EFFECT OF WATER ON BREAKDOWN CHARACTERISTICS OF POLYETHYLENE/SILICON NITRIDE NANOCOMPOSITES

SITI NUR RAHMAH BINTI MOHD ZAFRULLAH

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To my beloved parents, Mohd Zafrullah bin Sulaiman
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ABSTRACT

In developing future electrical networks, one of the important aspects to transfer efficient high power over a long distance is the use of proper insulating materials. The addition of nanofillers into polymers has provided significant improvements on the electrical properties including breakdown characteristics. This project seeks to determine the effect of water on the breakdown strength of Low Density Polyethylene (LDPE) when added with varying amounts of silicon nitride as nanofiller. This can be achieved by first preparing the samples using two roll mill machine prior to heat compressing using hot pressed machine. The samples were then immersed in distilled water for a certain time interval to determine the effect of water absorption. Moreover, in order to determine the effect of water absorption on breakdown characteristics, DC breakdown test was conducted before and after samples undergo absorption of water process following the standard of ASTM D149. The addition of nanofiller had shown to significantly alter the water absorption behavior of the composite material, thus affecting the breakdown characteristics of the nanocomposite.

ABSTRAK

Dalam membangunkan rangkaian elektrik akan datang, salah satu aspek yang penting untuk memindahkan kuasa tinggi yang cekap melalui jarak yang panjang adalah penggunaan bahan penebat yang bersesuaian. Penambahan zarah nano ke dalam polimer telah menyediakan peningkatan yang ketara pada sifat-sifat elektrik ciri-ciri pecah tebat. Projek ini bertujuan untuk menentukan kesan air pada kekuatan pecah tebat Polyethylene berketumpatan rendah (LDPE) apabila ditambah dengan jumlah nitrida silikon yang berbeza sebagai nanofiller. Ini boleh dicapai dengan menyediakan sampel dengan mesin pengilangan dua roll sebelum memanaskan dan memampatkan dengan menggunakan mesin. Sampel kemudiannya direndam dalam air suling untuk selang masa tertentu untuk menentukan kesan penyerapan air. Lebih-lebih lagi, untuk menentukan kesan penyerapan air ciri-ciri kerosakan, ujian voltan terus pecah tebat dijalankan mengikut standard ASTM D149 sebelum dan selepas sampel menjalani proses penyerapan air. Penambahan nanofiller telah menunjukkan perubahan tingkah laku penyerapan air bahan komposit, sekali gus menjejaskan ciri-ciri pecahan komposit nano.

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LIST OF ABBREVIATIONS

LDPE	-	Low Density Polyethylene
DC	-	Direct Current
AC	-	Alternating Current
ASTM	-	American Standard Testing and Material
UTM	-	Universiti Teknologi Malaysia
FKE	-	Fakulti Kejuruteraan Elektrik
IVAT	-	Institusi Arus Voltan Tinggi

LIST OF SYMBOLS

α	-	Scale parameter
β	-	Shape parameter
k	-	Kilo
V	-	Volt
mm	-	Millimetre
Si_3N_4	-	Silicon nitride
Wt%	-	Weight percentage
W	-	Weight difference percentage
M_d	-	Weight of sample after immersion
M_O	-	Weight of sample before immersion
E	-	Breakdown voltage
P(E)	-	Cumulative probability of breakdown

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In developing future electrical networks, high performance cable systems are needed to transfer a large amount of power over a long distance. One of the important factors that needs to be taken into account in delivering electricity via high voltage transmission is the use of proper insulating materials. In order to produce a material with enhanced dielectric properties, it is important to explore the capabilities of the material for use in high voltage insulation. In this regards, polymers offer advantages in dielectric properties, volume resistivity, thermal properties, mechanical strength and lighter weight. Other than that, polymeric insulators commonly have good water repellent properties (hydrophobicity)[1-4].

A lot of recent research indicates that dielectric properties of polymeric insulating materials can be improved by the dispersion of nanosized particles in polymer matrices. The addition of nanofillers into polymers, also widely known as polymer nanocomposites, is predicted to be capable of enhancing the dielectric performance while addressing thermal, mechanical and economic requirement [5, 6]. The capabilities of nanocomposites in providing enhanced dielectric performances are

believed to be related to the much smaller size of the filler, which subsequently leads to the presence of a large interfacial area as an interaction zone between the filler and the matrix.

However, the effect of water absorption in nanocomposites has been considered recently and unfortunately, it was found that nanocomposites can absorb significantly more water than the equivalent unfilled polymer when exposed to humid environmental conditions. The presence of water negatively affects the overall electrical properties [7-9]. To date, the effect of water on nanocomposites is still far from being understood. Significantly, a nitride-based nanofiller system could provide potential advantages over an oxide based nanofiller system through a reduction of surface hydroxyl groups, thus resulting in a composite with dielectric properties that are potentially much less influenced by absorbed water [7].

This project seeks to understand the effect of water on polyethylene nanocomposites containing silicon nitride nanofiller. Samples containing different weight percentage (wt%) of silicon nitride nanofiller dispersed in polyethylene will be fabricated. Breakdown strength test of the polyethylene nanocomposite samples will be investigated before and after the samples are immersed in water.

1.2 Problem Statement

The addition of nanofillers into polymers was found to negatively affect the dielectric properties of the resulting nanocomposites, especially when the materials were exposed to humid environment. This is because the addition of nanofillers could significantly alter the water absorption behavior of nanocomposites, thus affecting the breakdown characteristics of nanocomposites. Although a lot of research on

nanocomposites has been conducted on the effects of oxide-based nanofillers, the effects of nitride-based nanofillers have been less explored.

1.3 Objectives:

This project seeks to clarify and determine the effect of water on the breakdown strength of LDPE (low density polyethylene) when added with varying amounts of silicon nitride nanofiller. The main objectives of this project is:

1. to formulate and characterize samples of polyethylene added with different amounts of silicon nitride nanofiller.
2. to determine the effect of silicon nitride nanofiller on the breakdown strength of the resulting nanocomposite material.
3. to study the effect of water absorption on the breakdown strength of nanocomposites containing silicon nitride nanofiller.

1.4 Scopes of Project

The scope of this project are as follows:

1. LDPE and silicon nitride were used as the base polymer and nanofiller respectively
2. Different weight percentages (wt%) of nanofiller, i.e., 0 wt%, 1 wt%, 3 wt% and 5 wt%, were used in this project
3. Different levels of water absorption , ie 0 days, 10 days and 30 days were considered

4. DC breakdown test was conducted to test breakdown strength according to ASTM D419

REFERENCES

[1] S. Manjang, I. Kitta, K. B. Muhammadia, and R. N. I. Mulya, "Effect of water diffusion on dielectric behavior of polymer insulators," in *Electrical Engineering and Informatics (ICEEI), 2015 International Conference on*, 2015, pp. 192-196.

[2] J. K. Nelson, J. C. Fothergill, L. A. Dissado, and W. Peasgood, "Towards an understanding of nanometric dielectrics," in *Electrical Insulation and Dielectric Phenomena, 2002 Annual Report Conference on*, 2002, pp. 295-298.

[3] K. Y. Lau, A. S. Vaughan, and G. Chen, "Nanodielectrics: opportunities and challenges," *IEEE Electrical Insulation Magazine*, vol. 31, pp. 45-54, 2015.

[4] T. Tanaka, Y. Matsuo, and K. Uchida, "Partial Discharge Endurance of Epoxy / SiC Nanocomposite," in *2008 Annual Report Conference on Electrical Insulation and Dielectric Phenomena*, 2008, pp. 13-16.

[5] M. Praeger, I. L. Hosier, A. S. Vaughan, and S. G. Swingler, "The effects of surface hydroxyl groups in polyethylene-silica nanocomposites," in *2015 IEEE Electrical Insulation Conference (EIC)*, 2015, pp. 201-204.

[6] T. Tanaka, G. C. Montanari, and R. Mulhaupt, "Polymer nanocomposites as dielectrics and electrical insulation-perspectives for processing technologies, material characterization and future applications," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 11, pp. 763-784, 2004.

[7] I. L. Hosier, M. Praeger, A. S. Vaughan, and S. G. Swingler, "Electrical properties of polymer nano-composites based on oxide and nitride fillers," in *2015 IEEE Electrical Insulation Conference (EIC)*, 2015, pp. 438-441.

[8] C. Zou, J. C. Fothergill, and S. W. Rowe, "The effect of water absorption on the dielectric properties of epoxy nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 15, pp. 106-117, 2008.

[9] D. Fabiani, G. C. Montanari, L. Testa, R. Schifani, F. Guastavino, F. Bellucci, *et al.*, "Effect of water adsorption on the dielectric properties of polymer nanocomposites," in *Electrical Insulating Materials, 2008. (ISEIM 2008). International Symposium on*, 2008, pp. 510-513.

[10] R. C. Smith, C. Liang, M. Landry, J. K. Nelson, and L. S. Schadler, "The mechanisms leading to the useful electrical properties of polymer nanodielectrics," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 15, pp. 187-196, 2008.

[11] S. Li, G. Yin, and L. Jianying, "Breakdown performance of low density polyethylene nanocomposites," in *Properties and Applications of Dielectric Materials (ICPADM), 2012 IEEE 10th International Conference on the*, 2012, pp. 1-4.

[12] T. J. Lewis, "Nanometric dielectrics," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 1, pp. 812-825, 1994.

[13] J. K. Nelson, "Overview of nanodielectrics: Insulating materials of the future," in *2007 Electrical Insulation Conference and Electrical Manufacturing Expo*, 2007, pp. 229-235.

[14] D. Fabiani, G. C. Montanari, and L. Testa, "Effect of aspect ratio and water contamination on the electric properties of nanostructured insulating materials," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 17, pp. 221-230, 2010.

[15] J. W. G. C. XU, X. L. JI, J. Y. XIONG AND F. LI, "Effect of Nano-silicon Nitride on the Mechanical and Electric Properties of Polypropylene Nanocomposite," 2001

[16] K. Y. Lau, A. S. Vaughan, G. Chen, and I. L. Hosier, "Dielectric response of polyethylene nanocomposites: The effect of surface treatment and water absorption," in *Electrical Insulation and Dielectric Phenomena (CEIDP), 2012 Annual Report Conference on*, 2012, pp. 275-278.

[17] T. P. Hong, O. Lesaint, and P. Gonon, "Water absorption in a glass-mica-epoxy composite - [I: Influence on Electrical Properties]," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 16, pp. 1-10, 2009.

[18] I. L. Hosier, M. Praeger, A. F. Holt, A. S. Vaughan, and S. G. Swingler, "Effect of water absorption on dielectric properties of nano-silica/polyethylene composites," in *2014 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 2014, pp. 651-654.

[19] C. Zou, M. Fu, J. C. Fothergill, and S. W. Rowe, "The influence of water on dielectric behavior of silica-filled epoxy nano-composites and percolation phenomenon," in *2007 Annual Report - Conference on Electrical Insulation and Dielectric Phenomena*, 2007, pp. 372-375.

[20] L. Zhang, Y. Zhou, X. Cui, Y. Sha, T. H. Le, Q. Ye, *et al.*, "Effect of nanoparticle surface modification on breakdown and space charge behavior of XLPE/SiO2 nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 21, pp. 1554-1564, 2014.

[21] T. Imai, F. Sawa, T. Ozaki, Y. Inoue, T. Shimizu, and T. Tanaka, "Comparison of Insulation Breakdown Properties of Epoxy Nanocomposites under Homogeneous and Divergent Electric Fields," in *2006 IEEE Conference on Electrical Insulation and Dielectric Phenomena*, 2006, pp. 306-309.

[22] R. S. G. G. Iyer, R. Richert, "Dielectric Properties of Epoxy based Nanocomposites for High Voltage Insulation," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 18, 2011.

[23] I. P. Florin Ciuprina, Petru V. Notingher,Pascal Rain, "Dielectric Properties of LDPE-SiO2 Nanocomposites," *International Conference on Solid Dielectrics*, 2010.

[24] I. L. Hosier, A. S. Vaughan, and W. Tseng, "Effect of polyethylene on morphology and dielectric breakdown in EVA blends," in *2007 IEEE International Conference on Solid Dielectrics*, 2007, pp. 184-187.

[25] R. Kochetov, I. A. Tsekmes, P. H. F. Morshuis, J. J. Smit, A. J. Wanner, F. Wiesbrock, *et al.*, "Effect of water absorption on dielectric spectrum of nanocomposites," in *2016 IEEE Electrical Insulation Conference (EIC)*, 2016, pp. 579-582.

[26] L. S. S. Le Hui, J. Keith Nelson, "The Influence of Moisture on the Electrical Properties of Crosslinked Polyethylene/Silica Nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 20, p. 641, 2013.

[27] L. Hui, L. S. Schadler, and J. K. Nelson, "The influence of moisture on the electrical properties of crosslinked polyethylene/silica nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 20, pp. 641-653, 2013.

[28] G. Iyer, R. S. Gorur, R. Richert, A. Krivda, and L. E. Schmidt, "Dielectric properties of epoxy based nanocomposites for high voltage insulation," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 18, pp. 659-666, 2011.

[29] W. Qi, P. Curtis, and G. Chen, "Effect of nano-fillers on electrical breakdown behavior of epoxy resin," in *2010 Annual Report Conference on Electrical Insulation and Dielectic Phenomena*, 2010, pp. 1-4.

[30] F. Guastavino, A. Ratto, E. Torello, M. Hoyos, N. Garcia, H. Reinecke, *et al.*, "AC electrical strength measurements on LDPE nanocomposites," in *2006 IEEE Conference on Electrical Insulation and Dielectric Phenomena*, 2006, pp. 329-332.

[31] A. S. Vaughan, C. D. Green, Y. Zhang, and G. Chen, "Nanocomposites for high voltage applications: effect of sample preparation on AC breakdown statistics," in *CEIDP '05. 2005 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2005.*, 2005, pp. 732-735.