, SiO_2/Al_2O_3 ratio, clay minerals, quartz, and albite (feldspar), and crystal quality. The more balanced the SiO_2/Al_2O_3 ratio, the lower the resistivity or the higher the albite mineral composition (feldspar) will decrease the resistivity. Then, the purity of the feldspar crystal will affect the resistivity obtained. The test results also showed that chemical activation (NaOH activator) and physical (temperature 100°C) did not damage the mineral structure and effectively reduced resistivity with better resistance. Determination of this method is quite effective because alkaline activation using NaOH activator will make the material more polar. The absorption (adsorption) increases due to the loss of impurities and silica dissolution (Jozefaciuk and Bowanko, 2002; Lu et al., 2009).

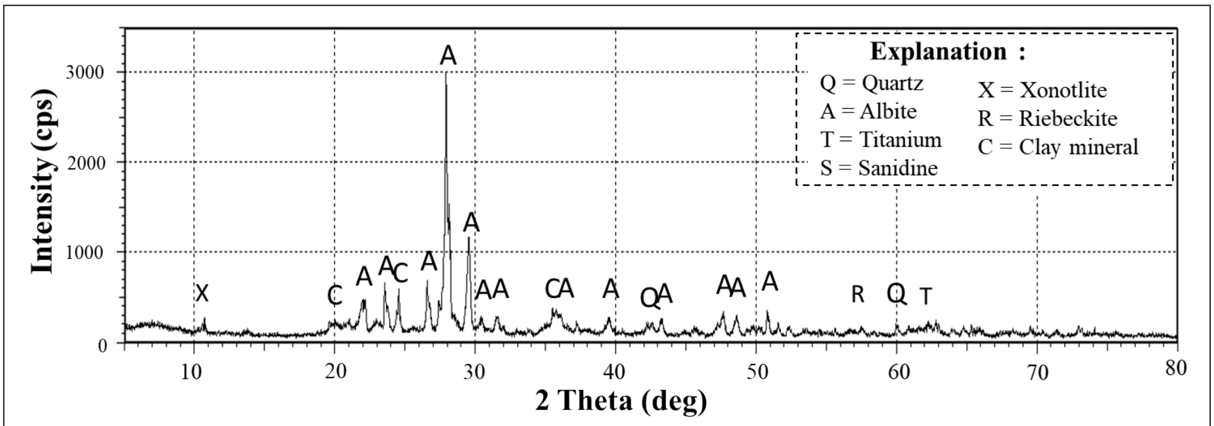

Figure 7. Vitric tuff (activated) XRD diffractogram

A significant decrease in resistivity indicates that vitric tuff has the opportunity to be developed as a raw material for Ground Enhancement Material (GEM) through further treatment or formulation with additives that have specific properties.

Effect of Additives and GEM Formulation

Based on the measurement results of the Soil Resistivity Meter and linear regression analysis showed that all formulas have low resistivity (≤ 0.2 Ω-m) with different effects on time (correlation coefficient or r). Formulation A (55:37:6:2) has a decreasing resistivity development and is resistant to time (linear regression equation, $y = -0.00013x + 0.01045$) with r = 0.881 (high). Formulation B (65:27:6:2) has a stable resistivity development with time ($y = -0.00000x + 0.01236$) with r = 0.111 (very low). Formulation C (75:17:6:2) tends to increase with slightly less stable resistance over time ($y = 0.000004x + 0.01477$), r = 0.958 (very high). Formulation D (85:07:6:2) has a tendency to increase resistivity development with less stable resistance ($y = 0.00011x + 0.01107$), r = 0.869 (high). The change and development of the resistivity of each formula is shown in Figure 8.

The results of the analysis show that formula B (65:27:6:2) is the best formulation with resistivity 0.2 Ω-m, linear regression equation $y = -0.00000x + 0.01236$ with r = 0.1. This equation shows that the resistivity is 0.0124 Ω-m and is very low so that it does not affect time (stable). Based on the obtained resistivity value, it is known that the percentage of decrease is very significantly more than 99%. The resistivity reduction is better than the use of 20% to 32% bentonite (Ismujianto et al., 2019; Lim, 2014; Lim et al., 2013, 2012), and salt 64.9% (Hakim et al., 2018). Physically activated bentonite 74% (Martin et al., 2019), chemical-physical activated bentonite 79.97 – 85.24% (Andini et al., 2016). These results indicate that activated vitric tuff with additives (activated charcoal and NaCl) qualifies as GEM.

The development of activated vitric tuff resistivity with additives shows that charcoal and NaCl significantly decrease resistivity, with a more stable level of resistance. Charcoal has hygroscopic properties and high adsorption power, then with chemical-physical activation treatment causes the loss of impurities so that its performance is more optimal (Sembiring et al., 2010). The addition

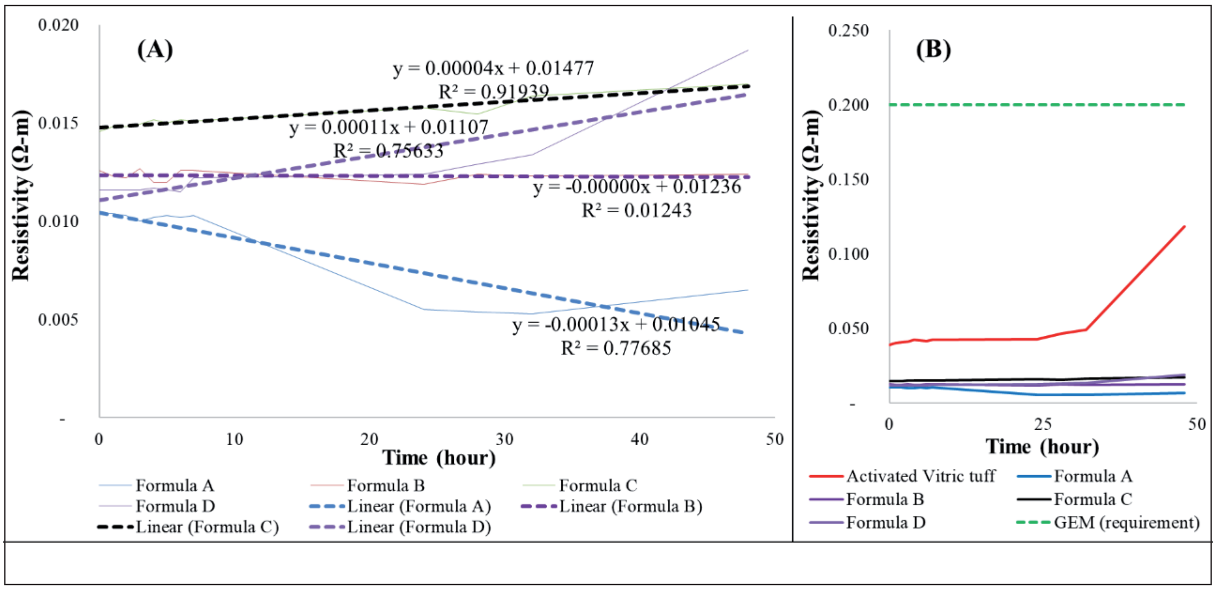

Figure 8. Resistivity development pattern with time, (A) each formula, (B) comparison: GEM limit, activated vitric tuff, and formulation with additives

of NaCl at a concentration of 6% (low) provides space for the ions as an electrolyte to move more freely and has been proven to be able to optimally reduce resistivity (Agustinus et al., 2010; Hidayati and Zainul, 2019; IEEE Standards Association, 2012).

CONCLUSIONS

Megascopically, vitric tuff has compact physical characteristics, white to brownish gray in color, fine-grained d < 2 mm, slightly weathered and oxidized. The mineralogy constituents include volcanic glass, feldspar (albite), clay minerals (halloysite), quartz, and opaque minerals. They are chemically dominated by silica (SiO_2), alumina (Al_2O_3), and impurities in the form of oxides. Raw material from vitric tuff cannot be directly used as a grounding repair material (ρ > 10 Ω-m).

With the treatment (chemical-physical activation and the addition of additives), a tuff-based GEM formulation that meets the requirements (ρ ≤ 0.2 Ω-m) is obtained, namely 65% activated vitric tuff, 27% activated charcoal, 6% NaCl, and 2% CMC. This formula produces a resistivity of 0.0124 Ω-m with a percentage decrease of > 99%, stable with time (r = 0.1).

Factors that affect the decrease in resistivity in vitric tuff are moisture content, the balance of SiO_2/Al_2O_3 ratio (quartz and feldspar minerals/albite), clay minerals, and crystal quality, carbon, and salt. With specific treatments, vitric tuff (aluminosilicate-phyllosilicates mineral group rock) can be used as a grounding repair material and or GEM.

Technically, vitric tuff is suitable for use as a raw material for grounding repair materials. Vitric tuff is spread throughout the region and has high added value with long-term sustainability prospects. Development to the industrial community requires a techno-economic feasibility study.

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