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Electrical Characteristics of Rubber Wood Ash Filled Natural Rubber at High Frequency

Salakjit Nilborworn*, Krerkchai Thongnoo and Pornchai Phukpattaranont

Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand

ABSTRACT

The purpose of this study was to identify a method to form rubber composites by incorporating natural rubber (NR) and wood ash from rubber trees with a preliminary electrical properties test. This formulation is intended to improve the rubber composites in order to obtain new materials for high voltage insulators. First, the rubber formulation and processing conditions were optimised before the composites are processed in the laboratory. Second, the interactions between the NR and wood ash were investigated with the following tests: cure time, agglomerate dispersion, SEM images, and the electrical characteristic test. In the electrical characteristic test, the experimental setup was designed for testing the frequency range from 50 Hz to 100 kHz, which is the range of high voltage power line switching frequencies. This energised transient frequency can occur due to switching operations or any other external causes in high voltage systems. Finally, the dielectric property of the rubber composites was evaluated and the equivalent circuit was formulated. The results show that the different properties tested with the new material not only correspond with the filler contents, but also with the frequencies in the transmission lines. The measured data are extracted and converted into other parameters at each frequency. The comparison results are closely matched. Moreover, the results revealed that relative permittivity and the conductivity increases the wood ash filler is increased.

Keywords: Rubber composites, high voltage insulator, rubber formulation, electrical characteristic test

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E-mail addresses:
n.salakchit@gmail.com (Salakjit Nilborworn),
krerkchai@psu.ac.th (Krerkchai Thongnoo),
pornchai.p@psu.ac.th (Pornchai Phukpattaranont)
*Corresponding Author

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INTRODUCTION

There is a rapid rise in demand for electricity. Hence, high voltage systems have become crucial power transmission. Power insulators in this high voltage transmission system is one of the indicators of power system stability. Faults in the system frequently occur due to the failure of insulation or an ineffective design. Both cause degradation in power quality and failure to withstand high voltage stress. Under the high voltage stress, there are four main types of testing methods to ensure stability of high voltage insulators: low and high frequency tests, constant DC test, and an impulse test. In addition to this typical high voltage withstanding capability, a high voltage insulator must also be capable of withstanding different high-frequency disturbances. These disturbances may occur due to switching operations or other external causes. The oscillated frequencies of switching transient can range from 300 Hz to over 10 kHz (Chapman et al., 1999). Thus, the insulating properties should cover all these abnormal spectra.

For this reason, a rubber composite has been designed. In a high powered insulator, rubber composites for high power appliances present many challenges related to their mechanical strength, electrical properties and environmental degradation. Based on their electrical properties, a rubber formulation was prepared by controlling appropriate ingredients using the dielectric constant. After the vulcanising process, the electrical properties of the new material become unpredictable. Thus, the characteristics of the material need to be considered. To ensure their capacity to withstand the disturbance in frequencies, this research reveals the electrical properties of the composite material as a function of frequency.

Nomenclature

R_s, R_p series and parallel resistance (Ω)

C_p the parallel capacitance (F)

Z impedance (Ω)

$\tan\delta$ loss tangent = $\varepsilon_r''/\varepsilon_r'$

ε' dielectric constant

σ conductivity (S/mm)

MATERIALS AND METHODS

The rubber composites were prepared according to the following procedures: mixing, forming, and vulcanising. First, the raw rubber was mixed in an internal mixture machine. Then all the curative chemicals and additional fillers were added according to the compounding formula design in Table. 1. Next, the procedure for forming the rubber composites were compressed with a designated thickness with a compression machine.

Table 1
Control variables setting of IEEE 30-bus test system

Ingredients	phr	Approximate ε′
Rubber	100	2.7
ZnO	5.0	10
Stearic Acid	1.0	2.3
Antioxidant (TMQ)	1.0	-
Sulphur	2.0	3.5
Rubber Wood Ash (RWA)	0, 5, 10, 20, 30, 40	3.5

The mixing process takes about 12 minutes for each batch. The mixing temperature setting varied between 60°C and 90°C. To ensure the homogeneity of the composites, the mixed rubber was compounded and formed in a typical two-roll mill for 15 minutes. The samples were prepared by varying the volume of RWA contents. It is found that NR/RWA at different formulations affect their cure characteristics and their properties. In general, the dielectric constant for rubber insulators needs to be low. If we design an insulator for appliances, the dielectric constant should be controlled. Table 1 shows typical dielectric constants (ε′) of each ingredient.

EQUIVALENT CIRCUIT OF RUBBER COMPOSITE

The dielectric involving parasitic is a combination of resistance (R) and capacitance (C). It can be lumped as the simplest series and parallel circuit model, which represents the real and imaginary (resistive and reactive) parts of the equivalent circuit. The sample model of the electrical conductivity is shown in Figure 3(a) and its equivalent circuit is shown in Figure 3(b). Based on this equivalent circuit, this hypothesis will provide for the measurement setup which is described in the next section. The agglomerate images of the rubber and the fillers are shown below.

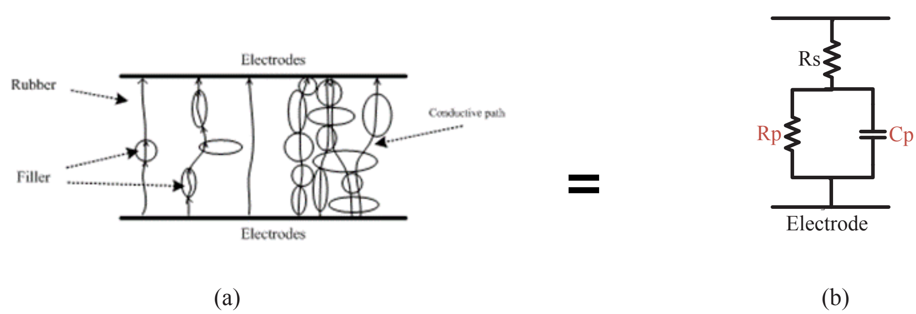

Figure 1. The sample model for (a) the electrical conductivities; (b) an equivalent circuit

MEASUREMENT SETUP

The test structure is shown in Figure 4. The LCR HiTESTER (HIOKI 3522) was used to measure the electrical values of R, X, Cp, and Z. The applied frequencies were sweeping from 50 to 100 kHz at room temperature (28°C). At least two values of measured data were converted into the desired parameters such as $|Z|$, ε' , ε'' , δ and σ. To investigate the electrical properties of the rubber composite, different formulas (0, 5, 10, 20, 30, 40 phr) were measured.

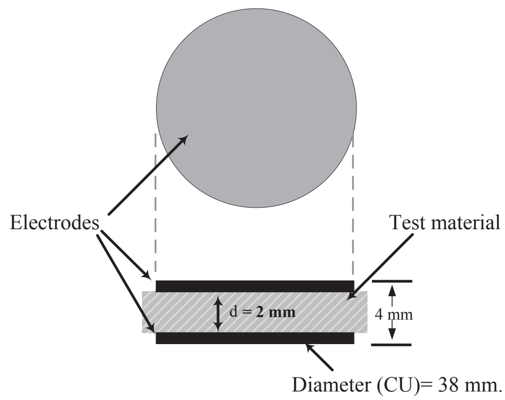

Figure 2. Rubber composite test structure

The test structure consists of two 38 mm diameter circular copper disks to form parallel plate electrodes with rubber composites in between. The disks are separated by a 2 mm thick rubber composite. The separation between the parallel plates is indicated as *d*, which is the thickness of the rubber composite. Based on the test structure, the measured data were calculated according to the RCL meter user's manual (Naidu & Kamaraju, 1996).

RESULTS AND DISCUSSIONS

In this research, the agglomerate shapes of the rubber, as well as the fillers were studied. At first, the amount of filler dispersion can be investigated by an image analysis technique from the Dispergrader according to ASTM D7723. This equipment uses highlights casted by agglomerates presented to measure the dispersion of the fillers in mixed rubber (Alpha technologies, 2016).

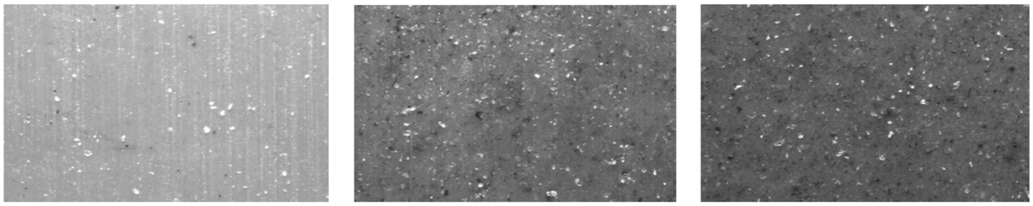

Figure 3. Dispergrader view of NR mixed with RWA 0, 5, 10 phr respectively

The sample images of NR/RWA at 0, 5, 10 parts per hundred of rubber (phr) are shown in Figure 1, when filler particles (white spots) and RWA (black spots) appear between the rubber matrix. The quantitative dispersions are 99.75%, 96.95%, 96.77% respectively. The filler dispersion of the rubber surface (Figure 2) was enlarged by the SEM micrographs for more details.

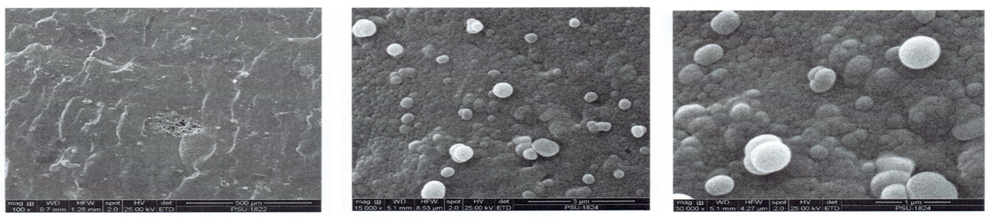

Figure 4. SEM of agglomerates for NR/RWA 10 phr

The purpose of SEM images is to show the agglomerate shapes of rubber and fillers when the RWA content is 10 phr. The images show that the structure of the mixtures is a combination between ellipsoidal and spherical shapes. Based on the RWA contents, the properties of the material depend significantly on the compound compositions. The effects of RWA additive in the compositions on the capacitive and impedance values are shown in Figure 5 and 6 respectively. All measured data were validated with the commonly use electrical insulator, Fr4 (dielectric permittivity <5.8 @1MHz). The measured capacitance value is very high at the lowest frequency. For the frequencies below 300 Hz, the values decrease exponentially and the values are approximately constant at high frequencies. Therefore, the capacitance causes the absolute impedance reduction as shown in Figure 6. Please note that the *C* is rather high due to the limitation of the RLC meter at power line frequency (50 Hz).

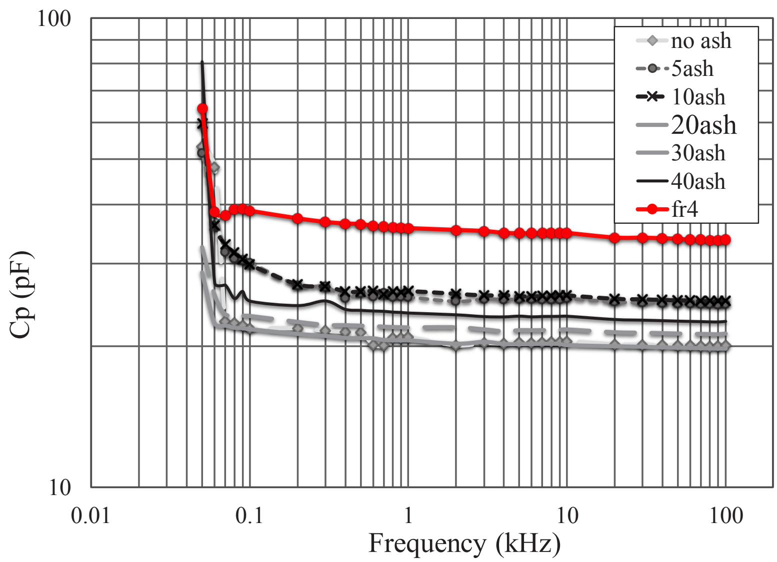

Figure 5. Parallel capacitance as a function of frequencies in logarithmic scale

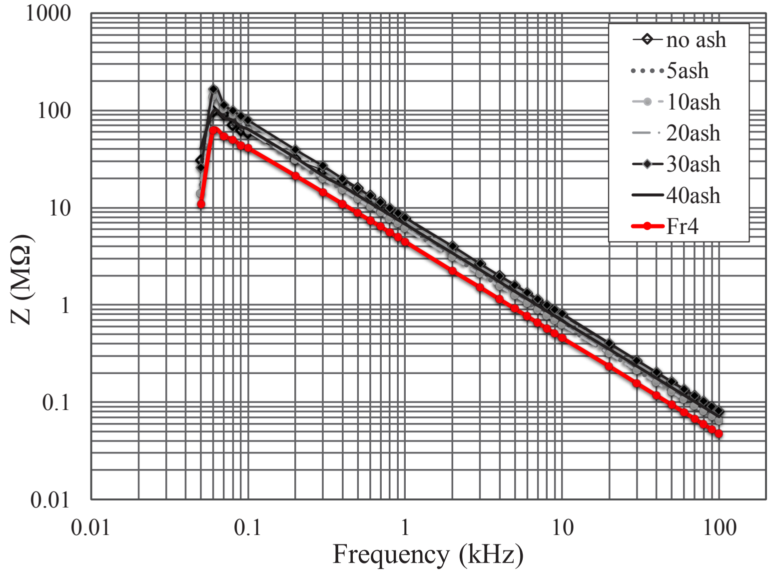

Figure 6. Absolute impedance as a function of frequencies in logarithmic scale

The calculated dielectric loss tangent values and conductivity of the materials are shown in Figures 7 and 8. It shows that dielectric loss tangent values decrease with increasing frequencies and move from a high loss tangent region at the lowest frequency towards a low loss tangent region as the frequency increases.

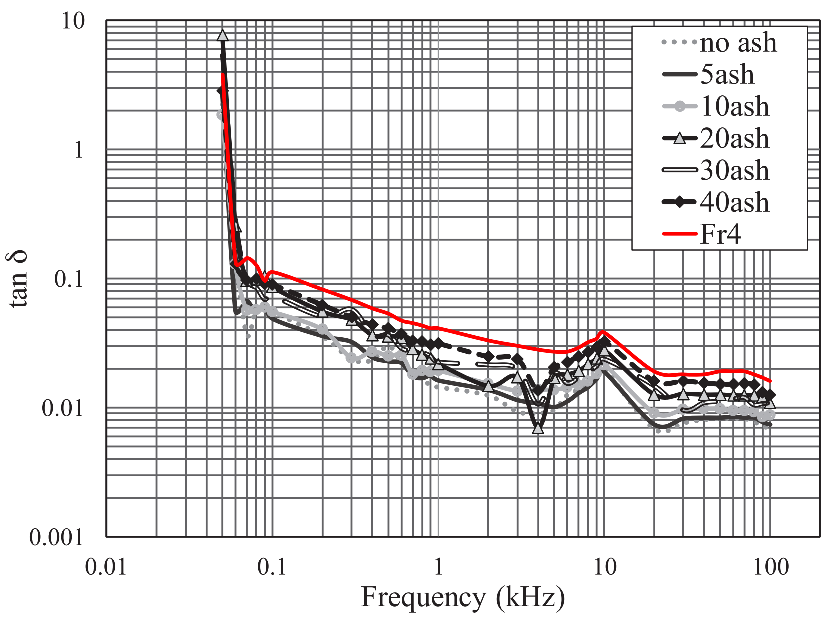

Figure 7. Dielectric loss tangent as a function of frequencies in logarithmic scale

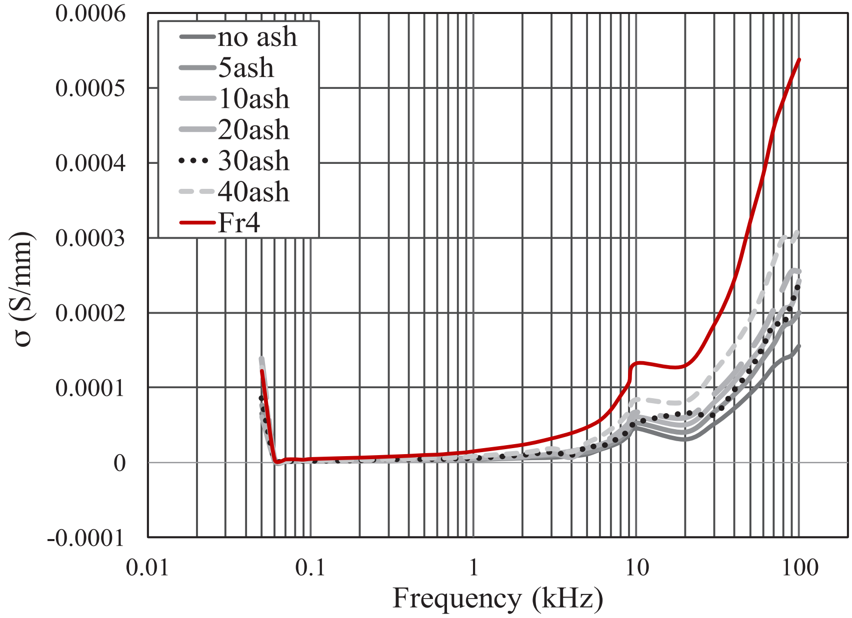

Figure 8. Conductivity as a function of frequencies in logarithmic scale

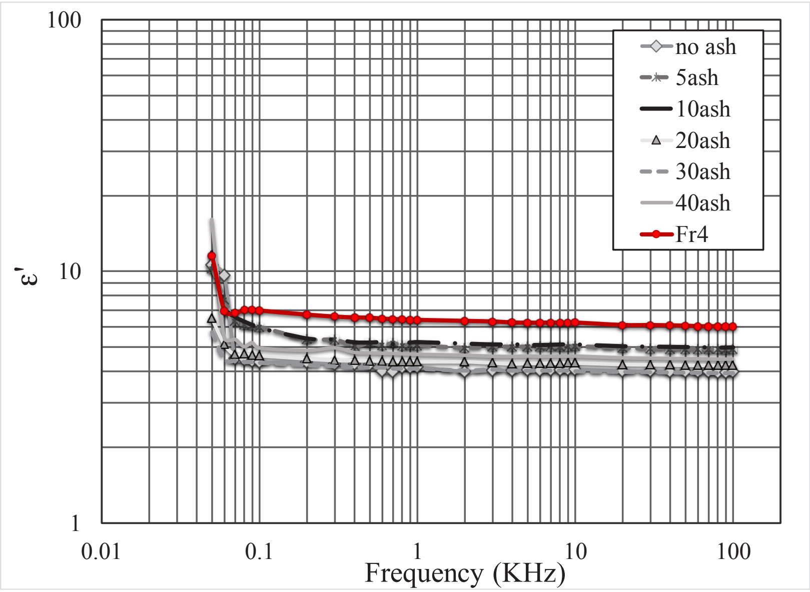

Figure 9. Calculated dielectric constant as a function of frequency

Figure 9 shows the dielectric constant which was calculated from the parallel plate capacitor as $\varepsilon' = C_{pd} / (\varepsilon_o A)$, where d represents the thickness of the rubber sheet, the variable A is the area of the plate electrode and ε_o is the permittivity of free space, 8.854×10^{-12} F/m.

The impedance which was generated from the equivalent circuits and measured data over the whole frequency range is shown in Figure10. Calculated data were compared and shown as a good fit with measured data.

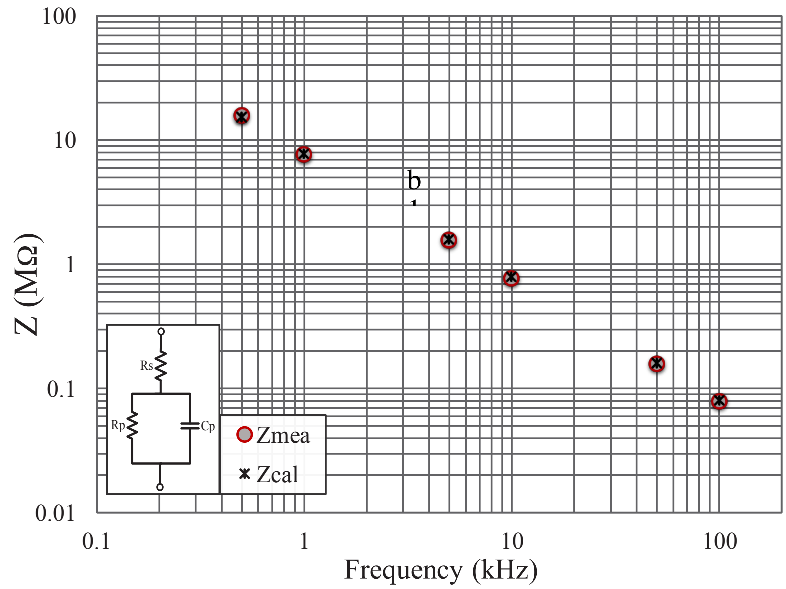

Figure 10. Measured and calculated impedance as a function of frequency

CONCLUSION

This research presents electrical properties of NR/RWA composite at high frequencies. The natural rubber was formed with different RWA contents. The RWA and other blends influence the electrical properties of the rubber composite, especially when involving transient frequencies in the power line system. The materials exhibited dielectric constant of 4-5 and insulation loss or loss tangent (<0.07) in the transient frequency ranges, which are comparable to the dielectric constant of FR4. The measured data agrees with the equivalent circuit which represents the microstructures morphologies of the rubber composite. Thus, these rubber composites can be a good candidate for power line insulators.

However, further tests must be carried out to avoid unexpected breakdown of insulators. These tests include the low-frequency tests, constant DC test, and impulse test. The results obtained from this study can be extended to predict and improve the processes of the rubber composite as a high-voltage insulator.

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REFERENCES

Alpha technologies. (2016). *disperGRADER αview*. Ohio USA: Alpha Technology.

Chapman, M. A., Martinez, A., Sabir, E., Wang, K., & Liu, Y. (1999). Switching and fault caused transients in electric power systems. *IEEE Power Engineering Society 1999 Winter Meeting* (p. 1015–1021).

HIOKI. (2006). *3522-50 LCR HiTESTER Instruction Manual*. Nagano, Japan: HIOKI E.E. Corporation.

Naidu, M. S., & Kamaraju, V. (1996). *High voltage engineering* (2nd ed.). New York: McGraw-Hill.