EFFECT OF ALUMINA AND HALLOYSITE CLAY IN SILICONE RUBBER NANOCOMPOSITE ON THE ELECTRICAL TREE CHARACTERISTICS

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by

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DECLARATION

I hereby declare that the work reported in this thesis is the result of my own investigation and that no part of the thesis has been plagiarized from external sources. Materials taken from other sources are duly acknowledged by giving explicit references.

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LIST OF SYMBOLS

kV	Kilovolt
sec	Second
Hz	Hertz
Ω	Ohm
°	Degree
vol%	Volume percentage
wt%	Weight percentage
A	Ampere
C	Celsius
T	Tesla

LIST OF ABBREVIATIONS

XLPE	Crosslink polyethylene
SiR	Silicone rubber
TIV	Tree inception voltage
SEM	Scanning electron microscopy
rms	Root mean square
TiO_2	Titanium dioxide
SiO_2	Silicon dioxide
MMT	Montmorillonite
OMMT	Organo-montmorillonite
LDPE	Low density polyethylene
EMJ	Extrusion molded joints
PJ	Prefabricated joints
EPDM	Ethylene propylene dienemonomer
IEC	International Electrotechnical Commission

KESAN ALUMINA DAN TANAH LIAT HALOISIT DALAM GETAH SILIKON NANOKOMPOSIT PADA CIRI-CIRI POKOK ELEKTRIK

ABSTRAK

Kajian kesan pengisi nano dalam SiR terhadap sifat dielektrik adalah masih baru. Oleh itu, kajian ini perlu diteruskan untuk mendapatkan pemahaman yang lebih jelas dan terang. Beberapa kajian telah dilaporkan bahawa pengisi nano-alumina dan tanah liat haloisit mampu meningkatkan ciri-ciri elektrik dan mekanik dalam bahan polimer seperti dalam nanokomposit epoxy dan LDPE. Oleh itu, dalam kajian ini kesan pengisi nano-alumina dan tanah liat haloisit dalam SiR terhadap ciri-ciri elektrik seperti voltan permulaan pokok (TIV), proses perkembangan pokok elektrik, kebarangkalian kejadian struktur pokok elektrik, jenis-jenis pokok elektrik, panjang pokok elektrik dan kadar perkembangan pokok elektrik telah dikaji. Selain itu, medan elektrik maksimum, kerosakan terkumpul dan faktor perkembangan juga telah dipelajari dan dikaji. Analisis struktur permukaan nanokomposit SiR/Alumina dan SiR/Tanah liat haloisit juga telah dilakukan menggunakan pengimbas Elektron Mikroskop (SEM). Selain itu, jarak antara zarah-zarah nano (permukaan ke permukaan) di dalam nanokomposit SiR/Alumina yang dianalisa menggunakan mesin SEM dipastikan dengan menggunakan perisian ImejJ dan persamaan untuk pengiraan jarak antara zarah-zarah juga turut dibincangkan. Keputusan telah menunjukkan 2 vol% nano-alumina di dalam SiR berkemampuan untuk memperbaiki ciri-ciri pokok elektrik seperti voltan permulaan pokok, panjang pokok elektrik dan kadar perkembangan pokok elektrik berbanding SiR yang asli. Walau bagaimanapun pengisian nano-alumina kepada 3 vol% telah menjatuhkan TIV secara drastik dan menyebabkan kadar perkembangan pokok dan pecah tebat berlaku dengan cepat. Sebaliknya pengisian tanah liat haloisit sehingga 3 vol% dalam SiR telah

memperbaiki voltan permulaan pokok, panjang pokok elektrik dan kadar perkembangan pokok elektrik berbanding SiR yang asli. Keputusan ini menunjukkan pengisian nano-alumina sehingga 2 vol% dan pengisian tanah liat haloisit sehingga 3 vol% di dalam SiR cenderung untuk pokok elektrik muncul dengan pokok jenis bush. Selain itu ia juga telah meningkatkan medan elektrik maksimum, kurangkan peratusan kerosakan terkumpul dan faktor perkembangan terjadi lebih kurang 1. Selain itu, keputusan dari analisa imej SEM menunjukkan bahawa nano-alumina bertaburan secara sekata sehingga 2 vol% walau bagaimanapun pengisian sehingga 3 vol% pengisi nano-alumina dalam SiR cenderung terjadinya gumpalan pada pengisi nano. Jarak antara zarah-zarah nano dalam nanokomposit SiR/Alumina(permukaan ke permukaan) pada 1 vol% dan 2 vol% hampir sama setelah dipastikan dengan menggunakan perisian ImejJ dan persamaan untuk pengiraan jarak antara zarah-zarah. Sementara itu, untuk tanah liat haloisit, pengisi nano bertaburan sekata sehingga 3 vol%.

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ABSTRACT

The research on the effect of nanofiller in SiR on the dielectric properties is still new. Thus, it needs to be explored to expand on past work in the field for better understanding. It has been reported that research on nano-alumina and halloysite nanoclay have been carried out where the nanofillers has an ability to enhance the electrical and mechanical properties in other polymer material such as in epoxy and LDPE nanocomposites. Thus in this research, the influence of nano-alumina and halloysite nanoclay in SiR on the electrical tree characteristics tree such as tree inception voltage (TIV), electrical tree growth process, probability occurrences of electrical tree structure, types of electrical tree, electrical tree length and electrical tree growth rate are investigated. In addition, maximum of electrical field, accumulate damage and expansion coefficient are also studied and investigated. Surface morphology analysis of SiR/Alumina nanocomposites and SiR/Halloysite clay nanocomposites using Scanning Electron Microscopy (SEM) are also performed. Furthermore, the inter particle distance of nanofiller (surface to surface) in SiR/Alumina nanocomposites analyzed from SEM images are evaluated using ImageJ software and inter particles distance equation is also discussed. The results have revealed that 2 vol% nano-alumina has an ability to improve the electrical tree characteristics such as tree inception voltage (TIV), electrical tree length, electrical tree growth rate compared to unfilled SiR. However the increase of nano-alumina up to 3 vol% drops the TIV and contributes to rapid electrical tree growth rate and insulation breakdown. On the other hand, the presence of halloysite nanoclay up to 3 vol% in SiR has improved the TIV, electrical tree length, electrical tree growth rate

compared to the unfilled SiR. It is shown that, the addition of nano-alumina up to 2 vol% and up to 3 vol% for halloysite nanoclay in SiR tends the tree structure appeared in bush type tree. Furthermore, it has also increased the maximum electrical field, reduced the percentage of accumulate damage and the expansion coefficient is varied almost to unity. In addition, the result from SEM image analysis depicted that nano-alumina is homogenously dispersed up to 2 vol% however further increase of 3 vol% nano-alumina in SiR yielded to the filler agglomeration. The inter particle distance of nano-alumina (surface to surface) in SiR/Alumina nanocomposites at 1 vol% and 2 vol% are considered similar evaluated by using ImageJ software and inter particles distance equation. Meanwhile, the halloysite nanoclay in SiR is homogenously dispersed up to 3 vol%.

CHAPTER ONE

INTRODUCTION

1.1 Overview

Transmission lines for high voltage power cables are the most important medium to transmit the electrical power from the power generation to the consumers. Generally the electrical power is distributed either by overhead or underground transmission line. Currently, Crosslink Polyethylene (XLPE) power cable is one of the high voltage underground transmission line cables which can stand the voltages range up to 500kV [1]. Generally, XLPE power cable used accessories such as cable joints and cable termination in order to join between two power cables and to terminate the end of the power cable [2].

Lately, Silicone Rubber (SiR) is being preferred and widely used in underground high voltage cable accessories for XLPE power cable as it offers for flexibility, stand for oxidization, excellent electrical and mechanical properties also can stand for wide temperature and voltage range application [3]. However, the power cables and the cable accessories that have been installed for a longer time may become aged and exposed to the contamination and moisture. Under influence of non-uniformed high electrical field, this power cables and the cable accessories may deteriorated and eventually may lead to the cable breakdown [4]. Besides, cable accessories have complex physical shape and structure and the distribution of electrical field inside the cable accessories is not as uniformed as in high voltage power cable and can cause to the generation of water tree, electrical tree and finally lead to the degradation and cable failure [5].

Electrical tree is one the main factors which can contribute to the failure of accessories and high voltage cable [6]. This phenomenon initiates at the weakest point of the cable accessories and high voltage cable that may occur at the cable joints or cable termination due to its complex physical structure and defect during installation and manufacturing process [7], [8]. Electrical tree may start from the creation of water tree due to the non uniform electrical field, contamination and moisture [9], [10]. Once water tree occurred in the cable under continuously electric field stressed, it will lead to creation of electrical tree. Electrical tree can be divided into three main stages. There are initial stage, propagation stage and breakdown stage. Once the electrical tree initiates, it will propagate and finally reach the breakdown stage [1].

In order to improve and upgrade the electrical and mechanical properties in cable accessories fabrication, a few approaches have been applied by SiR manufacturers such as improving the process of material preparation, concerning on material quality for cable accessories fabrication and producing the material with the inhibitor. Presently the application of nanofiller in nanocomposites material has been paid much concern because of its capability in enhancing the electrical and mechanical properties without modifying the polymer nanocomposites material compared to the conventional polymer [11]. The application of few nanofillers in different dielectric materials have been investigated and reported such as the effect of Titanium dioxide (TiO_2), Silicon dioxide (SiO_2), Montmorillonite (MMT) and Organo-montmorillonite (OMMT) on electrical tree resistance in SiR [12]. It is observed that the presence of these fillers in certain wt% concentration has improved the electrical tree resistance in SiR respectively [13]. In addition, it is reported that the nano-alumina up to 5 wt % has improved electrical properties in Low-density polyethylene (LDPE) nanocomposites such as partial discharge resistance, tree inception voltage and electrical tree length [14]. It is mentioned that the presence of certain wt% concentration of nano-alumina in epoxy nanocomposites has enhanced electrical tree properties compared to the unfilled epoxy [15]. It is also mentioned that the electrical breakdown strength significantly improved in SiR/EPDM nanocomposites with the presence of nano-alumina at certain vol% [16]. Furthermore it is reported that, nano-alumina offers excellent electrical resistance resistivity, has relatively high thermal conductivity and also offers affordable price.

On the other hand, it is reported that the presence of 3 wt% of halloysite nanoclay in cement mortar has shown better compressive strength up to 24% than unfilled one [17]. Besides, the presence of halloysite nanoclay in halloysite/bovine gelatin films nanocomposites and halloysite/fluoroelastomer nanocomposites have improved the mechanical properties respectively [18], [19]. Although many improvement on dielectric properties have been reported with the presence of nano-alumina and halloysite nanoclay in material nanocomposites, the influence of nano-alumina and halloysite nanoclay on electrical tree properties in SiR nanocomposites have not yet been studied and reported. Therefore, the main objective for this study is to investigate the electrical tree properties in SiR nanocomposites with the presence of nano-alumina (Al_2O_3) and halloysite nanoclay ($H_4Al_2O_9Si_2.2H_2O$) at 0, 1, 2 and 3 vol% of filler loading. Then, the electrical tree properties in SiR nanocomposites such as TIV, tree length, tree growth process, tree growth rate, tree structures, maximum electrical field, accumulate damage, expansion coefficient and image of filler dispersion have been studied and analyzed.

1.2 Problem Statement

High voltage cable accessories such as cable joints and cable termination is one of the most important parts in underground transmission line system. Nowadays SiR is widely used as cable accessories in XLPE high voltage power cable up to 500 kV because it offers wide range of temperature and voltage and application, flexibility, stand for oxidization and also offers superb electrical and mechanical properties. Generally, these cable accessories are used to join two high voltage power cables and to terminate the high voltage power cables. However the joint and termination area are more exposed to the defects and cable failures than the normal cable. It is because the part of jointed and termination area are exposed to the moisture and contamination which leads to the generation of water and electrical trees and finally can contribute to the cable breakdown. Moreover, their complex physical structure, defect during installation and the influence of non uniformed electrical field distribution may cause cable accessories failure and cable breakdown. As a result, numerous researchers have introduced nano technology as a new approach and a few nanofillers such as TiO_2, SiO_2, MMT and OMMT at different concentration (wt%) have been applied in order to enhance the electrical tree resistance in SiR nanocomposite. It is observed that these nanofillers have improved the electrical tree properties such as TIV, tree length and tree growth rate in SiR nanocomposites. However the influence of nano-alumina and halloysite nanoclay on electrical tree resistance in SiR nanocomposites at different vol% concentration is not known. Therefore the effect of nano-alumina and halloysite nanoclay in SiR is investigated in order to gain some knowledge on the electrical tree behavior and finally to evaluate the enhancement of electrical tree resistance in SiR nanocomposites.