EFFECT OF HUMIDITY AND NANOFILLER ON SELF-HEALING PROPERTIES OF SILICONE RUBBER

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ABSTRACT Silicone rubber (SiR) is a polymer-based material widely used in the industry as electrical insulation. Self-healing properties in SiR is an interesting phenomenon which is not found in other polymeric materials attracting many researchers to investigate further. SiR has other good characteristics such as oil and solvents resistant; it won't degrade when exposed to sunlight, high gas permeability, and certainly high insulation resistance. However, effect of humidity and nanofiller on self-healing properties of SiR is not clearly understood. In this research work, effect of humidity and nanofiller amount on self-healing properties of SiR sample were investigated. The results revealed that the self-healing properties are better in neat silicone rubber compared to the neat silicone rubber with 90% of humidity, and addition of nanofillers.

1. INTRODUCTION

Electrical tree is a pre-breakdown phenomenon in polymeric insulation material which occurs at the region of high divergent field such as voids, grazes, defects, protrusions, impurities and cracks (Ahmad, et al., 2012a). It is a damaging process which cause by partial discharge and progresses through the stressed dielectric insulation. Electrical treeing is involving electrical, chemical and mechanical processes. Electrical treeing is a breakdown mechanism that usually happened in polymeric materials and it is a main factor of electrical faults in high voltage applications.

Self-healing materials have the structurally incorporated ability to repair damage. It is capable of filling voids in or at least partially repairing damage to a dielectric material in which internal partial discharge occurs. The properties of the self-healing that occurred in dielectric material can be investigated by measuring the decrease of tree length, tree area and weight of the specimen. For an instance, the dielectric material which has a good self-healing property is silicone rubber (SiR).

Many researchers have been investigating on this research field (Kurnianto, R, et. al., 2012, Ahmd, M. H., et al., 2012b). However, effect of nanofiller and humidity on self-healing properties of SiR is not clearly understood. The objective of this research work is to investigate the effect of humidity and nanofiller amount against self-healing performance of SiR.

2. EXPERIMENT

2.1 Sample Preparation

In this research work, the leaf-like sample with a needle electrode made of tungsten wire (with 0.25 mm of diameter and 0.02 mm of tip diameter) was used in investigating the self-healing performance of SiR.

The most essential part in this investigation is preparation of the needles tip. The tip of the needles has to follow the specifications in order to obtain a good result in this experiment. Each of the needles need to be checked their tip radius and placed in a distance of 2mm from the ground electrode. The needle tip have been sharpen using electrolytic polishing using sodium hydroxide (NaOH) solution with a DC supply (30V, 3A). The sample types in this work are neat SiR, neat SiR with 90% of humidity, SiR added with SiO_2 by percentage of 0, 2, 4, and 6 wt%, respectively.

The schematic diagram of leaf-like specimen is shown in Fig 1. Samples for this experiment will be produced in form of leaf-like specimen as shown in Fig. 1. The lentgh of the distance between the needle tip and grounding electrode is set to 2mm. After the nanocomposites were prepared, this nanocomposites polymer was pour above the specimens and the slide glass was used to cover its top surface. Then the specimens were heated in the oven for 45 minutes at 100°C. For the neat samples, the specimens will be exposed at room temperature for 24 hours. While for humidity, the net silicone rubber will be leaved in the humidity chamber with 90% humidity for two days after the specimens were heated in the oven for 45 minutes.

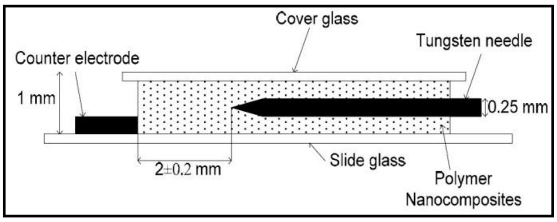


Fig. 1 Side view of schematic diagram of leaf-like specimen.

2.2 Technique

Fig. 2 shows the experimental setup for electrical tree monitoring investigation and self-healing performance of SiR. The tree inception time and tree propagation time for electrical treeing of net silicone rubber, net epoxy resin, silicone rubber filled with nanofillers and neat silicone rubber with 90% humidity are observed and recorded using a microscope-online monitoring system. The propagation of tree is obtained by applying the DC voltage to the specimens. The voltage are kept increase until 10kV with the increasing rate of 1kV/second and wait until the tree start to initiate and turn off the voltage when the electrical treeing length reach at 70%-80% of 2mm gap length. The tree inception time, tree propagation time and tree length is recorded in the computer by using Cellsens software.

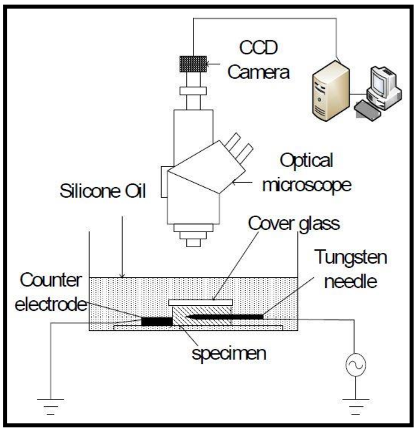


Fig. 2 Experimental setup for electrical tree monitoring investigation and self-healing performance of SiR.

3. ANALYSIS

Fig. 3 shows the electrical tree propagation on neat SiR sample. The tree length of self-healing performance for is measured in time intervals 0, 144, 288, and 432 h, respectively. Fig. 4 shows the electrical tree length for neat SiR samples against elapsed time. As it can be seen from the figures, the tree length and the branches are reduced by increasing the elapsed time. The longer of elapsed time, the shorter the tree and branches length of the samples.

Fig. 5 shows the electrical tree propagation on neat SiR sample with 90% of humidity. While for electrical tree length for neat SiR with 90% of humidity samples against elapsed time is shown in Fig. 6. The tree length reduction is smaller compared to the neat SiR.

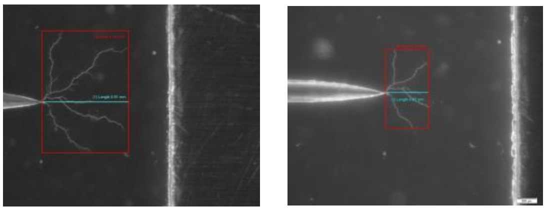
Fig. 7 shows the electrical tree propagation on SiR sample added with 2wt% of SiO_2 nanofiller. Fig. 8 shows the electrical tree length for all samples against elapsed time. It was observed that the self-healing properties of the sample are smaller compared to the neat SiR samples.

Fig. 9 shows the total tree length of all samples types. It is found that the longest length reduction is in neat SiR samples whereas the smallest reduction was occurred in the SiR sample added with 6wt% of SiO_2 nanofiller.

Neat silicone is a softer material than silicone rubber added with nanofillers. The existance of SiO_2 nanofiller in the SiR sample will increase the barrier in the material. Thus it will make the sample become harder. When nanofillers are well dispersed in a polymer matrix, it would result in delaminated or exfoliated particle structures. With this structure, electrical trees will follow the paths through the polymer or interface zones. A uniform arrangement of nanofillers causes electrical tree growth to be slowed down and therefore hindered (Ahmad, M. H., et al., 2012c).

In neat SiR samples, the tree patterns have number of branches with very small diameter and almost invisible. But in the case of the neat SiR with 90% humidity and silicone nanocomposites, the tree pattern is similar to the neat SiR samples but have larger diameter for the tree branches. The presence of the nanofiller, as the electrical tree propagate through the insulation, the electrons which are generated from high stress area collide with the nanoparticles, this in turn restrain the electron avalanches so that the tree channel takes a longer time to propagate in to the insulation compared to the neat SiR ones. With higher percentage of nanofiller, the number of obstructions will increase and tree channel will take more time to reach the opposite electrode (ground).

The treeing diameter obtained from neat SiR with 90% humidity samples are higher compared to the neat ones with room temperature. For 90% humidity, the propagation of the long tree branch almost reached to the ground electrode due to the present of the water layer and the insulation is wet and contaminated condition that would cause the insulation breakdown. In deteriorated insulation may cause the leakage current in the cable insulation. Because of this, the insulation reduces its self-healing properties and may eventually damage.



(a) 0h (b) 432h

Fig. 3 Self-healing performance of neat SiR silicone rubber for sample 1

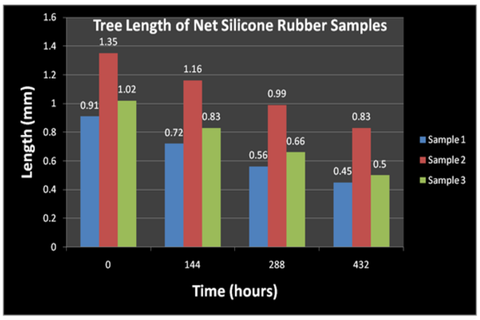
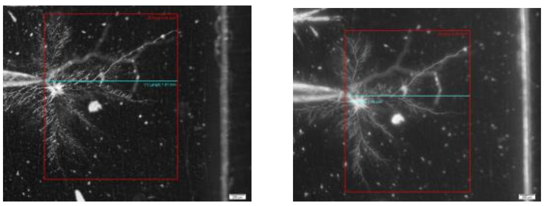


Fig. 4 Tree length of self-healing for neat SiR samples against elapsed time



(a) 0h (b) 432h

Fig. 5 Self-healing performance of neat SiR with 90% of humidity for sample 1

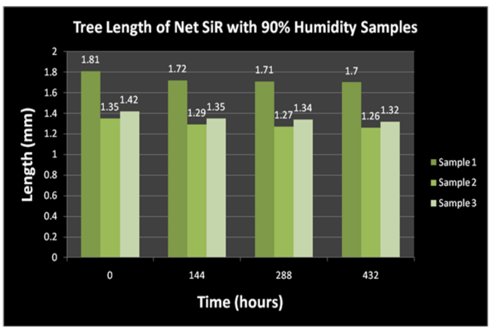
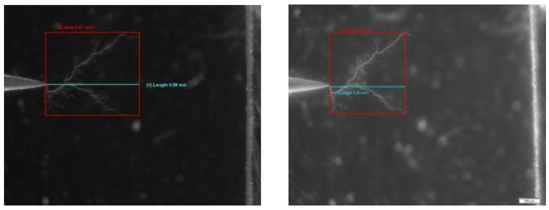


Fig. 6 Tree length of self-healing for neat SiR with 90% of humidity samples against elapsed time.



(a) 0h (b) 432h

Fig. 7 Self-healing performance of neat SiR added with 2wt% of SiO_2 nanofiller for sample 1.

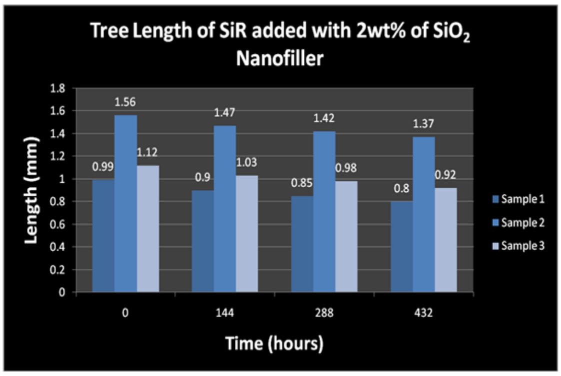


Fig. 8 Tree length of self-healing for neat SiR added with 2wt% of SiO_2 nanofiller samples against elapsed time.

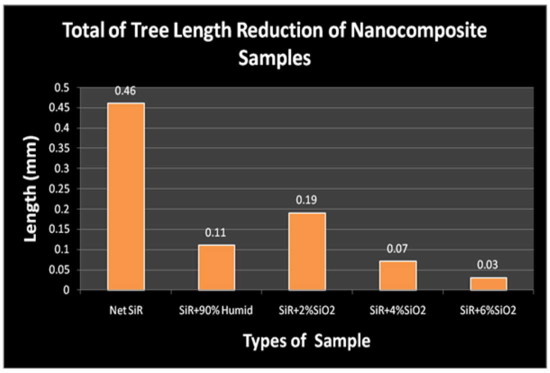


Fig. 9 Total of tree length reduction of all samples

4. CONCLUSION

Effect of humidity and nanofiller amount on self-healing performance of silicone rubber samples has been successfully investigated in this research work. Several important findings are as follows. The self-healing performance is better in neat silicone rubber samples compared to the ones with 90% of humidity. The presence of water layer in humid samples of insulation represents a wet and contaminated condition. Thus, their self-healing property is reduced and may eventually damage the samples. It was also found that the neat silicone rubber sample has better self-healing performance compared to the samples added with SiO_2 nanofiller. This is due to the different compositions of material in which neat silicone rubber is a soft material and thus electrical tree easily to propagates, leading to visible crack or damage on the samples. Self-healing performances of silicone rubber filled with lower percentage of nanofillers is better than those samples with higher percentage of nanofillers. Higher weight percentage (wt%) of nanofiller give slower recovery result.

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REFERENCES

Ahmad, M. H., et al, *Effects of oil palm empty fruit bunch filler on electrical tree propagation in Epoxy resin*, International Conference on High Voltage Engineering and Application (ICHVE), 2012a.

Ahmad, M. H., Ahmad, H, Bashir, N, Arief, Y. Z., Malek, Z. A., Kurnianto, R., and Yusof, F., *A New Statistical Approach for Analysis of Tree Inception Voltage of Silicone Rubber and Epoxy Resin under AC Ramp Voltage. International Journal* on Electrical Engineering and Informatics, 2012b.

Ahmad, M. H., et al., *Effects of Oil Palm Empty Fruit Bunch Filler on the Electrical Tree Propagation in Silicone Rubber.*, 3(0): p. 147-153, 2012c.

Kurnianto, R., et al, *The self-healing property of silicone rubber after degraded by treeing*, International Conference Condition Monitoring and Diagnosis (CMD), 2012.

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