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Effect of Alumina and Halloysite clay on Electrical tree growth in Silicone Rubber Nanocomposite

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Abstract: Nowadays Silicone Rubber (SiR) is recommended in high voltage cable accessories fabrication as it offers excellent electrical and mechanical properties. Electrical tree is one of the phenomenon which contributes to the main factor of SiR insulation breakdown. Recently, a new approach has been applied in order to enhance the insulation strength properties by introducing nano filler in undoped material. Thus, this paper presents the influence of nano-alumina and halloysite nanoclay on electrical tree growth in SiR at 0, 1 vol%, 2 vol% and 3 vol% concentration. The electrical tree growth was investigated at 8kVrms after tree inception voltage (TIV) within 30 minutes under room temperature. The results show reductions of electrical tree growth speed and accumulate damage (%) up to 2 vol% nano-alumina and up to 3 vol% halloysite nanoclay. Nevertheless the presence of 3 vol% nano-alumina in SiR leads to the faster electrical tree growth rate and the worst accumulate damage within 1 minute of electrical tree growth process.

Key words: *Tree growth rate; accumulate damage; nano-alumina; halloyste nanoclay nanocomposites*

INTRODUCTION

Recently Silicone Rubber (SiR) is widely implemented in XLPE cable accessories fabrication up to 500kV as it offers excellent electrical and mechanical properties. However, under the influence of high voltage stress it may contribute to the deterioration of the insulating material and finally lead to the degradation and cable failure. Normally underground cables are exposed to the moisture and contamination which can contribute to the generation of water tree, electrical tree and finally to the cable damage. Electrical tree is one of the main causes to the cable failure in underground cable where the electrical tree initiates at the fragile point of the cable, which may cause from the sharp edge, contaminations and voids [1-4].

Nowadays a few approaches have been taken by numerous researchers in order to enhance the electrical tree resistance in cable accessories fabrication such as improving the material preparation, upgrading the material selection and producing the dielectric material with inhibitor [5],[6]. For fast evolution of nano technology, nano filler has been found as one of the approaches in order to enhance and improve the electrical and mechanical properties in polymeric insulation fabrication. The presence of SiO_2, TiO_2, MMT and OMMT in Silicone Rubber (SiR), Low-density polyethylene (LDPE) and polyethylene (PE) have been reported and investigated [7-10]. Alapati et al have investigated that the presence of nano-alumina up to 5 wt% in LDPE nanocomposites has an ability to improve the electrical properties of the dielectric polymer such as partial discharge resistance, electrical tree length and tree inception voltage (TIV) [9]. Y. X. Zhou et al mentioned that more Bush type tree pattern could be observed regularly with the presence of SiO_2 in SiR. It shows that SiO_2 can prolong the electrical tree growth rate in polymer nanocomposites compared to unfilled polymer [11]. Fairus et al mentioned that there is an improvement of electrical breakdown strength in SiR/EPDM nanocomposites with the inclusion of 2 vol% nano-alumina [12]. A.Mohanty et al reported that Epoxy/Alumina nanocomposites shows better electrical insulation properties than unfilled Epoxy at a few wt%

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of nano-alumina [13]. Morever, X. Huang et al have reported that nano-alumina has relatively high thermal conductivity, affordable price and offers for high electrical resistance resistivity [14].

On the other hand, N. Farzadnia et al have reported that 3 wt% of halloysite nanoclay has better compressive strength in cement mortar up to 24% than unfilled composite[15]. Besides, as reported by H. C. Voon et al and S. Rooj et al there is an improvement of mechanical properties in halloysite/Bovine Gelatin Films nanocomposites and halloysite/fluoroelastomer nanocomposites respectively with the presence of halloysite nanoclay[16],[17]. Although numerous researchers have reported that nano-alumina and halloysite nanoclay have the ability to improve the dielectric properties in few nanocomposites respectively, the influence of nano-alumina and halloysite nanoclay in SiR nanocomposites to the electrical tree growth mechanism has not yet been studied and reported.

Thus, this paper reports the influence of nano-alumina and halloysite nanoclay to the electrical tree growth at 0 to 3 vol% concentration of fillers. The effect for both fillers at different concentration to the electrical tree growth in SiR nanocomposites are observed and analyzed. The electrical tree behaviour on electrical tree growth process such as electrical tree growth rate, and accumulate damage are discussed and presented.

EXPERIMENT SET UP

Test Specimens Preparation

Fig 1 shows configuration of test specimen sample where the needle electrode was put 2mm from the grounded electrode. A 0.25mm diameter of needle electrode was formed at 30° tip angle and 5µm tip radius. A camera-equipped microscope was used to justify and confirm the interval gap of needle electrode to the ground electrode. SiR of (PT910-3) with the curing agent, (produced by Penchem) was employed as the base polymer. Alumina nano filler (13nm primary size, TEM 99.5% trace metals) and halloysite nanocaly (50nm average tube diameter, 15nm inner lumen diameter and 1-3µm length) supplied by Sigma Aldrich, were selected to mix with the SiR base polymer separately. Both nanofillers were mixed with the SiR at 1 vol%, 2 vol% and 3 vol% individually. The unfilled SiR was also prepared for comparison. The weight ratio of SiR base polymer to its hardener was resolved at 10:1.

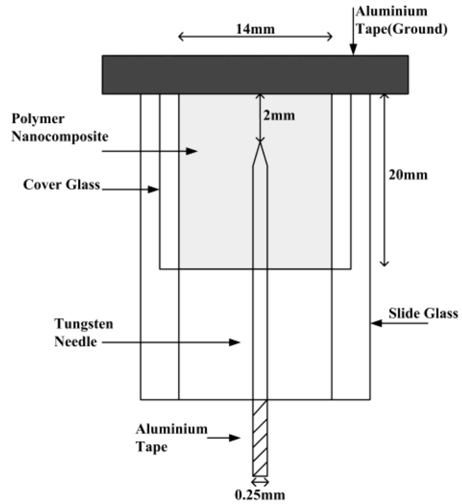

Fig 1 Configuration of block test specimen

The SiR was mixed with the nanofillers separately by using Ultrasonic mixer UP2005 for 10 minutes. Then, the sample was vacuumed for 60 minutes to remove generated voids by using 5831 National vacuum set. Another 10 minutes was required to remix the mixture with the hardener in order to cure the nanocomposites. The mixing process was performed by using Ultrasonic mixer UP2005. The mixture must be vacuumed again for 30 minutes by using 5831 National vacuum set to ensure all the generated voids were totally eliminated. Eventually, the SiR nanocomposites was poured on the slide glass mould. The dimension of the slide glass is 20mm x 14mm x 1mm as shown in Fig 1. The SiR nanocomposite was then covered by a slide cover glass and the sample was kept in room temperature for 24 hours for curing process.

Experimental Apparatus

Fig 2 illustrates the experimental set up to investigate the electrical tree growth process in SiR nanocomposites. A 5kVA, 240V/100kV, 50Hz high voltage transformer was used as a power source for this studies. For each specimen tested, the supply voltage was increased by the rate of 0.5kV/sec until the TIV was observed. Once the TIV was justified, the supply was kept constant at 8 kVrms in order to monitor the electrical tree growth process. For this purpose, online monitoring system consists of a stereo microscope (Leica M165C), a digital camera (Leica MC170HD) and LCD personal computer monitor was configured. During the recording process, the magnification capability of monitoring system was set at 60 times magnification for the best quality image.

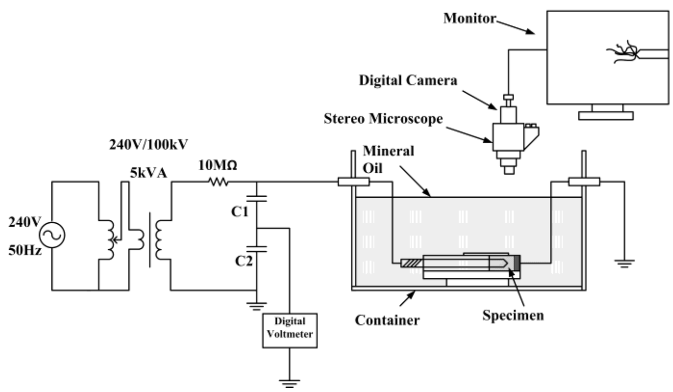

Fig 2 Set up arrangement for electrical tree observation

For the safety and precaution purpose, each of the samples tested was immersed into mineral oil in order to avoid surface flash over and the sample was placed directly below the lens of the camera. The process of electrical tree growth was monitored through the LCD personal computer monitor.

RESULT AND DISCUSSION

Electrical Tree Growth Rate

Fig 3 illustrates electrical tree growth rate as a function of time. The result shows the electrical tree growth process in unfilled SiR has a same trend with the SiR containing nano-alumina up to 2 vol% and Halloysite nanoclay up to 3 vol%.

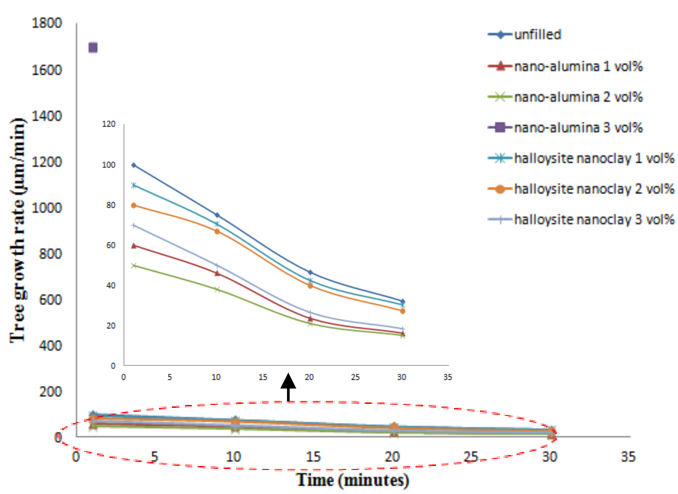

Fig 3 Electrical tree growth rate as a function of treeing time within 30 minutes at 8kVrms

The electrical tree grew faster at the first 10 minutes and became slow at the last 20 minutes.The presence of 2 vol% nano-alumina and 3 vol% halloysite nanoclay in SiR have improved the electrical tree growth rate compared to unfilled SiR. These filler loading has prolonged the electrical tree growth process in the composite. However, the electrical tree growth faster at 3 vol% of nano-alumina compared to the others.

Accumulate Damage

The accumulate damage of the nanocomposite due to electrical tree growth path is analyzed by using ImageJ software. The covered area of insulation material for each photo taken was fixed at 1232µm x 1354 µm as shown in Fig 4. This automatic image analysis software is capable to calibrate the measurement scale, process and finally display the data measurement output effectively.

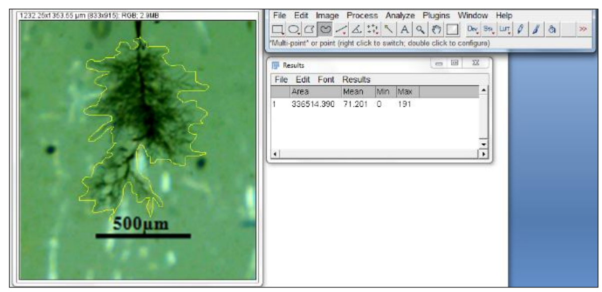

Fig 4 Accumulate damage measurement for unfilled SiR using ImageJ software

Fig 5 shows the typical type of electrical tree structure and accumulate damage in SiR nanocomposites at 30 minutes of electrical tree growth with 8kVrms. It can be observed that, the carbonized area and accumulate damage in unfilled SiR is quite large as shown in Fig 5(a). Fig 5(b) and 5(c) show reduction of accumulate damage in SiR/Alumina nanocomposites with the presence of nano-alumina up to 2 vol%. Meanwhile, the presence of halloysite nanoclay at 1, 2 and 3 vol% of halloysite nanoclay in SiR as shown in Fig 5(d), 5(e) and 5(f) also indicate improvement of accumulate damage compared to unfilled SiR.

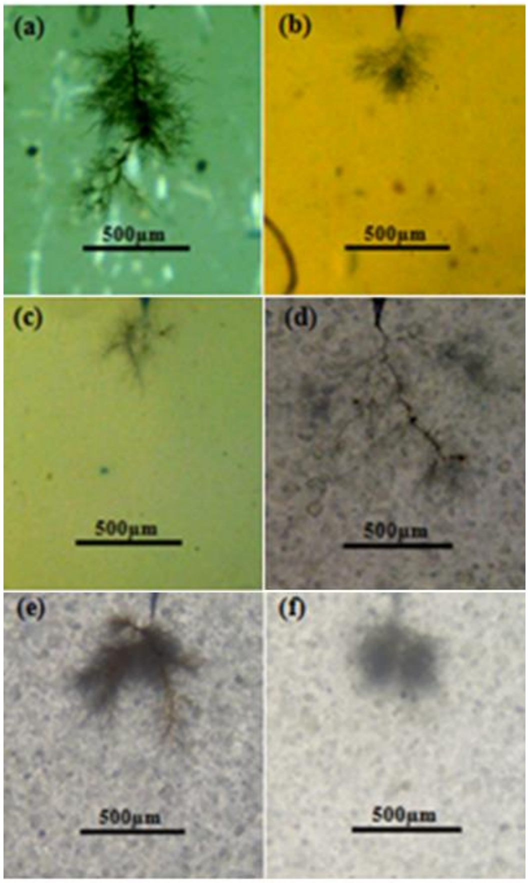

Fig 5 Typical type of electrical tree structure and accumulate damage in SiR nanocomposites with different concentration of filler captured at 30 minutes of electrical tree growth process (a)unfilled SiR, (b) SiR with 1 vol% nano-alumina, (c) SiR with 2 vol% nano-alumina, (d) SiR with 1 vol% halloysite nanoclay, (e) SiR with 2 vol% halloysite nanoclay,(f)SiR with 3vol% halloysite nanoclay

Fig 6 depicts the electrical tree growth and accumulate damage in SiR nanocomposites at 3 vol% concentration of nano alumina.

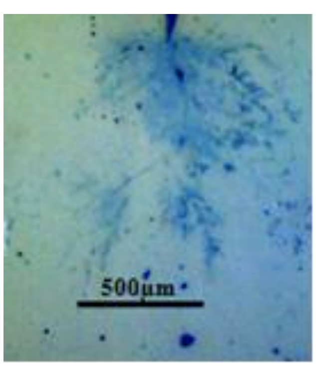

Fig 6 Electrical tree growth and accumulate damage in SiR with with 3 vol% nano-alumina only at 1 minute of electrical tree growth process

It can be seen that the electrical tree growth path have deteriorated the worst area of insulation gap only at 1 minute of electrical tree growth process compared to the other SiR nanocomposites as discussed in Fig 5. The worst accumulate damage at 3 vol% nano-alumina in SiR nanocomposites might be due to the agglomeration and overlapping of filler dispersion which contribute to the conductive path region area which finally led to the fastest electrical tree growth. The image captured

SEM Image Analysis

Fig 7 shows the image of Scanning electron microscopy (SEM) at 50K magnification for unfilled SiR and SiR filled with 3 vol% nano-alumina and halloysite nanoclay. Fig 7(a) shows the SEM image of unfilled SiR while Fig 7(b) shows SEM image of 3 vol% halloysite nanoclay.

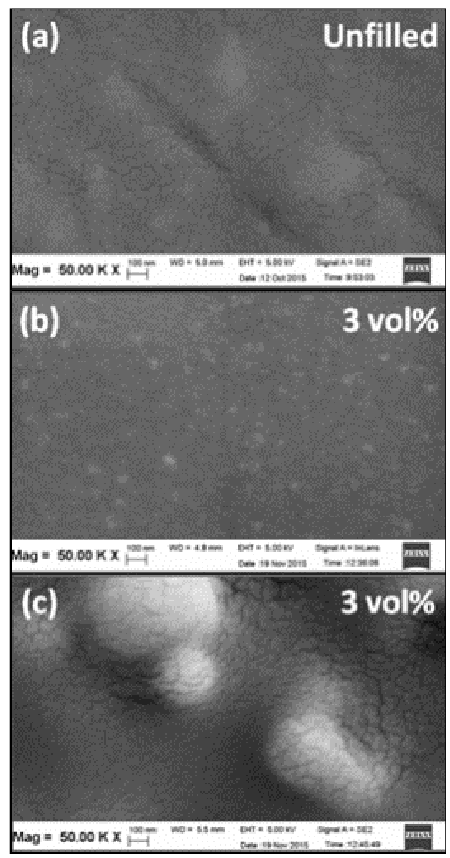

Fig 7 SEM image of unfilled SiR and SiR nanocomposites at different concentration of filler (a) unfilled SiR, (b) SiR with 3 vol% halloysite nanoclay, (c) SiR with 3 vol% nano-alumina

From the image, it is obviously depicts that the 3 vol% of halloysite nanoclay is homogeneously dispersed in SiR that may offer better electrical tree growth rate and less of insulation damage than unfilled SiR. This happens because of huge interfacial trap region area in SiR halloysite nanoclay compared to unfilled SiR [5].

However the presence of 3 vol% nano-alumina in SiR nanocomposites yield to the agglomeration of nanofiller as shown in Fig 7(c) The agglomeration of nanofiller in SiR is believed to contribute to the overlapping of filler dispersion.This kind of filler dispersion offers the conductive path region which leads to the fastest electrical tree growth rate and the worst accumulate damage only at 1 minute of electrical tree growth process[18].

CONCLUSION

The effect of nano-alumina and halloysite nanoclay up to 3 vol% on electrical tree growth mechanism has been studied. It is observed that the presence of 2 vol% nano-alumina and 3 vol% halloysite nanoclay in SiR nanocomposites show the slowest electrical tree growth rate and the less accumulate damage compared to unfilled SiR. It is believed that the improvement of electrical tree growth rate and accumulate damage is due to the reduction of inter particle distance in SiR nanocomposites which offers better electrical tree trap region area. However, it can be observed that there was obvious filler aggregation at 3 vol% nano-alumina which offers the conductive path region area in SiR nanocomposites. This kind of nanocomposites leads to the fastest electrical tree growth rate and the worst of accumulate damage only at 1 minute of electrical tree growth process.

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