UNIVERSITI SAINS MALAYSIA

Laporan Akhir Projek Penyelidikan Jangka Pendek

Study The Resistance To Tracking And Electrical Treeing Characteristics Of PP/EPDM Composite With Alumina And Organoclay Nano-Filler

by

Assoc. Prof. Dr. Mohamad Kamarol Mohd Jamil
Prof. Ir. Dr. Mariatti Jaafar @ Mustapha

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FINAL REPORT
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PROJECT LEADER: Assoc. Prof. Dr Mohamad Kamarol bin Mohd Jamil
I/C / PASSPORT NUMBER: 711217-13-5573

PROJECT MEMBERS: 1. Prof. Ir. Dr Mariatti Jaafar @ Mustapha
(including GRA) 2.

ROJECT ACHIEVEMENT *(Prestasi Projek)*

ACHIEVEMENT PERCENTAGE			
Project progress according to milestones achieved up to this period	**0 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state #%)			100%

RESEARCH OUTPUT		
Number of articles/ manuscripts/ books *(Please attach the First Page of Publication)*	**Indexed Journal**	***Non-Indexed Journal***
	2 Published	1 Published
Conference Proceeding *(Please attach the First Page of Publication)*	**International**	***National***
	4 Published, 2 Accepted	3 Published, 2 Accepted
Intellectual Property *(Please specify)*		

HUMAN CAPITAL DEVELOPMENT

Human Capital	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	MSc. Students: 1) Noor Syazwani Mansor (Graduated) 890421265048 PLM0003/13 2) Muhamad Fairus Adzha Muhamad Raslani PLM0015/14 3) Mohd Hafiz Ismail PLM0016/14
No. PHD STUDENT					
Student Fullname: IC / Passport No: Student ID:					
No. MASTER STUDENT	2		1		
Student Fullname: IC / Passport No: Student ID:					
No. UNDERGRADUATE STUDENT			2		Undergraduate students: 1)Muhammad Adli Syafiq Khairuzaman- 112214 (Graduated) 2) Siti Umaira Zakaria- 112229 (Graduated)
Student Fullname: IC / Passport No: Student ID:					
Total	2		3		

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Budget Approved *(Peruntukan diluluskan)* : **RM80,000.00**
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Percentage of Amount Spent *(Peratusan Belanja)* : 93.2 %

DDITIONAL RESEARCH ACTIVITIES THAT CONTRIBUTE TOWARDS DEVELOPING SOFT AND HARD SKILLS
ktiviti Penyelidikan Sampingan yang menyumbang kepada pembangunan kemahiran insaniah)

International		
Activity	Date (Month, Year)	Organizer
1) IEEE Conference on Energy Conversion (CENCON).	**1)** 19-20th, October, **2015**	1) Universiti Teknologi Malaysia & Korean Institute of Power Electronics (KIPE)
2) IEEE 11th International Conference on the Properties and Applications of Dielectric Materials	**2)** 19-22nd July, 2015.	2) University of New South Wales, IEEE & DEIS
3) International Conference on Condition Monitoring and Diagnosis	**3)** 21-25th Sept, 2014	3) Korean Institute of Electrical Engineers (KIEE)
National		
Activity	Date (Month, Year)	Organizer
1) School of Electrical and Electronic Engineering 5th Postgraduate Colloquium/EEPC	1) 9-11th Feb, 2015	1) School of Electrical and Electronic Eng., USM

2) MyHVnet Colloquium	2) 25th Jan, 2016	2) UTM & DEIS Malaysia Chapter
3) ROVISP 2016	3) 2-3rd Jan, 2016	3) USM

PROBLEMS / CONSTRAINTS IF ANY *(Masalah/ Kekangan sekiranya ada)*

Nil

RECOMMENDATION *(Cadangan Penambahbaikan)*

Nil

RESEARCH ABSTRACT – Not More Than 200 Words *(Abstrak Penyelidikan – Tidak Melebihi 200 patah perkataan)*

In this project, the investigation on dielectric properties and resistance to tracking and erosion of the PP/EPDM blends with three types of nanofillers such as Al_2O_3, AlN and organoclay was carried out. The percentage of filler loading for each specimen was 2 vol%, 4 vol%, 6 vol% and 8 vol%. The effects of Al_2O_3, AlN and organoclay nanofillers with various loading on dielectric properties, resistance to tracking and erosion, thermal conductivity and hydrophobicity of PP/EPDM blends were experimentally investigated. The result revealed that the addition of 2 vol% of Al_2O_3 and organoclay nanofillers into the PP/EPDM blend has increased the dielectric strength by 4.13% and 4.33%, respectively from that without nanofiller. In the other hand, the AlN has decreased the dielectric strength of PP/EPDM blends by 1.79%. The 2 vol% of Al_2O_3 nanocomposites has slightly same dielectric constant and higher dielectric strength with the unfilled PP/EPDM. The results revealed that addition of nanofillers significantly improved the resistance to tracking and erosion. The mass loss and erosion depth of the PP/EPDM nanocomposites decreased with the increase in filler loading. The PP/EPDM filled with 4 vol% organoclay and 6 vol% Al_2O_3 odward is considered to have hydrophilic surfaces. The PP/EPDM with AlN nanofiller reduces the hydrophobicity condition of the material when the concentrations of the filler increased and maintained the hydrophobic surface condition at 8 vol%.

Date : 11-01 -2016
Tarikh

Project Leader's Signature:
Tandatangan Ketua Projek

COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC)
(Komen, sekiranya ada/ Pengesahan oleh Pusat Pengurusan Penyelidikan)

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Name:
Nama:
PROF. DR LEE KEAT TEONG
Director
Research Creativity & Management Office
Universiti Sains Malaysia

Signature:
Tandatangan:

6/2/16

Date:
Tarikh:

UNIVERSITI SAINS MALAYSIA
UNIT KUMPULAN WANG PENYELIDIKAN/RU
JABATAN BENDAHARI KAMPUS KEJURUTERAAN
PENYATA KUMPULAN WANG
TEMPOH BERAKHIR 12/2015

1/15/2016

Tajuk Projek : STUDY THE RESISTANCE TO TRACKING AND ELECTRICAL TREEING CHARACTERISTICS OF PP/EPDM COMPOSITE WITH ALUMINA AND ORGANOCLAY NANO FILLER

TEMPOH :

Pusat Pengajian : Pusat Pengajian Kejuruteraan Elektrik dan Elektronik

Penyelidik : MOHAMAD KAMAROL MOHD JAMIL

Status Projek :

No Projek (Agensi) :

Tempoh Projek : 0 / 0 - 0 / 0

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Vot	Keterangan	Peruntukan Asal	Perbelanjaan Tahun Lalu	Peruntukan Semasa	Tanggungan	Belanja	Jumlah Belanja	Baki	%
11000	Gaji	36,000.00	$16,500.00	$18,000.00	$0.00	$13,500.00	$13,500.00	$6,000.00	75.00
		$36,000.00	**$16,500.00**	**18,000.00**	**$0.00**	**$13,500.00**	**$13,500.00**	**$6,000.00**	75.00
21000	PERJALANAN DAN SARA HIDUP	9,000.00	$628.48	$2,000.00	$0.00	$1,696.75	$1,696.75	$6,674.77	84.84
27000	BEKALAN DAN ALAT PAKAI HABIS	27,000.00	$15,386.36	$0.00	$0.00	$20,590.51	$20,590.51	($8,976.87)	0.00
29000	PERKHIDMATAN IKTISAS DAN HOSPITALITI	8,000.00	$5,700.00	$995.00	$0.00	$590.72	$590.72	$1,709.28	59.37
		$44,000.00	**$21,714.84**	**2,995.00**	**$0.00**	**$22,877.98**	**$22,877.98**	**($592.82)**	763.87
		$80,000.00	**$38,214.84**	**$20,995.00**	**$0.00**	**$36,377.98**	**$36,377.98**	**$5,407.18**	173.27

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Tensile Properties and Melt Flow Index of Polypropylene/Ethylene Propylene Diene Monomer Nanocomposites

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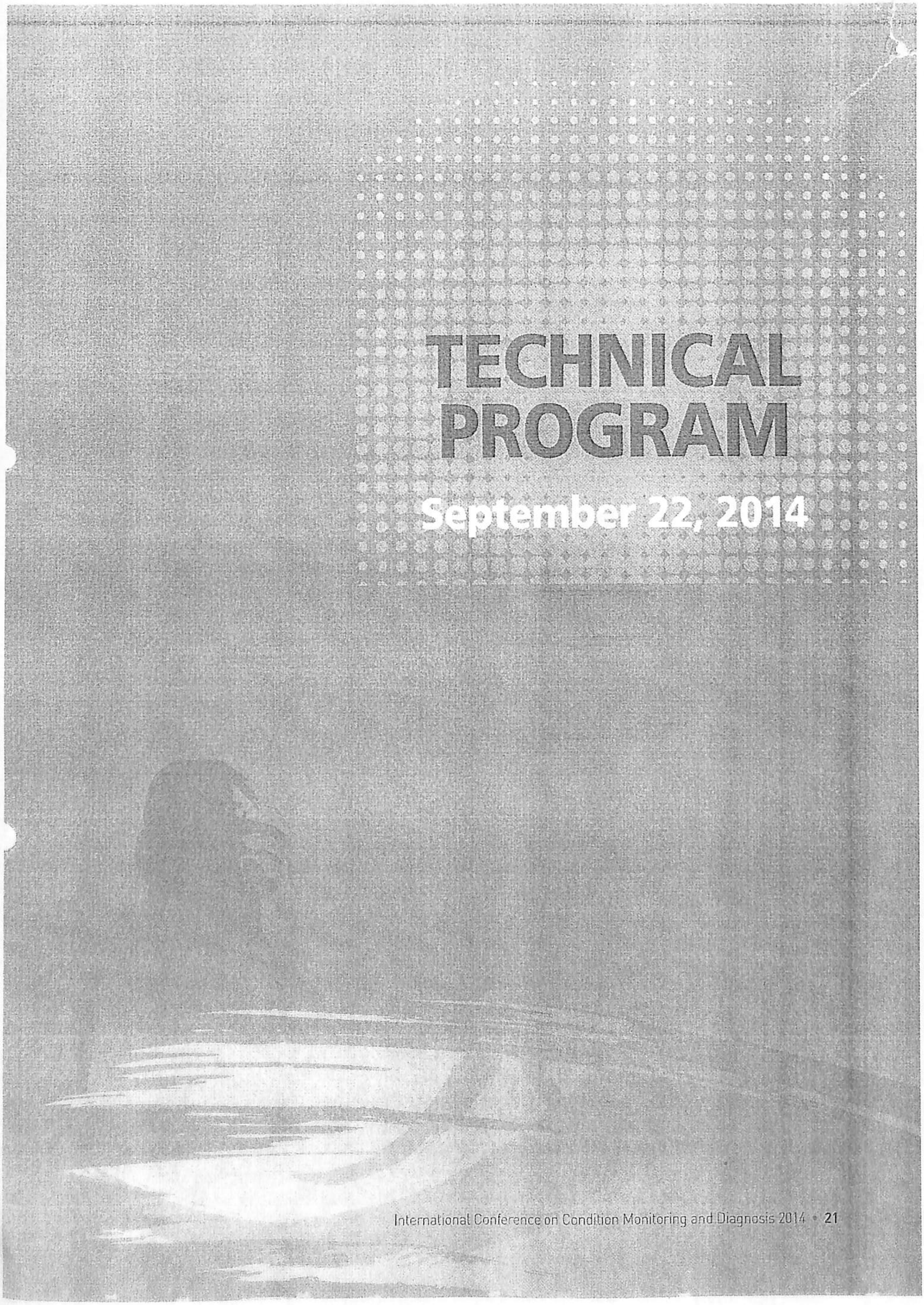
Keywords: Tensile Properties, Melt Flow Index, Polypropylene, Ethylene Propylene Diene Monomer, Polymer Nanocomposites

Abstract. In this article, we report three nanofillers filled polymer composite systems. Nanofillers composed of alumina, titania and organoclay were embedded separately in 50% polypropylene (PP) and 50% ethylene propylene dienc monomer (EPDM) blends. The nanocomposites were prepared using an internal mixer and were molded using a compression mold to form test samples. Effect of filler loading (2, 4, 6, and 8 vol.%) on the tensile properties and melt flow index (MFI) were determined. The mechanical properties of alumina are the highest compared to titania and organoclay. Alumina and organoclay shows an ascending trend in tensile strength with the increase of nanofiller loading. In contrast, the increment of titania filler loading reduces the tensile strength of the nanocomposites. The Young's modulus of the nanocomposites increases with the addition of filler loading. Elongation at break of the nanocomposites shows a descending trend with the addition of filler loading. The addition of 8 vol. % titania and organoclay slightly changes the MFI of the PP/EPDM nanocomposites whereas the addition of 8 vol. % alumina drastically decreased the MFI values. Further addition of nanofillers up to 8 vol. % decreases the MFI values of the PP/EPDM nanocomposites.

Introduction

Over the past few years, polymer nanocomposites have attracted a great deal of attention. In contrast to conventional filled polymer, nanocomposites are composite materials having several amounts of inorganic particles of nano-sized homogeneously dispersed into their polymer matrix. This new type of polymer composite has become attention over past few years because nanocomposite have the potential of improving the electrical, mechanical and thermal properties as compared to the neat polymers [1]. The use of polymer nanocomposites as insulators is expected to be intensively increased in the future since they promote cost reductions [2] and offer considerable advantages such as high breakdown voltage, higher mechanical strength to weight ratio, resistance to vandalism and better performance in the presence of heavy pollution and wet condition [3-4].

Insulation is one of the important factors in all aspects of the high voltage industry. EPDM is used in electrical insulation due to its combination of superior electrical properties, its flexibility over a wide temperature range and its resistance to moisture and weather [4]. However, synthetically produced EPDM is relatively expensive when compared with other conventional elastomers [5]. In order to reduce the production cost, polypropylene (PP) was blended with EPDM. PP is very popular as a high-volume commodity plastic. PP offers very interesting characteristics such as low density, good surface hardness and excellent price performance ratio, which make it a high consumption polymer [6]. For several decades, the use of PP/EPDM blends has been continuously growing in various industrial domains. PP/EPDM blends offer a wide spectrum of



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Dielectric and thermal properties of flame retardant fillers in polypropylene/ethylene propylene diene monomer composites

MS Hamzah[1], IN Hidayah[1], M Mariatti[1] and M Kamarol[2]

Abstract

The incorporation of zinc hydroxystannate, calcium borate, and a phosphorus-based nonhalogenated flame retardant fillers (with trade name of NP-100) in 50% polypropylene and 50% ethylene propylene diene monomer blends was investigated. The composites were prepared using an internal mixer and were molded using a compression mold to form test samples. Studies on the effect of filler loading (15, 30, 45, and 60 vol%) on dielectric breakdown strength, dielectric properties, and thermal conductivity were determined. The flow properties analyzed using the melt flow index revealed that the addition of zinc hydroxystannate increased the melt flow index of the polypropylene/ethylene propylene diene monomer blends, whereas the addition of calcium borate and NP-100 decreased the melt flow index values. A study on the dielectric properties of zinc hydroxystannate, calcium borate, and NP-100-filled polypropylene/ethylene propylene diene monomer composites found that polypropylene/ethylene propylene diene monomer/NP-100 has higher breakdown strength compared with polypropylene/ethylene propylene diene monomer/zinc hydroxystannate and polypropylene/ethylene propylene diene monomer/calcium borate. The dielectric constant of the polypropylene/ethylene propylene diene monomer/calcium borate system is the highest, followed by polypropylene/ethylene propylene diene monomer/NP-100, and the least value of the dielectric constant is exhibited by polypropylene/ethylene propylene diene monomer/zinc hydroxystannate. For the dielectric loss of the composite, the polypropylene/ethylene propylene diene monomer/zinc hydroxystannate, polypropylene/ethylene propylene diene monomer/calcium borate, and polypropylene/ethylene propylene diene monomer/NP-100 blends recorded the lowest, medium, and highest values, respectively. The thermal conductivity of NP-100 is the highest, followed by calcium borate, and then zinc hydroxystannate. The polypropylene/ethylene propylene diene monomer filled with 15 vol% of NP-100 is found to be the most suitable composition for electrical insulation compared with other volume composition percentages on account of low thermal conductivity, good flow ability, high breakdown strength, high dielectric constant, and low dielectric loss.

Keywords

Flame retardant filler, dielectric properties, thermal conductivity, polypropylene, ethylene propylene diene monomer

Introduction

Insulation is one of the important aspects of electrical power systems, such as in substation and distribution and in transmission lines. Porcelain or glass has previously been used as outdoor insulators because of their superior electrical and mechanical properties and their durability.[1] Polymer composites are widely used as electrical insulators because of their superior service properties in the presence of heavy pollution and wet conditions, resistance to vandalism, superior electrical parameters, and lower density compared with porcelain glass insulators.[2] Ethylene propylene diene monomer (EPDM) is used as an electrical insulator for its combination of superior electrical properties, flexibility over a wide temperature range, and resistance to moisture

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RESEARCH PAPER

Evaluation of PP/EPDM nanocomposites filled with SiO_2, TiO_2 and ZnO nanofillers as thermoplastic elastomeric insulators

I. N. Hidayah[1], M. Mariatti*[1], H. Ismail[1] and M. Kamarol[2]

Thermoplastic elastomer, which has important characteristics for cable insulation, was developed by melt blending of polypropylene (PP) with ethylene propylene diene monomer (EPDM) at various blend ratios together with SiO_2, TiO_2 and ZnO nanofillers at fixed loading of 2 vol.-%. The influence of EPDM content and the presence of nanofillers in the blend on burning rate, hydrophobicity and dielectric breakdown strength were investigated. Burning rate of PP/EPDM/ZnO was significantly reduced, implying that there was an improvement in fire retardancy with the addition of ZnO nanofillers in the polymer blend. Both SiO_2 and ZnO filled system showed an improvement in hydrophobicity. Furthermore, dielectric breakdown strength showed higher value in EPDM rich blends. In addition, the presence of nanofillers deteriorated the dielectric breakdown strength of PP/EPDM nanocomposites.

Keywords: PP/EPDM nanocomposites, Burning rate, Hydrophobicity, Dielectric Breakdown strength, Morphology

Introduction

Blending an elastomer with a thermoplastic polymer can result in thermoplastic elastomers (TPEs), where the elastic property of the elastomer is combined with the processability of the thermoplastic polymers. Many commercial TPEs have been developed for various applications such as footwear, medical instruments, packaging and piping because of the unique combination properties of the elastomer and thermoplastic.[1,2] Recently, TPE has attracted many researchers in electrical insulating field. Hui *et al.*[3] worked on low density polyethylene/ethylene vinyl acetate/nanosilica system, focusing on the effects of variations in silica loading, sequence of addition of ingredients, use of a coupling agent, and controlled electron beam irradiation on the dielectric properties, volume resistivity, and breakdown voltage of such nanocomposites. George *et al.*[4] reported on the dependence of dielectric constant, dissipation factor, loss factor and volume resistivity of polypropylene (PP)/acrylonitrile butadiene rubber to the presence of filler, crosslinking agent and blending ratio.

PP/ethylene propylene diene monomer (EPDM) blend is the most representative example of TPE. The properties of this blend have been widely reported by many researchers focusing on the mechanical,[5] rheological,[6,7] flammability[8,9] and morphological[6,7] aspects. However, very little work has been done on the performance of PP/EPDM blend on electrical insulating parts. EPDM is known to have an outstanding resistance to attack by oxygen, ozone and weather due to non-conjugated diene component[10] and because of its saturated chain backbone, it can be employed in different formulations.[11] Apart from that, EPDM is flexible at low temperature, possesses a wide range of tensile strength and has great electrical resistance.[12] Meanwhile, PP, as a thermoplastic resin, has a number of advantages such as lower cost, good processability, good mechanical properties at room temperature and also good electrical resistance. These properties, being particularly important in the electrical sector, have stimulated the idea of developing PP/EPDM blend as TPE candidate for high voltage (HV) insulators.

Incorporating inorganic fillers in the polymeric materials is believed to increase the mechanical, thermal and electrical properties of the materials. These improvements have received attention in electrical insulation prospects for many years. Previous works have shown that the compounds filled with optimum amount of inorganic fillers could enhance the resistance to tracking,[13] withstand voltage[14] and dielectric response,[3] and reduce flammability.[7] The common fillers used are alumina trihydrate,[15] silica,[16] alumina[15] and various other metal oxides. With the advent of nanotechnology, the improvement on the properties of composite insulators has been achieved through the utilisation of nanosize fillers in the polymer matrix. Owing to the enormously large sectional area of the interface between the filler and the matrix compared with conventional microcomposite materials, the electrical, mechanical, physical and thermal properties of the polymer composite are enhanced. Oxide nanofillers are also reported to be able to improve the thermal stability and flammability properties of the composites.[16]

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Effect of Nanofiller on Resistance to Tracking and Hydrophobicity of PP/EPDM Blends

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Abstract—In this paper, three different types of nano-fillers such as AlN, Al_2O_3 and organoclay were used to blends with PP/EPDM composite. The effect of adding these nano-fillers in PP/EPDM composite on the resistance to tracking and hydrophobicity has been investigated. The performances of PP/EPDM blend with the nano-fillers were compared with the PP/EPDM without nano-fillers. The experimental result shows that AlN and Al_2O_3 nano-fillers have took longer erosion time of 152 min and 135 min respectively, for the carbon path tracks to reach 25mm. On the other hand, the organoclay took 90 min to be eroded. The AlN nano-filler shows the optimum performance against erosion depth and mass loss compared with the others nano-fillers. In addition, the PP/EPDM with 2% of AlN loading have yield to the better performance of hydrophobicity.

Keyword – resistance to tracking, hydrophobicity, PP, EPDM, nanofiller

I. INTRODUCTION

Tracking is one of the major issues for outdoor insulation application. When a solid dielectric subjected to electrical stresses for a long time, normally two kinds of visible markings will be emerged on the dielectric materials. There are the presence of a conducting path across the surface of the insulation, and a mechanism whereby leakage current passes through the conducting path resulting the formation of a spark [1]. Filler plays an important role to impart tracking and erosion resistance under dry band arcing conditions [2]. From this point of view, the tracking resistance of nano-composites should be further investigated to gain additional knowledge of the nano-composite dielectric properties. This can be a guideline for the development of new insulating materials. Therefore in this paper we investigated the effect of AlN , Al_2O_3 and Organoclay nano-fillers in PP/EPDM blend on the resistance to erosion and hydrophobicity and compared with the PP/EPDM blends without filler.

II. EXPERIMENTAL SETUP

A. Sample preparation

PP/EPDM was blend with 50:50 weight percentage (wt %). Vulcanizing agent dicumyl peroxide was added to the PP/EPDM as a curing agent. The PP/EPDM was blended using Haake internal mixer at 180°C at 50 rpm with a total mixing time of 10 minutes. The AlN, Al_2O_3, and Organoclay nanofillers were blended with the PP/EPDM at 2 wt% loading. Table 1 shows the composition of samples for PP/EPDM blends. The samples size is around 50 mm x 120 mm x 6mm. The samples are mounted on a support stand with an angle of 45° slanting where the test surface facing downwards. The size of the samples for hydrophobicity tests were 15mm x 40mm x 1mm.

Table 1 Composition of samples

Composite	PP (%)	EPDM (%)	DCP (%)	Filler (%)
PP/EPDM	50	50	2.0	-
PP/EPDM/ AlN	50	50	2.0	2
PP/EPDM/ Al_2O_3	50	50	2.0	2
PP/EPDM/ Organoclay	50	50	2.0	2

Investigation on Dielectric Strength of Alumina Nanofiller with SiR/EPDM Composites for HV Insulator

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Abstract— **It is believed, by the addition of nano-filler into the SiR/EPDM blends could further improve its electrical properties. In this paper, the dielectric strength of SiR/EPDM composite with Alumina nano-filler for outdoor AC high voltage insulator has been investigated. Thus, the specimen with different loading concentration of Alumina nano-filler (1 Vol%, 2 Vol%, 3 Vol%, 4 Vol% and 5 Vol%) has been prepared. Decumyl Peroxide (DCP) with 98% active as a vulcanize agent was used in this composition. The composition of SiR/EPDM with Alumina nano –filler was prepared in heated two rolls mixer, MDR machine and hot press machine. Then, the loading concentration of Alumina nano-filler dependence of dielectric strength was investigated according to the IEC 60243-1 standard. The dielectric properties of SiR/EPDM nano-composite were analysed based on a Weibull probability plot. The result showed that the SiR/EPDM composition with Al_2O_3 of 1 Vol% loading gives the highest dielectric strength of 35.28 kV/mm among others loading concentration. Hence, the presence of 1 Vol% of nano Alumina into SiR/EPDM composite significantly has improved the dielectric strength of SiR/EPDM polymer.**

Keywords—SiR/EPDM; nano-filler; Alumina; MDR machine; dielectric strength; specimen.

I. INTRODUCTION

High voltage insulators for the overhead transmission line are the most significant part in electrical power system. Practically, insulator for high voltage is installed together with the outdoor tower or pole. There are several types of insulators in overhead high voltage power line, but their main functions are identical to prevent electrical current flow directly to the ground through the tower or poles. Weather shed insulator is widely used in suspension and strain insulator covered up the fiber core rod to hold the conductor wire and tighten together with the transmission line tower. Conventionally, the traditional weather sheds insulator was made of ceramic and glass material, known as inorganic material. The performance and efficiency of inorganic material on overhead transmission line were degraded due to rain, direct sunlight and air contamination. It has been replaced with polymeric material since 1960's to overcome the previous material type problem [1]. An organic based material (polymer) insulator has several advantages such as able to reduce breakage at minimum, better breakdown voltage, lower installation cost, less load to support structure due to light weight and smaller size, higher tensile strength compared to inorganic material and also less cleaning required because the hydrophobic nature of the insulator. Recently, the application of the polymer insulators (PI) in high voltage (HV) system is widely used due to its supremacy properties. It has been manufactured with a variety types of polymer materials for example, with Silicone Rubber (SiR), Epoxy Resin, Ethylene Propylene Diene Monomer (EPDM), Ethylene Propylene Rubber (EPR), High Density Polyethylene (HDPE) and an alloy of SiR/EPDM. With the variety of polymer materials available these days, many studies has been performed with unique material composition as well as adding additives into the polymer based. The entire investigation objectives are to improve the PI characteristic such as dielectric properties, chemical, thermal stability, and physical resistance. The outdoor PI, especially weather shed is directly exposed to unforeseeable weather and contaminations, which may influence the quality of polymer performance as high voltage insulator.

In the past couple years, the developments of new polymeric synthesis with SiR/EPDM with 50:50 ratios were investigated by numerous researchers. It was found that the balanced polymeric composite yields the optimal electrical and mechanical properties [2]. Therefore, the study on this optimal balanced composite still continues with the diversity of additives/fillers such as Silica (SiO_2), Alumina Trihydrate (ATH), Zinc Dioxide (ZnO), Sulfur and Organically Modified Montmorillonite (OMMT) into their based composite [3]–[5]. Most of their studies investigated the effect of filler on the balanced polymeric material (50:50). Thus, the process to develop a new electrical insulation material incorporate with nano-filler is significant which the dielectric strength is the priority to be considered [6].

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Electrical Tree Characteristics With The Addition Of Alumina In Silicone Rubber

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Abstract—**The introduction of nano technology gives many benefits to the consumers and industries especially in cable insulators fabrication. This technology offers better cable life time and better cable resistance to face the cable failure. With the inclusion of nano filler in unfilled polymer, it shows that the nano filler has the ability in refining the electrical, mechanical and thermal properties compared to the unfilled polymer. In this paper, nano-alumina with the amount of 0 to 3 vol% was employed to upgrade the electrical tree properties in unfilled silicone rubber (SiR). Electrical treeing inception and propagation in SiR with and without filler were studied. 8kV$_{rms}$ 50Hz ac voltage was given through the needle electrode to inspect the tree inception voltage and treeing propagation process. This needle electrode was positioned in rectangular mould test specimen. The dimension of the specimen was 20mm x 14mm x 1mm. With the inclusion of nano-alumina in SiR, the results showed that the SiR nanocomposites can delay the occurrences of tree inception, tree growth and electrical breakdown up to 2 vol% which may influence better electrical treeing characteristics. However with 3 vol% nano-alumina, SiR nanocomposites has the fastest treeing growth and eventually breakdown at the time less than 1 minute.**

Keywords—electrical tree; silicone rubber nanocomposites; tree inception; propagation characteristics

I. INTRODUCTION

One of the main causes of failure and deterioration in high voltage cable insulator is caused by electrical phenomenon which is called electrical treeing. Electrical treeing will appear when ongoing stress is applied through the insulation cable. When the tree inception appeared, it begins to propagate through the insulation cable and will lead to cable damage. In present day technology, silicone rubber (SiR) is widely used in the production of high voltage cable insulator because it offers superb electrical and mechanical insulating properties. In addition, the approaches to refine the processes of material preparation, increasing the time delay of treeing propagation, and altering the material selection have been tried to strengthen the insulator properties [1], [2].

Due to the nano technology evolution, nano filler has been noticed as a new technique in order to upgrade the electrical and mechanical properties without modifying polymer material as compared to the pure polymer [1], [3]. As reported by some researchers, enhancement in electrical treeing initiation and propagation of polymer (epoxy resin, polyethylene) can be seen with the addition of nano filler [1], [2]. Recently, a few awareness on the treeing behavior in SiR nanocomposites fabrication have been investigated. Alapati et al stated that nano alumina filler has a great potential to delay the tree inception and tree propagation growths [4].

In this paper, the study will focus on the electrical treeing in SiR nanocomposites containing alumina nanoparticles. The use of alumina nanoparticles is highlighted as it has never been applied as nano filler in vol% in neat SiR for electrical treeing investigation. In addition, it offers high electrical resistivity, high thermal conductivity and affordable yet inexpensive price. Thus nano alumina was employed and preferred as filler for this study to examine the reaction of nano-alumina filler in SiR on electrical treeing [5].

II. EXPERIMENT SET UP

A. Specimen Preparation

SiR PT 910-3 supplied by Penchem with curing agent was employed for this study. The weight ratio for this SiR base polymer to its hardener is 10 to 1 for well preparation of test specimens. Nano-alumina filler used for this study is commercially 13 nm primary particle size provided by Sigma Aldrich. For well dispersion of nano-alumina in SiR, the nanocomposites were produced by mixing the unfilled SiR with nano-alumina in ultrasonic mixer UP2005 for 10 minutes. Then, the nanocomposites sample was vacuumed to eliminate the voids inside the polymer that was generated earlier during the dispersion process by using 5831 National vacuum set for 60 minutes. After that SiR nano-alumina nanocomposites with the hardener were mixed again for 10 minutes using ultrasonic mixer UP2005. Later, the sample was vacuumed for the second time, again to eliminate the voids inside the polymer that was generated during the dispersion process by using the same 5831 National vacuum set for another 30 minutes.

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Investigation of Electrical Treeing Structures in SiR/Alumina Nanocomposites

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***Abstract*—Electrical tree is the one of phenomena that can initiate to the electrical breakdown in polymeric insulating material. In this paper, the structure of electrical tree growth in Silicone Rubber (SiR) with different concentration of nano-alumina has been observed. The test specimen samples were prepared by mixing SiR base polymer with 0, 0.5, 1, 1.5, 2, 2.5 and 3 vol% of nano-alumina. The structure of electrical tree was investigated at apply voltage of 8kVrms after tree inception voltage under room temperature. The influences of nano-alumina with different concentration to the electrical tree structure were investigated. The result shows high probability occurrence of Bush type tree with the increased of nano-alumina in SiR up to 2 vol%. However, at 3 vol% nano-alumina with slight agglomeration in SiR/Alumina nanocomposites, the tree structure drastically change to Pine Branch type which lead to the fastest tree inception voltage and tree propagation rate.**

Keywords—structure; electrical tree; nano-alumina; nanocomposites

I. INTRODUCTION

In general, underground and overhead high voltage cables are used to transmit and distribute electrical supply from power generation to the consumers. Basically all these cables are exposed to the contaminations and weather which contribute to the generation of water and electrical trees under influence of high electric field. If this situation continuously occurs, the cables may easy to degrade and finally lead to the cable failure.

Nowadays, Silicone Rubber (SiR) is preferable as an insulator in high voltage cable because it offers a wide range of temperature application, withstand to oxidation and also offer good resistance to ultraviolet (UV) radiation degradation [1-3]. However, with the migration of water into the cable and ongoing high stress voltage applied through the cable can cause to the degradation and cable failure. This phenomenon is known as electrical treeing started at the weakest point in the dielectric material insulator [4-6].

As mentioned by M.Bao et al, electrical tree structures give a deep influence factor for the electrical treeing behaviors in polymer nanocomposites [7]. Y. X. Zhou et al stated that bush type tree can be observed frequently by increasing SiO_2 nano particles in SiR nanocomposites. It means that by increasing SiO_2 nano particles in SiR nanocomposites, higher density electrical tree branch can be observed, which leads to the creation of Bush type tree and longer electrical growth propagation rate [8]. S. Alapati and M. J. Thomas revealed that the improvement of tree inception voltage, electrical treeing growth and resistance to the partial discharge can be obtained with the presence of nano-alumina in certain amount in LDPE nanocomposites [9]. P. Preetha and M. J. Thomas mentioned that nano-alumina improve the degradation resistance in epoxy nanocomposites due to the partial discharge [10].

Thus in this paper, for excellent dielectric insulator properties offer by SiR and nano-alumina, the influence of nano-alumina with the concentration from 0 to 3 vol% in SiR are prepared and analyzed. The results of the tree structure image captured by the digital camera in unfilled and filled with nano-alumina are discussed.

II. EXPERIMENT SET UP

A. Test Specimens Preparation

The needle-plane electrodes were utilized in this experiment. The needle electrode was prepared by using tungsten wire with the diameter of 0.25mm. The NaOH solution was used in this electrochemical etching method to form fine needle tips angle and radius at 30 degree and 5μm respectively. The DC power supply of 30-V, 3-A was used in the electrochemical etching process. The positive supply was connected to the tungsten wire while the negative supply was connected to steel which functioned as the cathode. The camera equipped microscope was used to observe and justify the needle tips angle, radius for every fabricated needle and the gap between the needle and grounded electrodes. The gap between the needle tips to the grounded electrode which was 2mm as shown in Fig. 1.

Universiti Sains Malaysia (USM) and Malaysia Ministry of Higher Education

SiR/EPDM Solid Polymeric Blends for AC High Voltage Insulation : A Review of Specimen Preparation Techniques and Dielectric Strength

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Abstract— **Polymer insulator has been increasingly utilized by power utilities companies as a replacement for non-organic porcelain and glass insulator. Previously, there are many types of organic insulators has been developed by few scholars. However, the composition of the material is confidential. The researcher discovered the appropriate SiR/EPDM rubber with 50:50 blend ratios, which are capable to provide a balance in mechanical and electrical properties. Thus, the investigations on the SiR/EPDM mixture to increase the performance against the characteristics are focused in this study. This paper summarizes a review on specimen preparation techniques and dielectric strength of SiR/EPDM Solid Polymeric Blends for AC High Voltage Insulation.**

Keywords-organic; SiR/EPDM; specimen; dielectric strength; insulator

I. INTRODUCTION

In the past decade, polymers insulators (PI) are widely used over the world in electrical power system for generation, transmission, and distribution stage. PI has many applications such as in high voltage transmission line insulators, lightning arresters, and cable accessories. Generally, strain insulator is installed at outdoor application to the sharp corner or dead end of high voltage transmission line. However, the strain insulator part such as weather shed is exposed directly to rain, sunlight and air contamination. These factors can contribute to the degradation of insulator performance and efficiency [1-2].

Polymer insulator is also known as composite or non-ceramic insulator. The applications of polymer insulator are widely expanded due to their benefits compared with the traditional ceramic and armoured glass insulators. Traditional insulator materials have few disadvantages. As an example the material made from glass could contribute a leakage of electric current path in the system due to the natural environment moisture and atmosphere dust which can easily condensed on a glass plane. The bubble and air impurities inside the ceramic material may affect the degradation of dielectric properties [3]. The polymer insulator lead to the minimum breakage, lower installation cost, and less load to support structure due to the light weight and smaller size behaviour. In addition, the polymer insulator has higher tensile strength compared to the ceramic material. Moreover, the PI required less cleaning because of the hydrophobic nature of the insulator [4].

Silicone (SiR) is a non–reactive, stable and had a resistance capability (-55°C<R<300°C) to the extreme environment. However, the Silicone

A Review Of Electrical Treeing Trends In Solid Insulators With AC Stress

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Abstract— **Electrical treeing is one of the common failure in high voltage insulator cable due to continuous stress given. Nowadays with the development of nanocomposites technology new approach has been taken to prolong the life time of the cable. It is to introduce fillers in polymer base for insulator cable fabrication. This review papers will discuss the effect of micron and nano particle fillers to the pure Epoxy, pure Silicone rubber (SiR) and pure Low density polyethylene (LDPE).Silica or silicone dioxide (SiO_2) and alumina are used as a filler in this review papers. The main characteristics of electrical treeing with and without filler is discussed and concluded here such as tree inception and propogation, micron and nano particle effect and effect of morphology on electrical tree growth.**

Keywords-nanotechnology;nanocomposites;nano-fillers; electrical treeing;

I. INTRODUCTION

The best selection of materials are very important especially in high voltage cable fabrication. Epoxy, Silicone rubber (SiR) and Low density polyethylene (LDPE) are among the best selection in high voltage cable fabrication because they offer excellent electrical and mechanical properties. However with the electrical stress given the materials can deteriorate which can lead to the failure of the cable. Electrical treeing is one of the main failure mechanisms in high voltage cable insulation, where the additional paths progressively grow from high stress regions and branch into hollow channels in the solid dielectric [1-4].In order to enhance the electrical tree resistance in high voltage cables many approaches have been done such as improving the material processing, adding treeing inhibitors, modifying the material and etc [5, 6].

With the development of nano technology, nano sized fillers have been pay more attention as they are found to have improved properties in polymers nanocomposites with micron and nano sized particles.Some of the researchers have reported that there is an improvement in electrical treeing resistance of polymer with the addition of nano-fillers [7-9]. In this paper the effect of micron and nano size particles to the pure Epoxy, pure SiR and pure LDPE is reviewed.

II. TREE INCEPTION AND PROPOGATION OBSERVATION

Tree inception voltage is defined as the voltage when the tree length observed by the CCD camera had exceeded 10 µm [10]. Epoxy polymer with silica fillers has a higher mean tree inception voltage than unfilled Epoxy when tested under 60 Hz ac stress, increasing rate by 1 kVrms/30s step. Figure 1 shows AC tree inception voltage for Epoxy polymer with and without silica fillers.

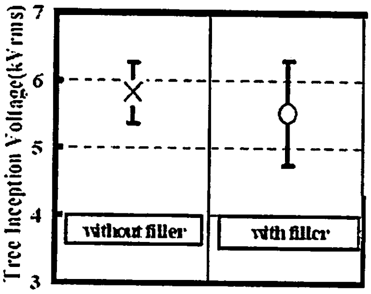

Figure 1. Ac tree inception voltage for Epoxy polymer with and without silica filler [9].

For SiR/SiO2 nanocomposite, filler acts as a barrier to prolong tree inception time compare with pure SiR. Nano fillers content in polymer matrix will increase the ability of electron to be absorbed so carrier's electrode is easily to be trapped in and around the nano particle surface. Figure 2 shows Cumulative probability of treeing breakdown in SiR with different content of nano fillers. In SiR cumulative probability of treeing breakdown decrease with the increasing of fillers content. It is tested from unfilled to 5% rate of filler loading.

Effect of Nanofiller on Resistance to Tracking and Hydrophobicity of PP/EPDM Blends

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Abstract— In this paper, three different types of nano-fillers such as AlN, Al_2O_3 and organoclay were used to blends with PP/EPDM composite. The effect of adding these nano-fillers in PP/EPDM composite on the resistance to tracking and hydrophobicity has been investigated. The performances of PP/EPDM blend with the nano-fillers were compared with the PP/EPDM without nano-fillers. The experimental result shows that AlN and Al_2O_3 nano-fillers have took longer tracking time of 152 min and 135 min respectively, for the carbon path tracks to reach 25mm. On the other hand, the organoclay took 90 min to be eroded. The AlN nano-filler shows the optimum performance against erosion depth and mass loss compared with the others nano-fillers. In addition, the PP/EPDM with 2% of AlN loading have yield to the better performance of hydrophobicity.

Keyword – tracking time, hydrophobicity, PP, EPDM,

I. INTRODUCTION

Tracking is one of the major issues for outdoor insulation application. When a solid dielectric is subjected to electrical stresses for a long time, normally two kinds of visible markings will be emerged on the dielectric materials. There are the presence of a conducting path across the surface of the insulation, and a mechanism whereby leakage current passes through the conducting path resulting the formation of a spark [1]. Filler plays an important role to impart tracking and erosion resistance under dry band arcing conditions.[2]. From this point of view, the tracking resistance of nano-composites should be further investigated to gain additional knowledge of the nano-composite dielectric properties. This can be a guideline for the development of new insulating materials. Therefore in this paper we investigated the effect of AlN , Al_2O_3 and Organoclay nano-fillers in PP/EPDM blend on the resistance to erosion and hydrophobicity and compared with the PP/EPDM blends without filler.

II. EXPERIMENTAL SETUP

A. Sample preparation

PP/EPDM was blend with 50:50 weight percentage (wt%). Vulcanizing agent dicumyl peroxide was added to the PP/EPDM as a curing agent. The PP/EPDM was blended using Haake internal mixer at 180°C at 50 rpm with a total mixing time of 10 minutes. The AlN, Al_2O_3, and Organoclay nanofillers were blended with the PP/EPDM at 2 wt% loading. Table 1 shows the composition of samples for PP/EPDM blends. The samples size is around 50 mm x 120 mm x 6mm. The samples are mounted on a support stand with an angle of 45° slanting where the test surface facing downwards. While the size of the samples for hydrophobicity test were 15mm x 40mm x 1mm.

Table 1 Composition sample

Composite	PP (%)	EPDM (%)	DCP (%)	Filler (%)
PP/EPDM	50	50	2.0	-
PP/EPDM/ AlN	50	50	2.0	2
PP/EPDM/ Al_2O_3	50	50	2.0	2
PP/EPDM/ Organoclay	50	50	2.0	2

Technical Report

Fundamental Research Grant Scheme (FRGS)

2/2013

Study the resistance to tracking and electrical treeing characteristics of PP/EPDM composite with Alumina and Organoclay nano-filler

Project Leader:

Assoc. Prof. Dr Mohamad Kamarol bin Mohd Jamil

Co-Researcher:

Professor Dr. Ir. Mariatti binti Jaafar @ Mustapha

1. Introduction

The generation and consumption of electric power are seldom in close vicinity. Electric power can be transmitted through overhead lines from the generating sites to the distribution line. Most of these lines span over several thousands of kilometers. In order to minimize losses, power is transmitted at higher voltages in the order of several hundred kilovolts. The high voltage line conductor has to be physically attached to the tower support structure, which is at ground potential. For the purpose of electrically isolating these line conductors from the support structure as well as providing mechanical support to them, insulators are used (Gorur et al. 1999).

Most of the insulators are often under high electrical as well as mechanical stress. The increasing demand for electrical energy worldwide has lead to the use of even higher system voltages for power transmission. Higher voltage rating puts the insulators under a large amount of electrical stress. The high voltage insulators used in outdoor applications are degraded by various environmental factors including precipitation, winds, temperature variations and pollution. Under wet and polluted conditions, the electric field along their length gets intensified which might lead to flashover. Flashover of insulators in service could give way to interruptions in power supply, which affects the reliability of these bulk systems. Also, interruptions could incur heavy monetary losses to many customers and industries. It is important to avoid flashovers from occurring by regular checking of pollution deposit on every insulator and cleaning or replacement of dusty or faulty insulator. It is however very difficult to check energized insulators due to their height, voltage across them, and their location. Transmission lines pass through mountains, terrains, and horrible places (Syakur & Berahim 2012). Therefore, the insulator must have high relative permittivity in order for the dielectric strength to remain high, high ratio of puncture strength to flashover and also hydrophobic surface to withstand in wet environment.

The outdoor insulation string has always being made from glass or porcelain since long time ago and many researchers are trying to reduce the drawback of these insulators types. Polymeric insulators offer many advantages such as light in weight which can reduce cost, reduce the chance of breakage, hydrophobic in nature which can reduces transmission losses and higher tensile strength compared to porcelain insulator. Continuous efforts were made to improve the polymeric insulators since 1970s (Ehsani et al. n.d.). Figure 1.1 illustrates the example of the polymeric insulator used in transmission lines.

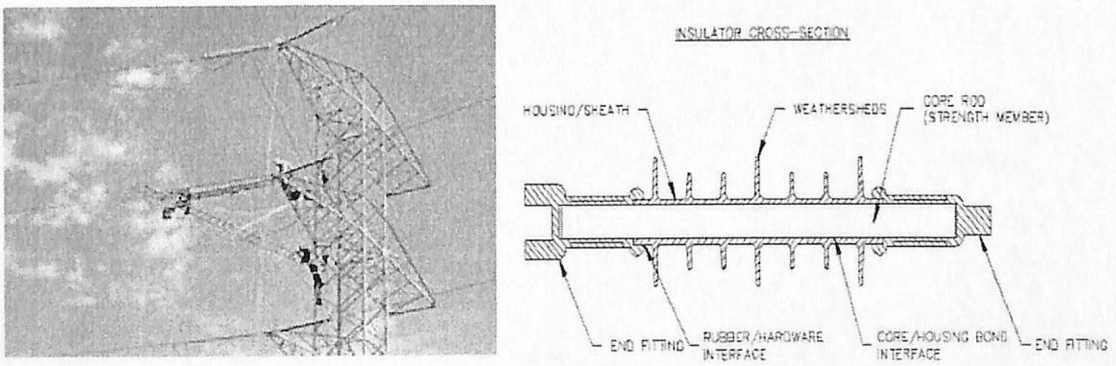


Figure 1.1 : Polymeric Insulators

Today, the most commonly used polymeric materials for high voltage applications are Silicone Rubber (SiR), Ethylene Propylene Rubber (EPR), and Ethylene Propylene Diene Monomer (EPDM) (Naidu et al. 2009). SiR samples with hydrophobic surfaces have discrete water droplets rather than thin film of water on their surfaces under moist conditions (rain, fog etc). Therefore, the insulator provides a high resistance path to the flow of leakage current. This helps in reducing the probability of flashover. EPDM is also a preferred material for the application of electrical insulation because it composes of excellent electrical properties, flexibility in a wide temperature range, and resistance to moisture and weather (Ehsani et al. 2004; Nasrat & Sharkawy 2007). Although SiR, EPR and EPDM have been widely used as insulator in power industry, however, many efforts are still going on to further improve their insulation performance. In the work reported by Prabu et al (Prabu et al. 2007), they revealed that the mechanical properties of SiR and EPDM blends can be improved and do not cause significant reductions in any electrical properties. Mixture of commodity polymer, Polypropylene (PP) with EPDM could reduce the production cost because EPDM alone is very expensive compared with the other conventional elastomer (Ismail & Akil 2005). The PP/EPDM blends have been utilized widely as an insulator for several decades in various industrial areas. Since mixing PP in any ratio is possible, a wide spectrum of materials is obtained, from elastified PP to EPDM rubber reinforced with thermoplastic (Arroyo et al. 2000; Fernando & Gubanski 2000; Öksüz et al. 2006)

Most of the researchers have been reported on the mechanical properties (Öksüz et al. 2006; Reza et al. 2007; Barkoula et al. 2008), rheology (Ismail & Akil 2005; Bouchart et al. 2008) and morphology of PP/EPDM blends (Reza et al. 2007; Bouchart et al. 2008). In order to increase the insulators performance, nanotech filler were been introduced. Nanotechnology, sometimes shortened as nanotech, deals with the manipulation and manufacturing of structures of which at least one of the dimensions is less than 100 nanometers (Of et al. 1998). As many improvements in material properties are been exploit from using nanocomposites, a lot of electrical properties are also seen to have been enhanced making use of nanocomposites. There are several results from previous research shows an enhancement of electrical properties using nanocomposites. One of the significant advantages of using nanoscale fillers instead of micrometer-scale fillers may be an increased in the breakdown strength. Bearing this finding in mind, many researchers around the world have been focused to find the better fillers that can increase the dielectric properties of polymeric insulator. As reported by Hamzah et al, organoclay nanofiller gives the highest result in dielectric strength of PP/EPDM followed by aluminium oxide (Al2O3) nanofiller (Hamzah et al. 2014). Venkatesulu et al (Vas et al. 2012) also reports that the addition of 4% by weight (wt) of nano alumina composite showed the erosion performance is equivalent to the 30% by wt of micro ATH composite. They are also observed that the erosion performance of nanocomposite is attributed to its better thermal stability. This result obtained provides new ideas for continuing research with both filler and aluminium nitride (AlN) since the AlN has high thermal conductivity (Cao et al. 2004).

From this point of view, the resistance to tracking and erosion of PP/EPDM nanocomposites should be further investigated to gain additional knowledge of the nanocomposite dielectric properties. The knowledge can be a reference and guidance to the engineers for the development of new insulating materials. In this project, investigation of dielectric properties, resistance to tracking and erosion, contact angle and thermal conductivity of PP and EPDM were evaluated with three types of nanofiller with various percentage of filler loading. The blending ratio 50:50 of PP/EPDM is selected because it possesses balanced electrical and mechanical properties. Nanofillers that used in this project were Al_2O_3, AlN and organoclay. Vulcanizing agent dicumyl peroxide (DCP) 5 was added in the blending as a curing agent to enhance the breakdown strength and also as a cross-linking agent in the PP/EPDM system (Reza et al. 2007).

The results of this investigation would contribute to new ideas in producing better insulation properties of polymeric blends and generate development in electrical insulating systems in current situation. This investigation also would provide better understanding towards dielectric properties and resistance to tracking and erosion of PP/EPDM polymeric insulators. In addition, it is useful as guidance and references in designing a new outdoor application that suitable in tropical area such as Malaysia.

1.1 Objectives

The objectives of this research are:

i. To study the effect of nanofiller loading on the thermal and electrical insulation properties of PP/EPDM nanocomposites

ii. To compare dielectric strength of PP/EPDM with three types of nanofillers (aluminium oxide, aluminium nitride and organoclay)

iii. To investigate the resistance to tracking and erosion of PP/EPDM nanocomposites

1.2 Scope of Project

This project mainly focuses on the investigation of the dielectric properties and the effect of the resistance to tracking and erosion of PP/EPDM with and without filler. The investigation of dielectric strength and the resistance to tracking and erosion was carried out based on IEC 60243 standard and IEC 60587 standard, respectively (Motors & Store 2011). In this project, three types of nanofiller were chosen namely Al_2O_3, AlN and organoclay. The experiment for dielectric strength and resistance and erosion to tracking were conducted in Power laboratory by using AC high voltage power system while the test for contact angle and thermal conductivity are conducted in Material and Chemical of Engineering School. The data collected were being discussed and analyzed.

2. Experimental setup

2.1 Sample preparation

The based composite that was used in this experiment was commercial grade homopolymer PP (Titanpro 6431) with the density of 0.9 g/cm3. The material was supplied by Titan Polymer (M) Sdn. Bhd. The EPDM grade Buna 3950 (Mooney viscosity: 24 ± 5 MU, ML (1+4) 125°C) with density of 0.86 g/cm3 contained 69 wt% ethylene and 11.5 wt% ethylidene norbomene was blended with PP. The material was supplied by Bayer (M) Sdn. Bhd. Dicumyl peroxide (DCP) which was received from Bayer (M) Sdn. Bhd was added at 2 phr in all blend compositions to introduce crosslinking between PP and EPDM. Fillers that had been used in this experiment were Alumina (Al2O3) with the density of 4.00 g/cm3 and Aluminium Nitride (AlN) with the density of 3.26 g/cm3. The fillers were supplied by Sigma-Aldrich. Meanwhile, Organoclay with density of 1.66 g/cm3 was obtained from Southern Clay Product Inc. Organoclay (organically-modified nanoclays) are an attractive class of hybrid organic-inorganic nanomaterials.

Figure 2.1 shows the flowchart of process flows of the project. The experiment was started from the preparation of composite samples, compression moulding, electrical properties testing and finally characterization of nanocomposite. Each of the material was weighted accurately using precision weighing before the mixing process. The specimen samples were prepared using equation 2.1-2.3. The weight of each material was tabulated in Table 2.1.

The amount of fillers was determined by using the following equation (Anon n.d.):

$$V_f = \left[\frac{m_T - m_f}{m_f}\left(\frac{\rho_f}{\rho_m}\right) + 1\right]^{-1} \tag{2.1}$$

The amount of PP and EPDM was determined by using eq. 2.2 as follows (Anon n.d.):

$$m_{pp} \text{ or } m_{EPDM}(g) = \frac{(40 - V_f)}{2} \tag{2.2}$$

The amount of DCPs was defined as (Anon n.d.):

$$m_{DCP} = \frac{2}{100} \times m_{EPDM} \tag{2.3}$$

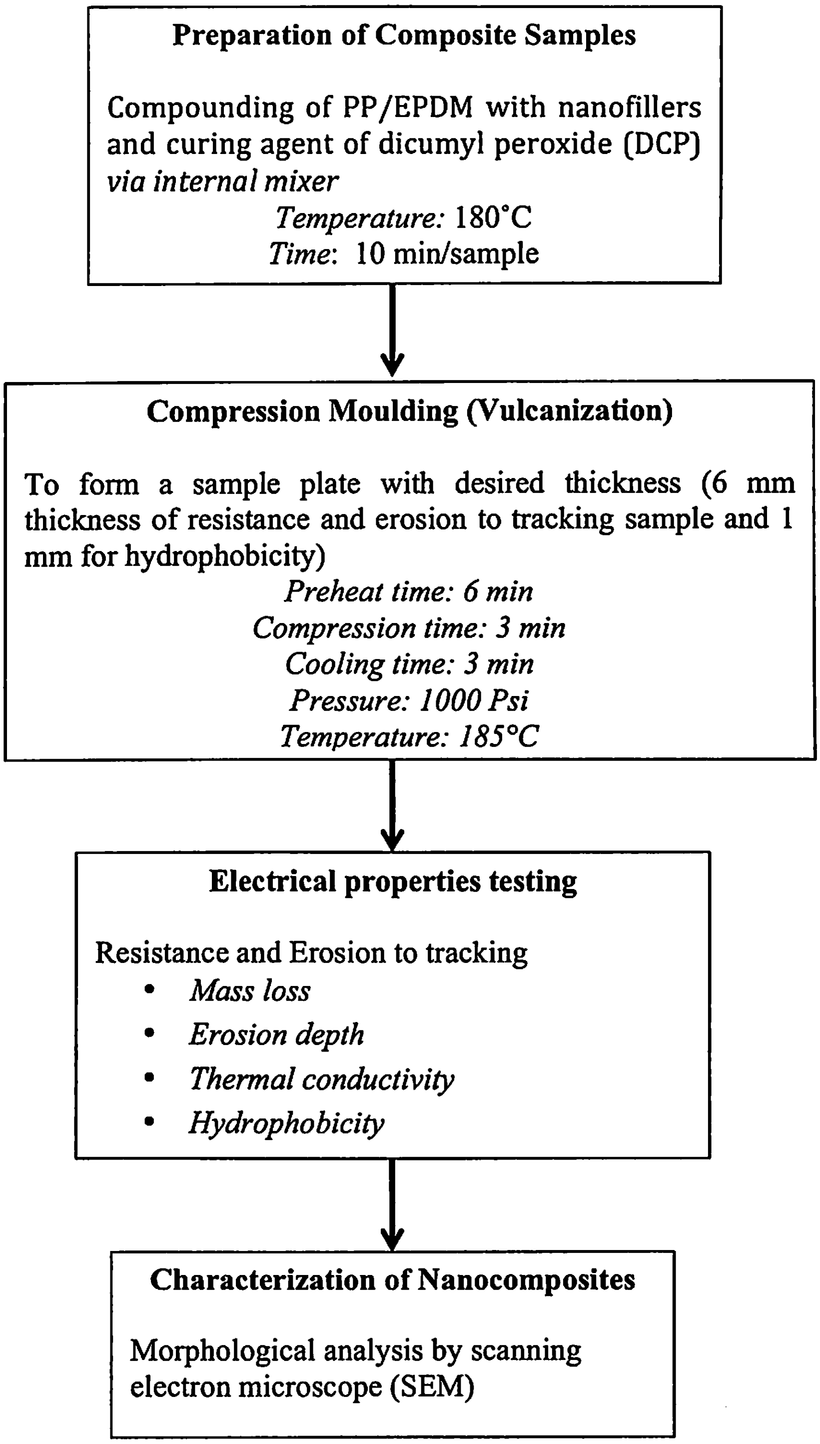
Where, V_f = volume of nanofiller

m_T = total mass of PP/EPDM and nanofiller (40g)

m_f = mass of nanofiller (g)

ρ_f = density of nanofiller (gcm-3)

ρ_m = *density of PP/EPDM (gcm-3)*



Preparation of Composite Samples

Compounding of PP/EPDM with nanofillers and curing agent of dicumyl peroxide (DCP) *via internal mixer*

Temperature: 180°C
Time: 10 min/sample

Compression Moulding (Vulcanization)

To form a sample plate with desired thickness (6 mm thickness of resistance and erosion to tracking sample and 1 mm for hydrophobicity)

Preheat time: 6 min
Compression time: 3 min
Cooling time: 3 min
Pressure: 1000 Psi
Temperature: 185°C

Electrical properties testing

Resistance and Erosion to tracking

- *Mass loss*
- *Erosion depth*
- *Thermal conductivity*
- *Hydrophobicity*

Characterization of Nanocomposites

Morphological analysis by scanning electron microscope (SEM)

Figure 2.1: Flow chart diagram

Table 2.1: PP/EPDM composition with and without fillers

Formulation	PP (wt%)	EPDM (wt%)	Al_2O_3 (vol%)	AlN (vol%)	Organoclay (vol%)
PP/EPDM	50	50	-	-	-
PP/EPDM/2% Al_2O_3	50	50	2	-	-
PP/EPDM/4% Al_2O_3	50	50	4	-	-
PP/EPDM/6% Al_2O_3	50	50	6	-	-
PP/EPDM/8% Al_2O_3	50	50	8	-	-
PP/EPDM/2% AlN	50	50	-	2	-
PP/EPDM/4% AlN	50	50	-	4	-
PP/EPDM/6% AlN	50	50	-	6	-
PP/EPDM/8% AlN	50	50	-	8	-
PP/EPDM/2% Org	50	50	-	-	2
PP/EPDM/4% Org	50	50	-	-	4
PP/EPDM/6% Org	50	50	-	-	6
PP/EPDM/8% Org	50	50	-	-	8

The compounding process of PP/EPDM with and without nanofillers (Al_2O_3, AlN and organoclay) was conducted using Haake Internal Mixer. The photograph of the Mixer is shown in Figure 2.2. The mixing process was conducted for 10 min at 180 °C and 50 rpm. DCP was added at 2 phr in all blend compositions to introduce the crosslinking in PP/EPDM nanocomposites. During the compounding process, PP was first discharged into the mixer and melted for 3 minutes. Then, EPDM was added to the molten PP. Five minutes later, the filler was added and mixed for about 3 minutes, then followed by DCP for another 2 minutes. After the compounding process, the samples were compression-molded in an electrically heated hot press at 185°C to form a plate shape. The samples were prepared with ~~the~~ thicknesses of 1 mm for dielectric properties test and hydrophobicity analysis, 6 mm for thermal conductivity and resistance to tracking and erosion test. The photograph of the molding machine is shown in Figure 2.3. The samples were preheated for 8 minutes and held under a pressure of 1,000 psi for 3 minutes. Eventually, the sample undergoes the cooling process at the same pressure for 3 minutes.

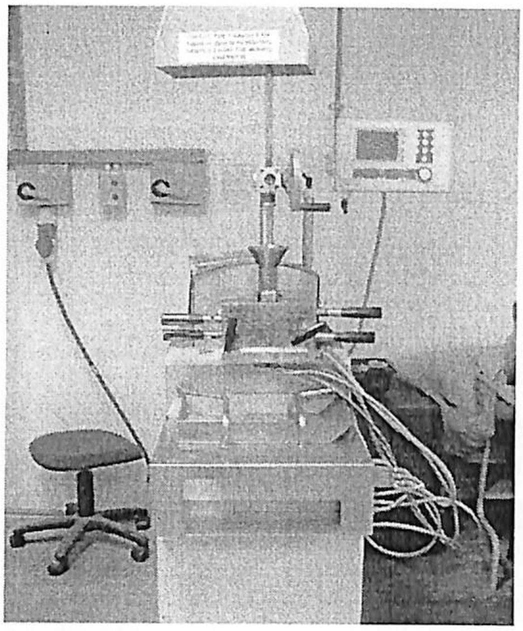


Figure 2.2: Haake PolyDrive Machine

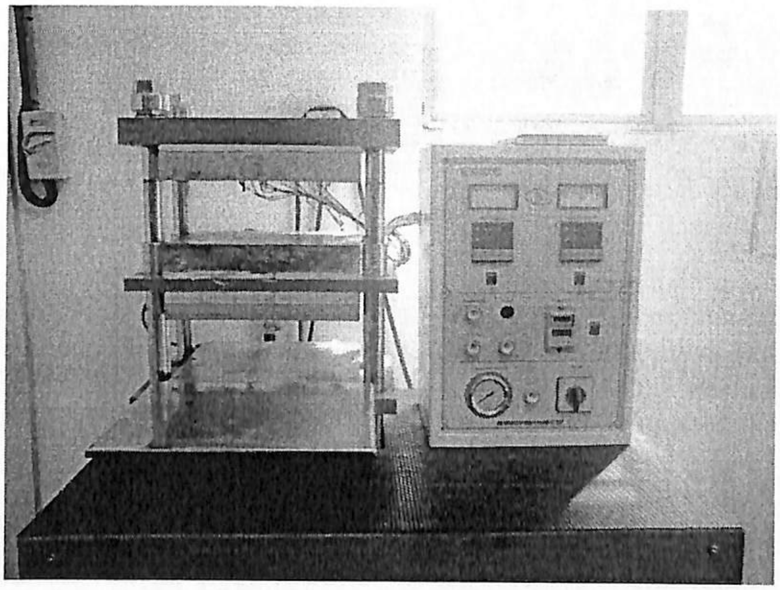


Figure 2.3: Kao-Tieh Compression (Moulding Machine)

2.2 Dielectric Strength Measurement

Figure 2.4 shows the schematic diagram for dielectric strength measurement. The input voltage of 240V, 50Hz was fed to the voltage regulator. A circuit breaker was connected between voltage regulator and the power supply. The circuit breaker protected the electrical circuit from damage caused by overload or short circuit. The voltage regulator was used to control the output voltage value of the transformer from 0 to 100 kV. The 5MΩ limiting-resistor was connected in series with the secondary side of the HV transformer to suppress the leakage current. The dielectric strength measurement was conducted based on the IEC 60243 (Motors & Store 2011). Figure 2.5 shows the schematic diagram of the plane-plane electrodes. The electrodes were made from stainless steel. The specimen of 1mm thickness was kept between two electrodes and been immersed in 400 ml transformer oil to avoid surface flashover. An incremental AC voltage of 0.5kV/s was applied until electrical breakdown occurred. Ten samples had been implemented in the test to record ten electrical breakdown data.

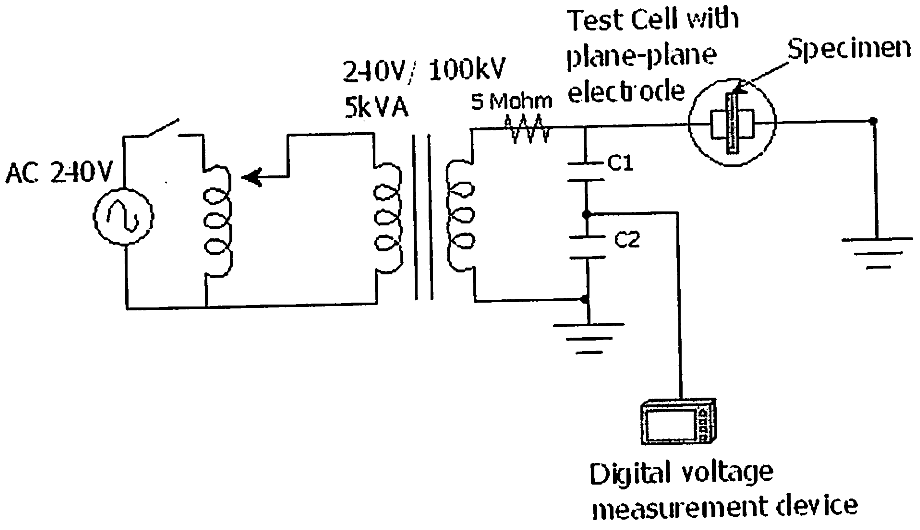


Figure 2.4: Schematic diagram for dielectric strength test

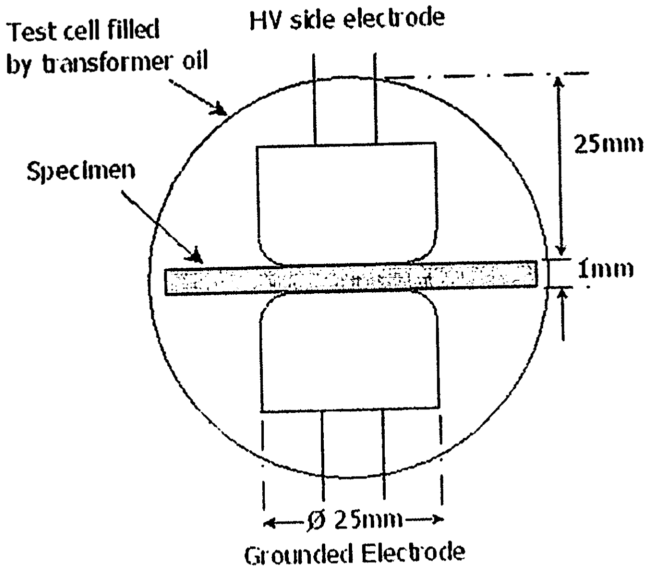
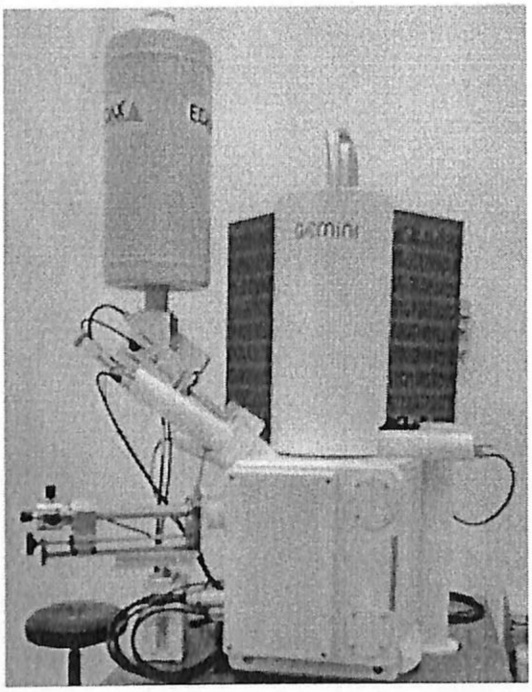


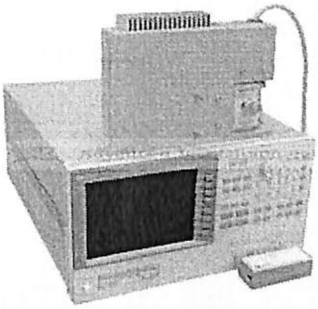
Figure 2.5: Schematic diagram of the sample placed in between the plane-plane electrode

2.3 Characterization Measurement

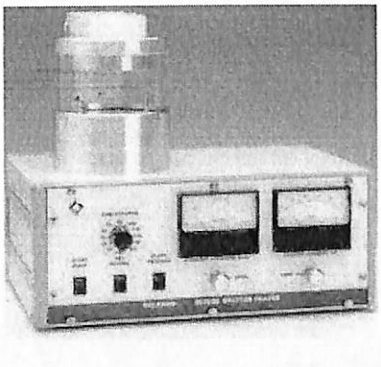
The morphological analysis of selected samples was carried out using SEM (model ZEISS SUPRA 35 VP). The samples were first cryogenically fractured using liquid nitrogen. The fractured surface of the sample was coated with a gold-palladium layer using a Sputter Coater Polaron SC 515 to avoid electrostatic charging during observation. Meanwhile, the dielectric constant of the PP/EPDM blend with and without fillers was measured using Material Analyzer, Hewlett Packard 4219B. The measurements were conducted in the frequency range of 10^7 Hz to 10^9 Hz under room temperature. The equipment utilized for this measurement are shown in Figure 2.6 (a), (b) and (c).



(a) SEM model ZEISS SUPRA 35 VP



(b) Material Analyser (Hewlett Packard 4219B)



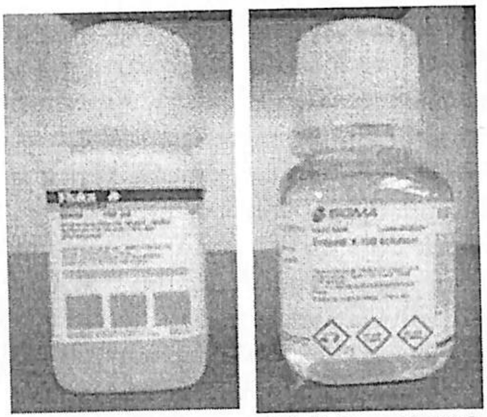
(c) Sputter Coater (Polaron SC 515)

Figure 2.6: Equipment utilized for characterization measurement

2.4 Resistance to Tracking and Erosion Test

2.4.1 Contaminant Preparation

According to IEC 60587 test method (Motors & Store 2011), the specification of the contamination used in the resistance to tracking and erosion test is 0.1 % ± 0.002 % by mass of NH_4Cl (ammonium chloride) and 0.02 % ± 0.002 % by mass of Triton X-100 (a non-ionic wetting agent) in distilled water or deionized water. Figure 2.7 shows the photograph of bottles contaminant NH_4Cl and Triton X-100. Based on the standard (Motors & Store 2011), the mass percentage of concentration of a solution can be determined when the mass of the solute was divided by mass of total solution expressed as a percentage. After being measured, the contaminant solution and the non-ionic wetting agent were dissolved in distilled water. The contaminant resistivity was determined by using the LCR817 Meter as shown in Figure 2.8. In addition, eight layers of filter paper with a thickness of 0.2 mm ± 0.02 mm were clamped between the top electrode and the specimen to act as a reservoir for the contaminant. The dimension of the filter paper is shown in Figure 2.9.



(a) NH_4Cl (b) Triton X-100

Figure 2.7: Photograph of contaminant bottles

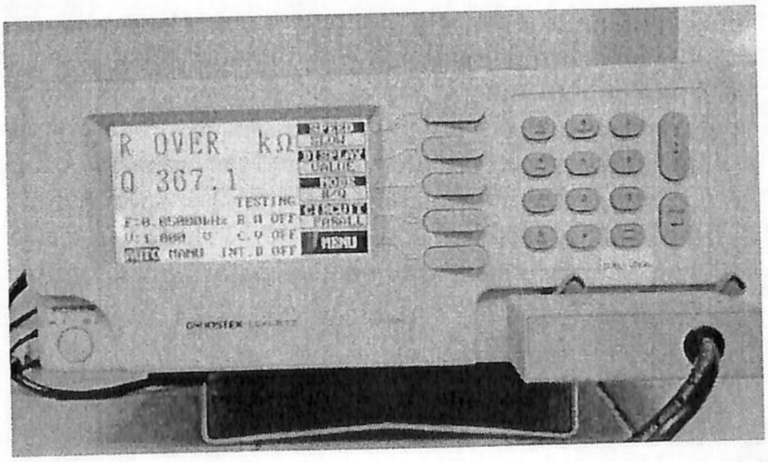


Figure 2.8: LCR817 Meter for resistivity measurement

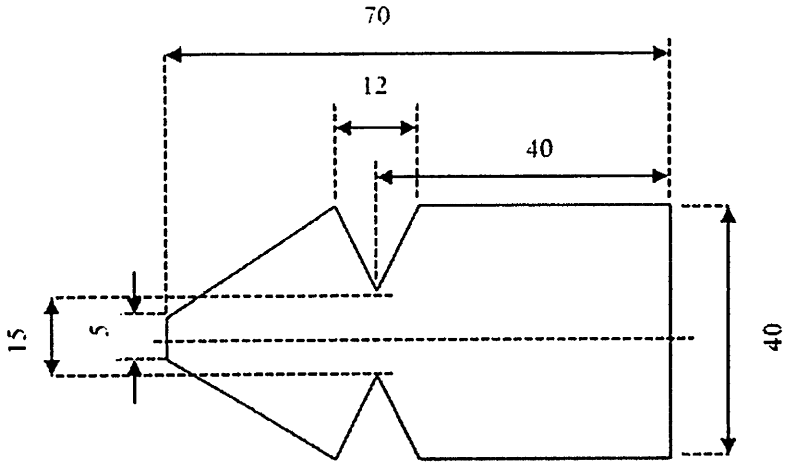


Figure 2.9: Shape of the Filter-paper and it dimension

2.4.2 Experimental Setup for Resistance to Tracking and Erosion

The electrical apparatus utilized in this experiment are the voltage source, step-up transformer, digital multimeter, resistors and overcurrent relay. Figure 2.10 shows the schematic diagram of the test system, which according to the IEC60587 standard. The voltage source-used for this project was 240 V AC. The step-up transformer with a capacity of 5 kVA was used to supply the high voltage to the specimen. The maximum output voltage of the transformer is 100 kV. A voltage regulator was used to control the require voltage to the specimen. The applied voltage and the current limiting resistor used in the experiment were 4.5 kV and 33 kΩ, respectively. The applied voltage and the limiting resistor were determined to permit current flow less than 0.1 A during the experiment (Motors & Store 2011). The limiting resistor, which was connected in series with the electrodes, was used to restrict the damage by current or voltage surge during breakdown. The capacitive divider was connected in parallel with the transformer to measure the applied voltage, which has been scaled down to the ration of 1000:1. The specimen was placed between two electrodes. The top electrode was connected to the high-voltage side, while bottom electrode was connected to the ground. The peristaltic pump was used to control the contaminant flow with a rate 0.6 ml/min. The surface of the specimen after the application of high voltage was observed using a USB camera.

The gap distance between the top and bottom electrode was adjusted to 50 mm as shown in Figure 2.11 (Motors & Store 2011). The dimension of specimens was 50 mm x 120 mm. The preferred thickness was 6 mm. The specimen was mounted with the flat test surface on the undersire at an angle of 45° from the horizontal as shown in Figure 2.11. Each of the specimens was weighed before and after test to determine the eroded mass.

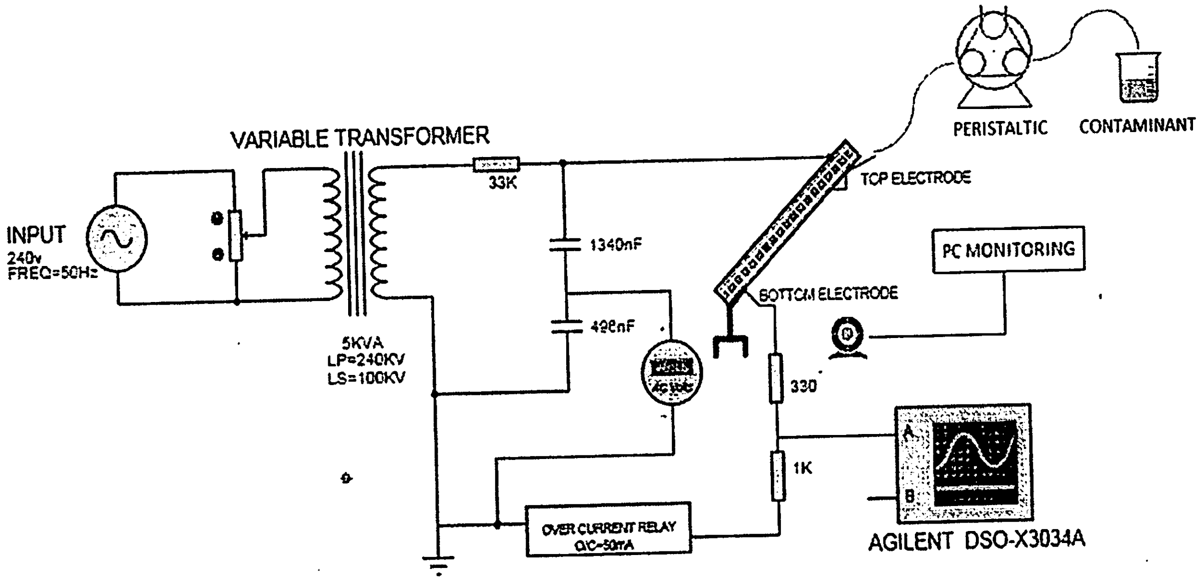


Figure 2.10: Schematic circuit diagram of the experimental setup

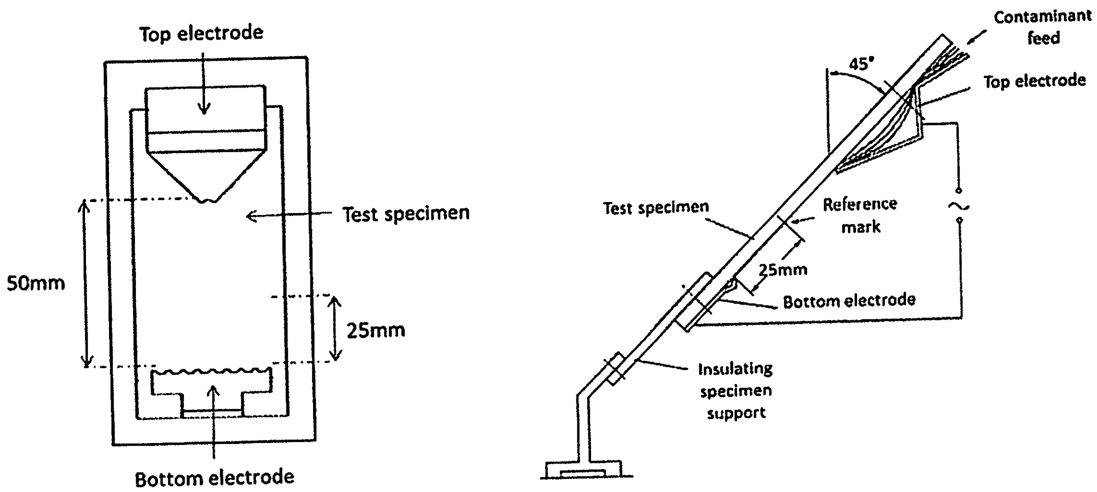


Figure 2.11: Assemble of the electrode

2.5 Contact Angle Measurement

Ganiometer from Rame-heart was used to evaluate the hydrophobicity of the sample surface. The distilled water was dropped on the surface of horizontally laid specimen using a micropipette. The thickness of the specimen was 1 mm. The image of the water drop was obtained from the side of the specimen using a camera to measure the contact angle. This measurement was repeated five times at different points of the specimen surface, and the average contact angle was calculated. Figure 2.12 shows the experimental setup for the contact angle measurement test.

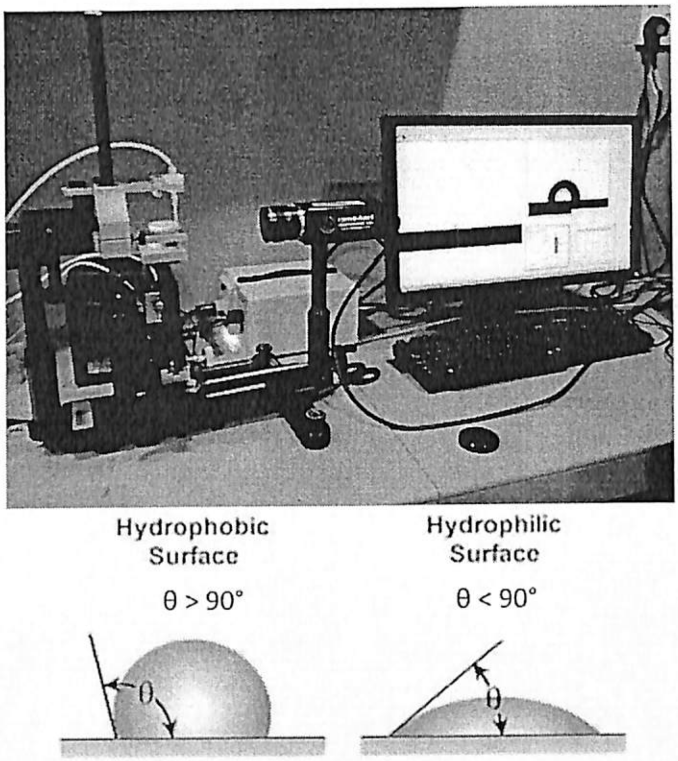


Figure 3.12: Experimental setup for contact angle

2.6 Thermal conductivity measurement

The thermal conductivity of the samples was measured using Hot Disk TP2500S. Figure 2.13 shows the experimental setup for thermal conductivity measurement. The disk sensor was placed between two pieces of the sample with a thickness of 6 mm and heated with a constant electrical current for a short period. The generated heat dissipated from the sensor and into the surrounding nanocomposites sample, thereby increases the temperature surrounding the sample. The sensor detected the average transient temperature increase. The range was from 0.5 K-5 K, which was simultaneously measured by monitoring the change in electrical resistance. The temperature coefficient of resistivity for the sensor material correlated with the change in resistivity as well as with the corresponding change in temperature.

Hot disk TP2500S

Disk sensor or
heating element

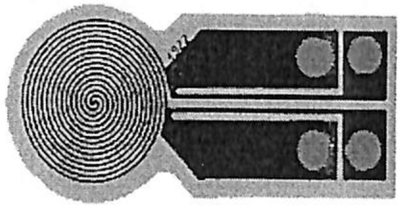


Figure 2.13: Thermal conductivity measurement devices

3. Experimental Results and Discussion

3.1 Dielectric strength

Figures 3.1, 3.2 and 3.3 show the Weilbull probability distribution of dielectric strength of PP/EPDM blends with and without nanofillers. The dielectric strength probability was determined at 63.2% based on Weibull probability plot (Wang & Chen 2012). It is because the conformity of the Weibull distribution started to decrease at below than 63.2%. The parameters for PP/EPDM blends with and without filler are shown in Table 3.1. The scale parameter, *h*, and shape, *b* denoted the dielectric strength characteristics of the samples at the failure probability 0.6321 and the scattering breakdown values, respectively.

The results from Figure 3.1 and Table 3.1 show that the addition of 2 vol% of Al_2O_3 slightly increased the dielectric strength of the composite material by 4.31%. However, further addition of Al_2O_3 weakened the dielectric strength of PP/EPDM composite considerably. Similar result of dielectric strength was also determined for PP/EPDM blends with 2 vol% of organoclay nanofiller. This nanocomposites has higher dielectric strength of 38.59 kV/mm compared with the other ratio of nanofiller.

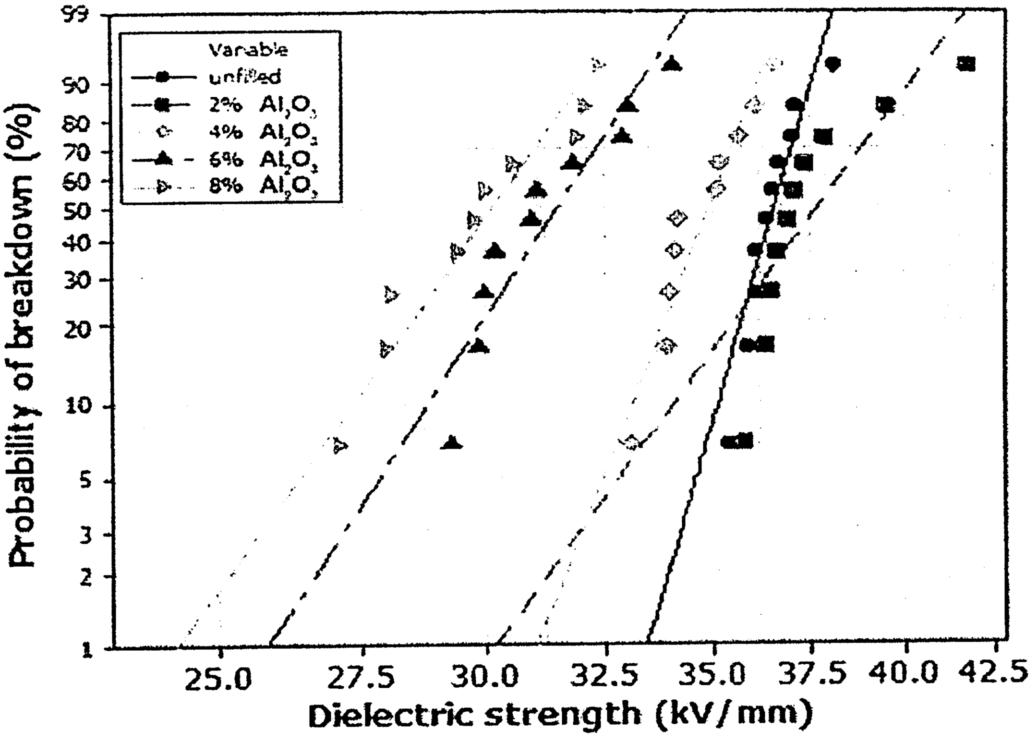


Figure 3.1: Weibull distribution plots for unfilled, 2, 4, 6, and 8 vol% Al_2O_3–filled PP/EPDM composites

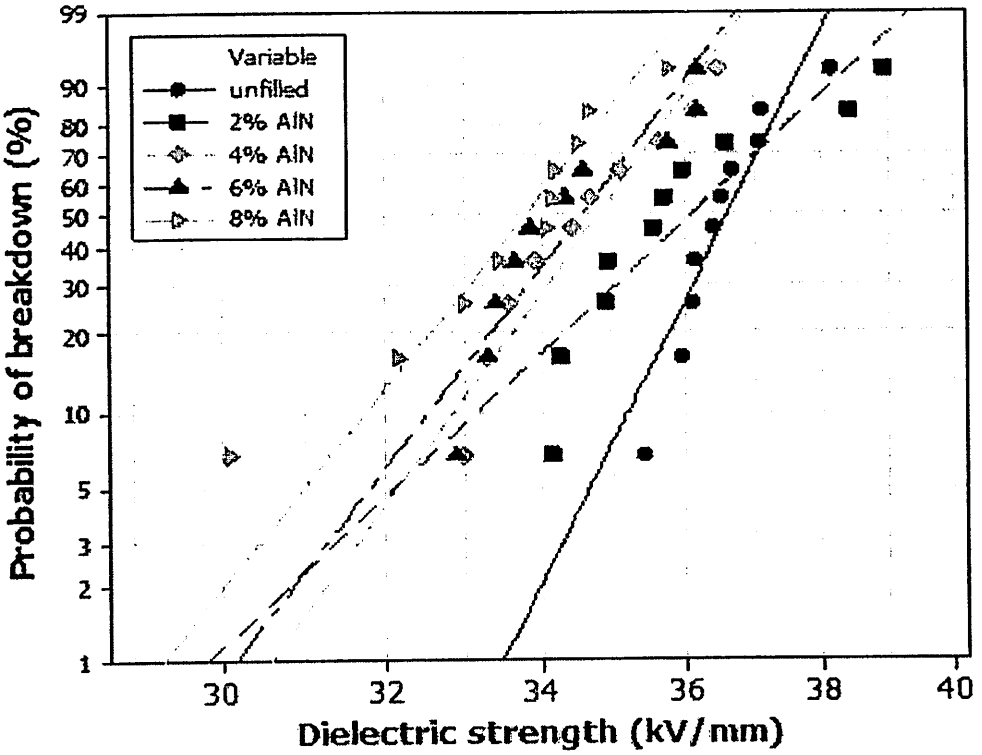


Figure 3.2: Weibull distribution plots for unfilled, 2, 4, 6, and 8 vol% AlN-filled PP/EPDM composites

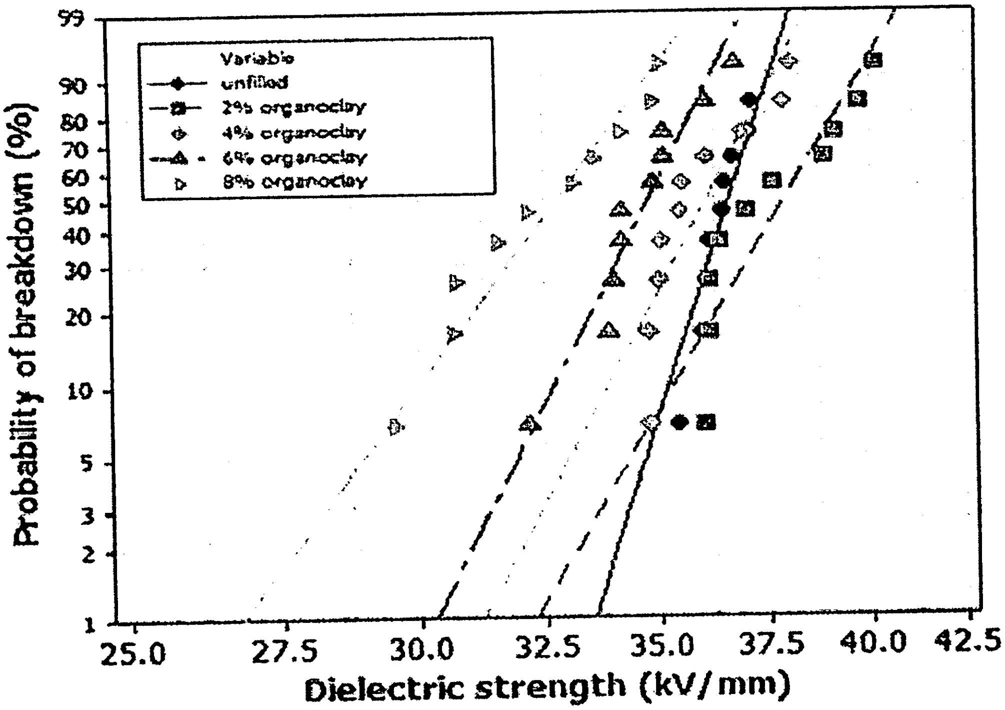


Figure 3.3: Weibull distribution plots for unfilled, 2, 4, 6, and 8 vol% organoclay-filled PP/EPDM composites

Table 3.1: Weibull parameters of dielectric strength of each sample

Samples	Weibull parameter	
	Shape, *b*	Scale, *h* [kV/mm]
Unfilled PP/EPDM	47.52	36.92
2% Al_2O_3	18.99	38.51
4% Al_2O_3	35.67	35.36
6% Al_2O_3	21.16	32.11
8% Al_2O_3	19.50	30.76
2% AlN	22.16	36.72
4% AlN	32.78	35.20
6% AlN	30.96	35.00
8% AlN	29.62	34.26
2% Organoclay	26.25	38.59
4% Organoclay	29.33	36.58
6% Organoclay	30.70	35.21
8% Organoclay	20.99	33.40

Based on the result obtained, the addition of nanofillers has a significant effect on the dielectric strength of nanocomposites. The addition of nanofiller will produce an interfacial region between polymer matrix and nanofiller as introduce in dual layer model based on the report written by Singha and Thomas (Singha & Thomas 2008). This dual layer model consists of tightly bound region and loosely bound region. The tightly bound region could act as charge traps to reduce the number of free charge carriers for charge transport whereas the loosely bound region is more electrically conductive in nature. With 2 vol% of filler loading, the number of particles in the nanocomposite is higher. It will contribute to the smaller inter-particle distance, decreasing the volume fraction of loosely bound and the nanoparticles themselves start acting as barriers to the flow of current between the electrodes. These can result a hindrance to the flow of current in the nanocomposites and consequence increase the dielectric strength of the system. On the other hand, although the addition of 2 vol% of AlN nanofillers in PP/EPDM blend yield to the dielectric strength of 36.72 kV/mm, which is higher than the other ratio of AlN nanofiller, it does not improve the dielectric strength of the composite. Furthermore, the increasing of nanofillers from 4 vol% until 8 vol% decreases the dielectric strength of PP/EPDM. There is also a further decrease in inter-particle distance. The possibility for the loosely bound region of interface to overlap with each other is sufficiently high. Such reduction of dielectric strength might due to the overlapping of the loosely bound region. This overlapping of nanoparticles will form conductive paths that allow charge carriers travel through much easier. Figure 3.4 shows the illustration of PP/EPDM system with increasing of nanofiller loading. With addition of 2 vol% of nanofiller, the nanocomposite is well distributed compared to the addition of 4 vol% onwards. The nanofillers started to overlap each other and contribute to the lower dielectric strength of the nanocomposite.

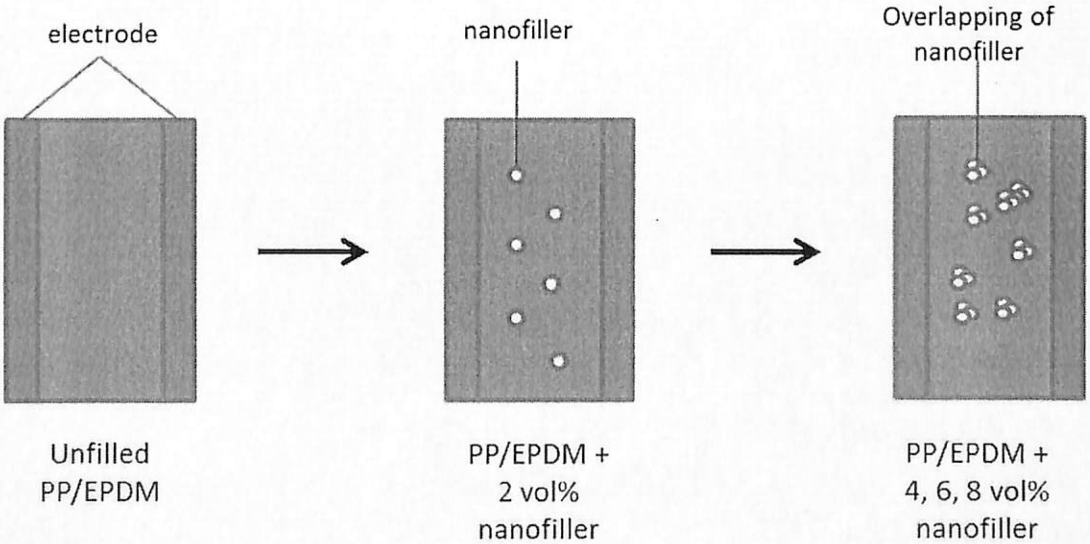


Figure 3.4: The illustration PP/EPDM system with increasing of nanofiller loading

The dielectric strength of the PP/EPDM nanocomposites can also be explained with the morphology analysis of the material as shown in Figures 3.5 to 3.8. The agglomeration of fillers and formation of micro and nano sizes voids were obviously observed in PP/EPDM/AlN composite as shown in Figure 3.7. The agglomeration of AlN nanofiller could result in a large volume fraction of the loosely bound. The mobile charge carriers could travel easier through the loosely bound region under the applied field resulting lower dielectric strength. 2 vol% AlN-filled PP/EPDM also depicted the obvious presence of voids, which can significantly reduce the dielectric strength of the composite which can significantly reduce the dielectric strength of the composite (Guo et al. 2013; Woodhead et al. 2008). The formation of these voids at filler-polymers interface may due to the poor adhesion between polymer and the as-received nanofillers, which introducing charge carriers that significantly lead to the lower electrical breakdown (Laoutid et al. 2009; Amin et al. 2009). In addition, the presence of a void creates local electric field strength irregularities and with the lower permittivity of air exists in the void causing an intensification of the electric field at the solid/void interface. Consequently, breakdown that preferentially occurs first at solid/void interface has the effect of disrupting the polymer structure and increasing void size.

On the other hand, the morphology of 2 vol% Al_2O_3 and organoclay-filled PP/EPDM nanocomposite is well distributed as compared to the 2 vol% AlN as shown in Figures 3.6 and 3.8, respectively, and contains fewer voids which may causes less intensification of the electric field at the solid and void interface and eventually contributes to higher dielectric strength of the composite material. Furthermore, the dispersion of PP/EPDM blends with 2 vol% of organoclay was better than than 2 vol% Al_2O_3–filled PP/EPDM which indicates that the organoclay nanofiller PP/EPDM may results slightly higher dielectric strength than PP/EPDM/ Al_2O_3 nanocomposite. However, further increase in filler loading concentration up to 8 vol% for all nanocomposite yields to slightly reduction of dielectric strength. The increment of filler loading concentration could resulting in lower inter-particle distance and might possibly form an overlapping of loosely bound region. The overlapping of loosely bound region could develop conductive path that permit charge carries easily travel through the nanocomposite material and eventually contribute to the reduction of dielectric strength.

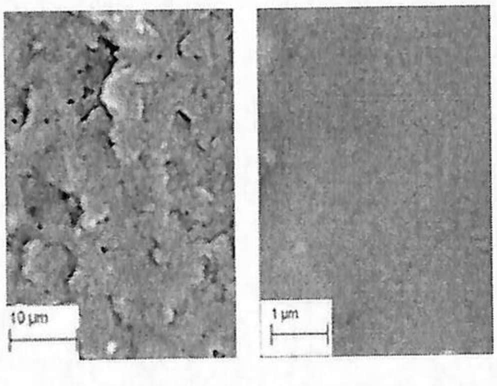


Figure 3.5: Scanning electron microscope micrograph showing fracture surface morphology of unfilled PP/EPDM

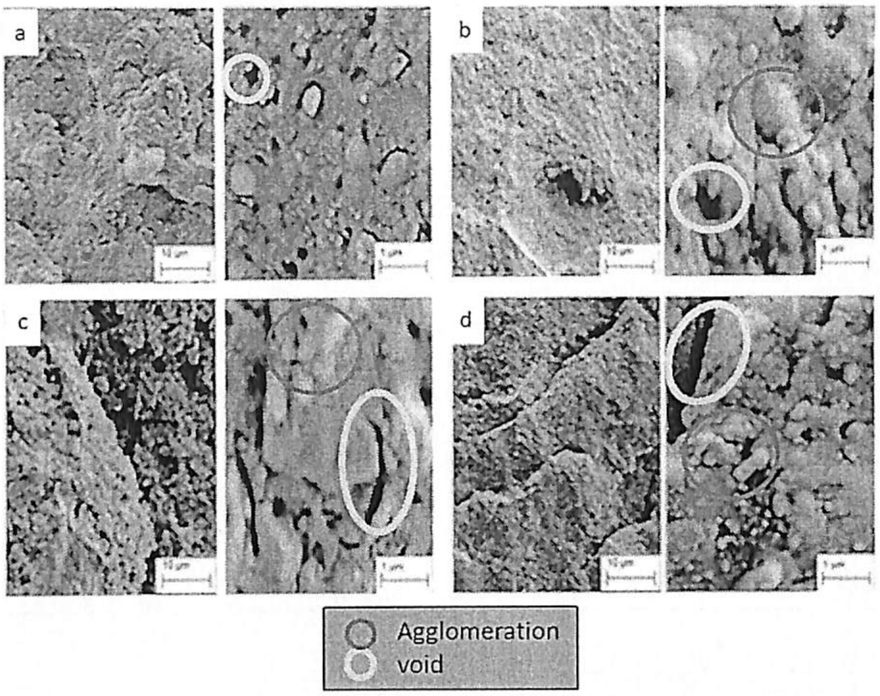


Figure 3.6: Scanning electron microscope micrograph showing fracture surface morphology of (a) 2 vol% Al_2O_3, (b) 4 vol% Al_2O_3, (c) 6 vol% Al_2O_3, (d) 8 vol% Al_2O_3-filled PP/EPDM composites

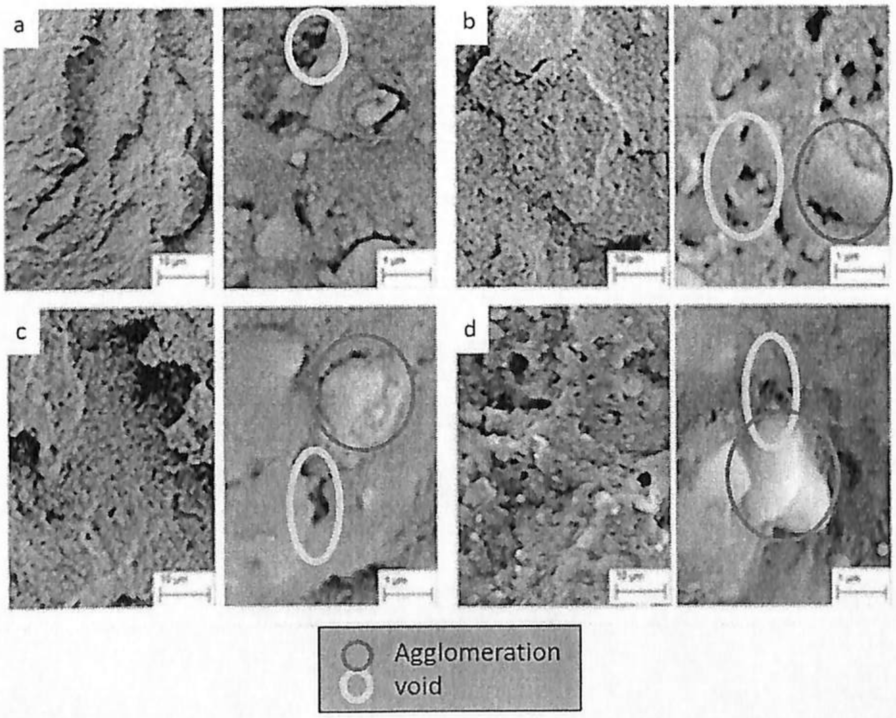


Figure 3.7: Scanning electron microscope micrograph showing fracture surface morphology of (a) 2 vol% AlN, (b) 4 vol% AlN, (c) 6 vol% AlN, (d) 8vol% AlN - filled PP/EPDM composites

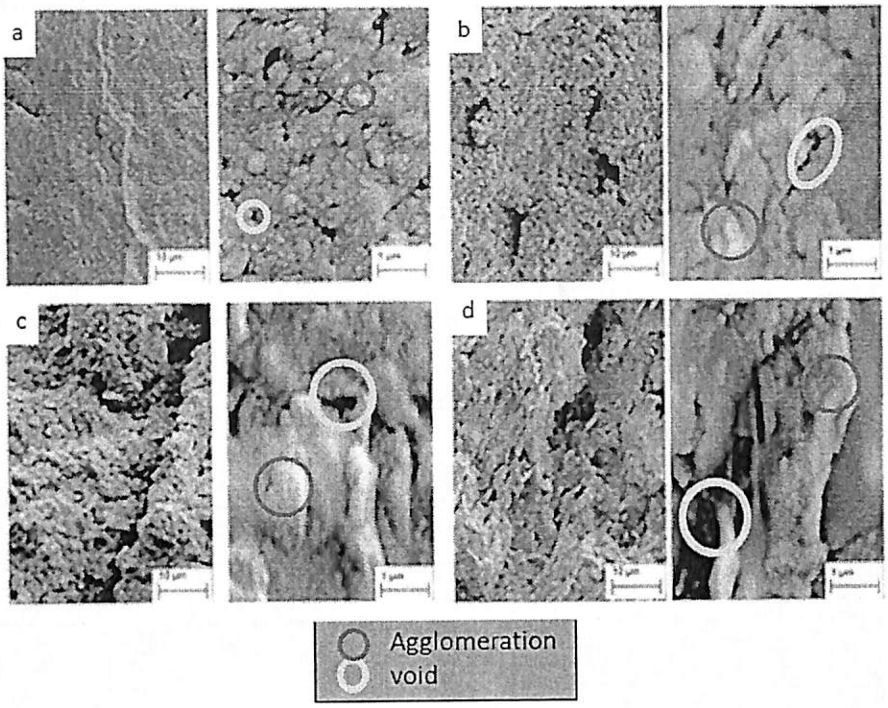


Figure 3.8: Scanning electron microscope micrograph showing fracture surface morphology of (a) 2 vol% Organoclay, (b) 4 vol% Organoclay, (c) 6 vol% Organoclay, (d) 8 vol% Organoclay-filled PP/EPDM composites

3.2 Dielectric constant, ε_r

Figure 3.9 shows the dielectric constant, ε_r of PP/EPDM blends as a function of frequency for different type of filler and filler loading. The dielectric constant, ε_r was measured between the frequency ranges 1 MHz to 1 GHz. Within this frequency the variation in permittivity contribute small errors of the order of 0.1% (Tsagaropoulos, G , Eisenberg 1995). The result in Figure 3.9 depicts the comparison between 2 and 8 vol% Al_2O_3, AlN and Organoclay filled-PP/EPDM nanocomposites. The addition of nanofillers resulted in increasing of ε_r of PP/EPDM blends. Organoclay nanofiller show the highest dielectric constant followed by AlN and Al_2O_3. The 2 vol% filler loading of Al_2O_3 slightly increase the dielectric constant of PP/EPDM and it shows the best performance in dielectric breakdown measurement. With the filler loading continue to increase up to 8 vol%, the inherent high permittivity of Al_2O_3, AlN and Organoclay start to present its influence on relative permittivity of nanocomposites. This is because the permittivity of two phases dielectric satisfies the Lichtenecker-Rother logarithmic law:

$$\log \varepsilon_c = x \log \varepsilon_1 + y \log \varepsilon_2 \tag{3.1}$$

where, ε_c is the resultant composite permittivity, ε_1 and ε_2 are the permittivity of filler and PP/EPDM and x, y are concentration of filler and polymer. It is apparent from the result shows in Figure 4.9 that the nanofiller permittivity at 2 vol% of fillers loading of Al_2O_3, AlN and Organoclay were relatively less influence to the PP/EPDM nanocomposite permittivity at all frequencies. At this level of nanofiller loading, the PP/EPDM nanocomposite permittivity is mainly influence by the PP/EPDM polymeric blends. As the loading of nanofillers in PP/EPDM blends increases up to 8 vol%, the permittivity of the PP/EPDM nanocomposite was also increased due to an increment of the number of nano-particle in the PP/EPDM polymeric blends. The increasing relative permittivity, ε_r of the PP/EPDM nanocomposites would be mainly attributed to the increasing of immobile nanolayers around the nanoparticles that allow the nanoparticles to have a far stronger interaction with the second layer of loosely bound polymer (Singha & Thomas 2008). Existence of these immobile nanolayers may finally reduce the chain mobility in the nanocomposites even further.

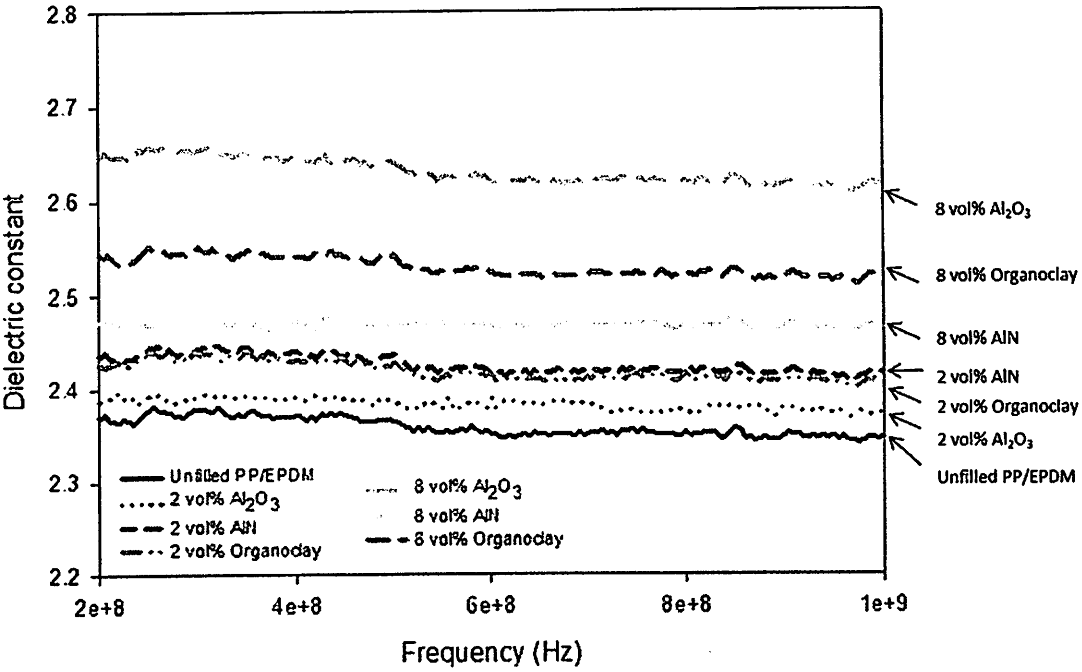


Figure 3.9: Variation of dielectric constant (ε_r) of Al_2O_3, AlN, and organoclay filled PP/EPDM nanocomposites as a function of frequency

3.3 Resistance to tracking and erosion

The resistance to tracking and erosion of the PP/EPDM polymeric blends with and without nanofillers was evaluated. Figure 3.10 shows the typical photographs of the PP/EPDM samples with and without AlN at 2, 4, 6 and 8 vol% loading. The photograph showed that the resistance to tracking and erosion of 2 vol% and 4 vol% of AlN nanofillers were severe compared with the specimens with filler loadings of 6 vol% and 8 vol% . The severity of resistance to tracking and erosion was reduced with the increase in filler loading. Figure 3.11 depicts the filler loading dependence of mass loss per minute. The mass loss of the PP/EPDM nanocomposite decreased with the increase in filler loading up to 6 vol%. No mass loss was determined at 6 vol% to 8 vol% of nanofillers because the tracking time was fast, which did not affect the surface erosion of the material. The same trend was also observed for Al_2O_3 and Organoclay nanofillers. This result was obtained because the generated heat was conducted quickly in the specimen and maximum temperature decreased with the high content of filler loading, which resulted to a low erosion decomposition of the material. The PP/EPDM without nanofillers showed the highest mass loss per minute of 0.0065. The addition of 2 vol% of AlN, Al_2O_3 and organoclay into PP/EPDM composite reduced the mass loss of the nanocomposite from the unfilled one by 77.2%, 77.1% and 59.9%, respectively.

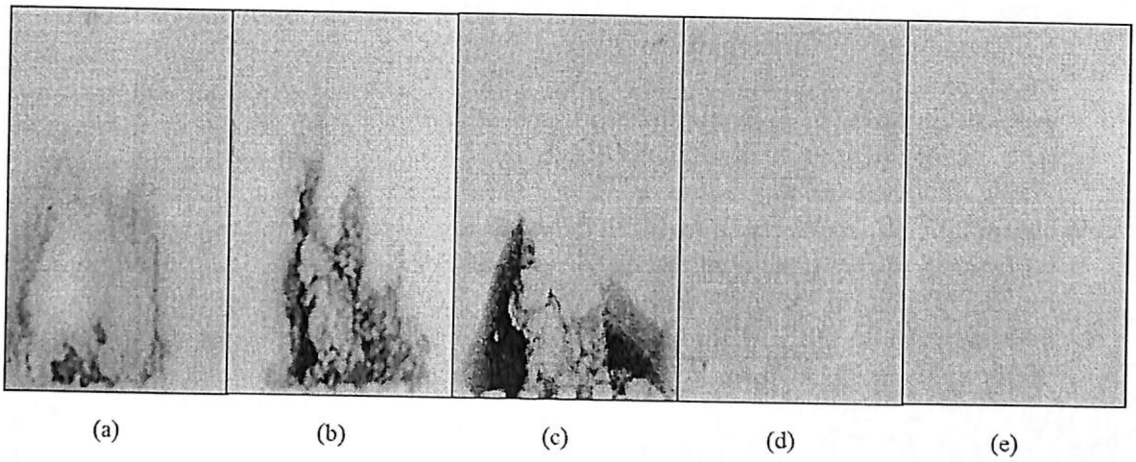


Figure 3.10: Typical photographs of (a) unfilled, (b) 2 vol% AlN, (c) 4 vol% AlN, (d) 6 vol% AlN, and (e) 8 vol% AlN

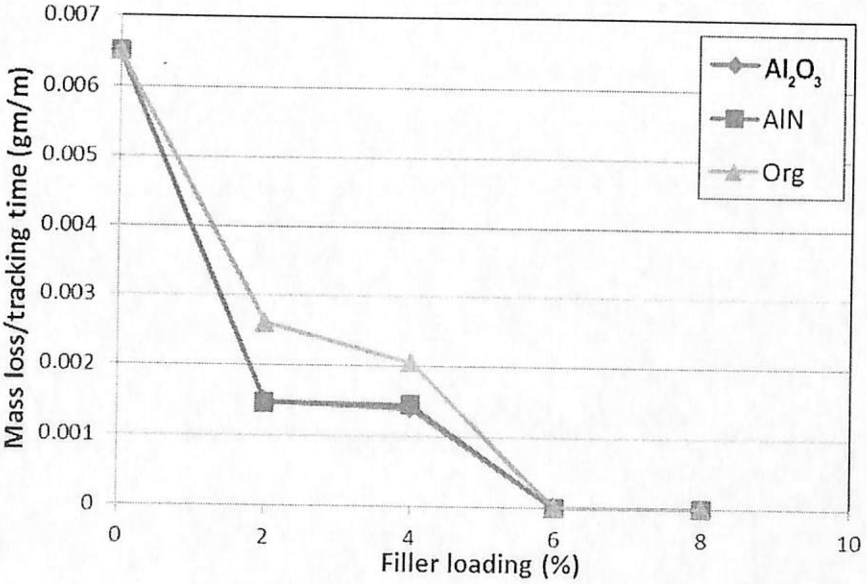


Figure 3.11: Relationship between filler loading and mass loss (Al_2O_3, AlN, Org (Organoclay))

A similar tendency was also found for erosion depth as shown in Figures 3.12 and 3.13. Figure 3.12 shows typical photographs of the PP/EPDM samples filled with and without nanofillers at 2 vol% filler loading. Figure 3.13 shows the relationship between erosion depth and erosion length of unfilled, 2 vol% of Al_2O_3, AlN and Organoclay. All the specimens were discharged after the tracking reached 25 mm of the sample from the bottom electrode. The measurement of erosion depth was obtained from the bottom electrode until 25 mm of the sample as shown in Figure 3.12. Based on the result shown in Figure 3.13, the unfilled sample had the highest erosion effect compared with the other samples. This significant difference of the mass loss and erosion effect of PP/EPDM with and without nanofillers depended on the thermal conductivity (Prabu et al. 2007). Heat is transported in composite by both phonons and free electrons. When the specimen exposed to the continuous contaminant for certain period under the influence of leakage current, the hydrophobicity of PP/EPDM nanocomposite can be lost which will lead to the development of a conductive path on the surface. Normally, for high voltage insulator application, thermal conductivity for high voltage insulation should be in range 0.25-0.30 W/mK to ensure that the heat will spread quickly and reduce the degradation effect of specimen and could dissipate heat during the tracking processes. Under continuous flow of contaminants on the surface of the nanocomposite, the leakage current occurs and bridged the electrodes which resulted in conduction and Joule heating (Du & Xu 2014). The arc begun to appear when the dry bands were formed in the conductive path and the voltage applied was over the breakdown voltage. Dry bands more likely to form at the bottom of the water film, thus the dry band arcing was mainly concentrated near the bottom electrode (Du & Xu 2014). The relationship of the measured thermal conductivity and filler loading are plotted in Figure 3.14. The thermal conductivities of all nanocomposites were higher than that of the unfilled specimen. The result showed that the thermal conductivity increased with increasing filler loading in polymer matrix.

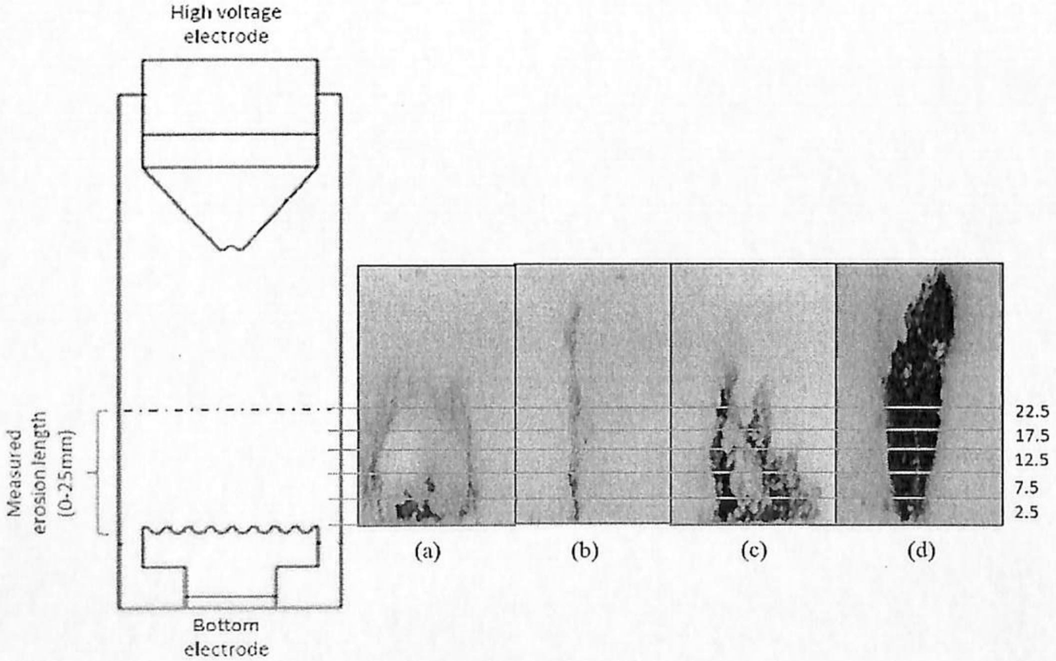


Figure 3.12: Typical photographs of; (a) unfilled PP/EPDM, (b) 2 vol% Al_2O_3, (c) 2 vol% AlN, (d) 2 vol% Organoclay

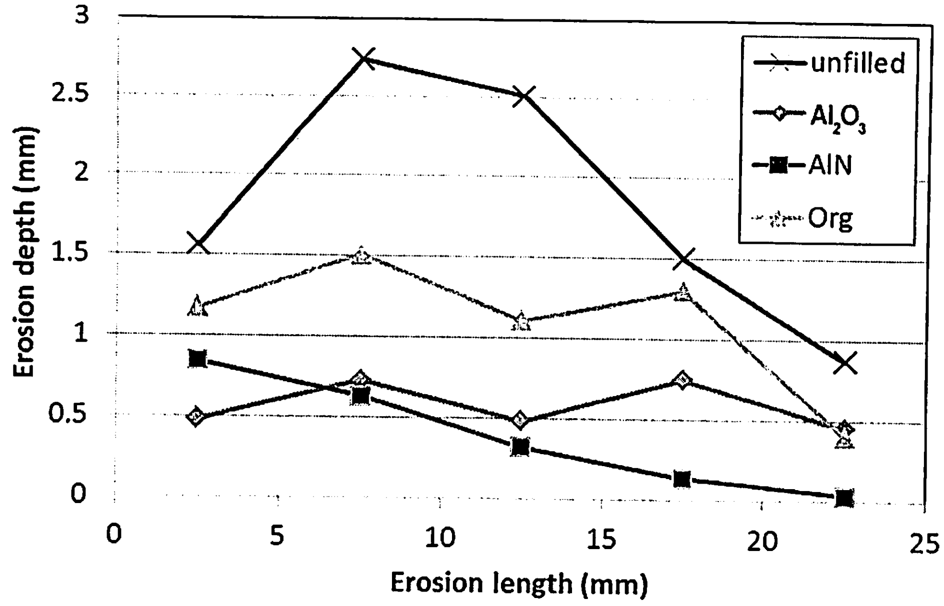


Figure 3.13: Relationship of erosion depth and erosion length of unfilled, 2 vol% of Al_2O_3, AlN and Org (Organoclay)

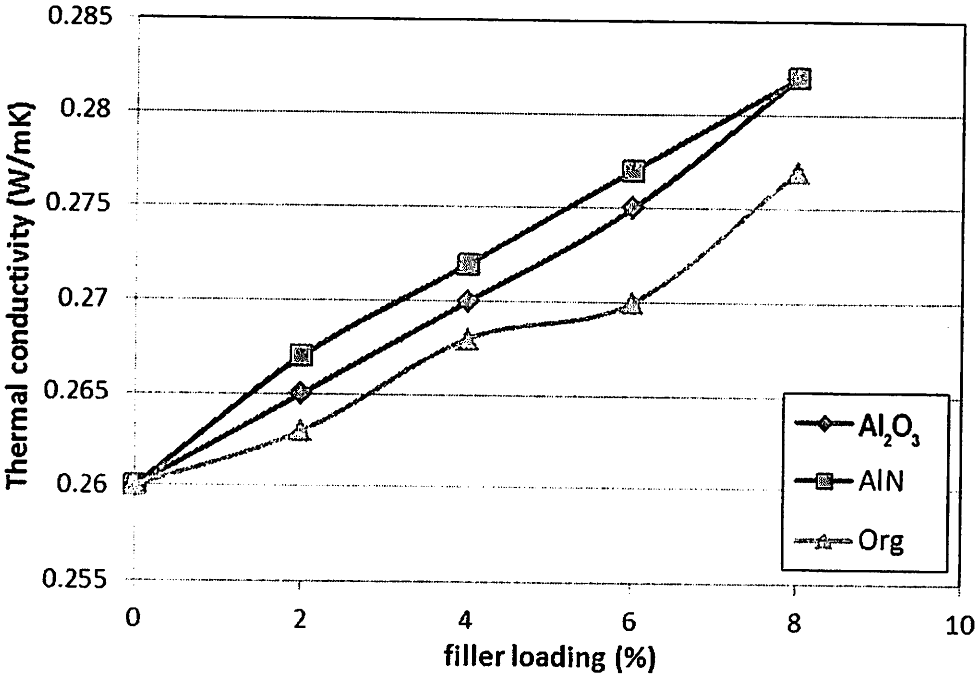


Figure 3.14: Relationship between the thermal conductivity and the filler loading (Al_2O_3, AlN, Org (Organoclay))

The unfilled PP/EPDM sample showed the lowest value of thermal conductivity compared with the sample having nanofiller. The AlN nanofiller showed the highest result of thermal conductivity followed by Al_2O_3, and organoclay. The relationship between thermal conductivity and filler loading is based on the heat dissipation concept (Amin et al. 2007). The heat would spread to a large region of the specimen with a higher thermal conductivity. Therefore specimens with high thermal conductivities presented a relatively low temperature in the discharge area and a high temperature in the surrounding area. The heat dissipation in the specimen improved with increasing filler loading up to 8 vol%. Increasing the filler loading also increased the thermal conductivity of the nanocomposites, consequently reducing the eroded mass of the sample.

3.4 Analysis of hydrophobicity of material

Figure 3.15 shows the filler loading dependence of the contact angle and tracking time of the nanocomposites. These results indicate that the hydrophobicity of the sample does affect the tracking time performance. The analysis result demonstrated that the PP/EPDM filled with Organoclay and Al_2O_3 started to lose hydrophobicity at 4 vol% and 6 vol% of filler loading, respectively. At this concentration of filler loading, these materials have a contact angle of less than 90° and a large contact surface area. Therefore, the PP/EPDM filled with 4 vol% Organoclay and 6 vol% Al_2O_3 onwards easily contributes to the wettable surface of the material and considered to have hydrophilic surfaces. Meanwhile, the PP/EPDM with AlN nanofiller slightly drops the hydrophobicity condition of the material when the concentrations of the filler increases and maintains the hydrophobic surface condition at 8 vol%. This material allows less water surface contact (Kannan et al. 2015). The tracking time for all nanocomposites started to decrease when 2 vol% of filler loading are added to the PP/EPDM. Comparing the results of tracking time with the contact angle of the specimen, it is revealed that the loss of hydrophobicity in the nanocomposite material results in a fast tracking time (Arroyo et al. 2000). At 2 vol% filler loading, the AlN nanofiller is considered to have a better performance in the erosion results and relatively the same tracking time compared with unfilled PP/EPDM.

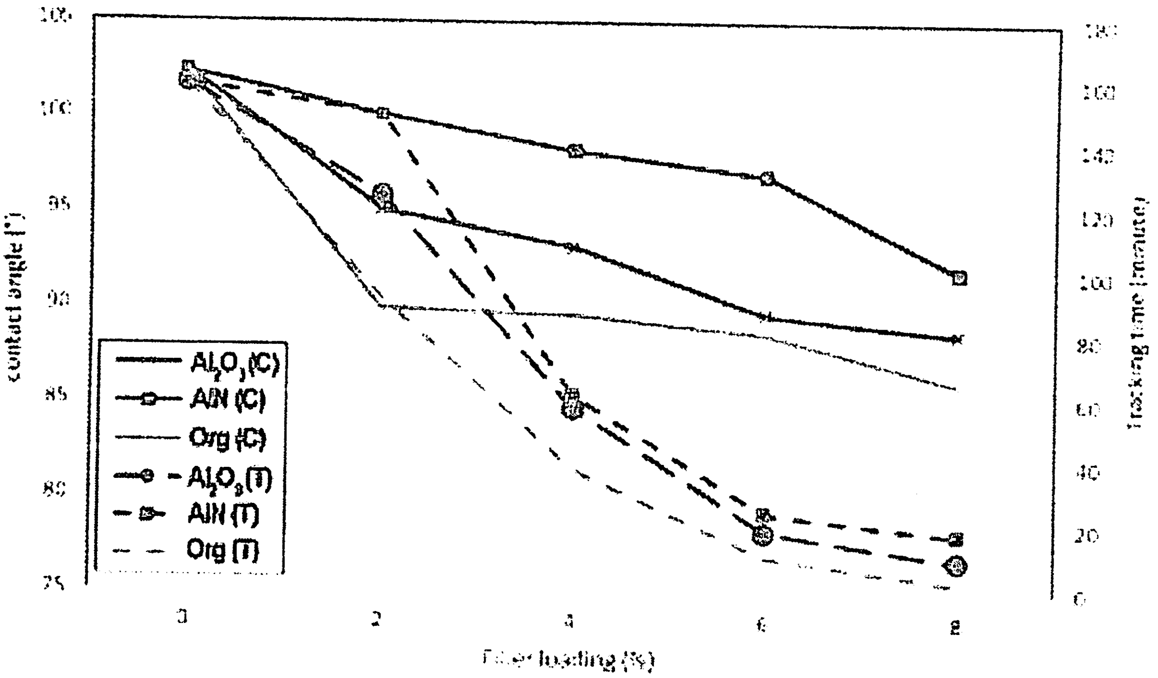


Figure 4.15: Relationship between contact angle (Al_2O_3 (C), AlN (C), Org (C)) and tracking time (Al_2O_3 (T), AlN (T), Org (T))

3.5 Summary

From the results obtained, the dielectric strength of nanocomposites material depends on the concentration of filler loading. PP/EPDM filled with 2 vol% Organoclay gives the highest dielectric strength followed by Al_2O_3 and AlN. For dielectric constant results, it also proved that the increasing concentration of filler loading will increase the value of dielectric constant. On the other hand, the AlN shows better result in resistance and erosion to tracking test followed by Al_2O_3 and Organoclay nanofiller. This is based on the lower mass loss and erosion depth results. In addition, the AlN also depicts the highest thermal conductivity and hydrophobicity as compared to the others. As a conclusion, AlN gives the optimum results in all testing and can be considered as better nanocomposite in high voltage insulator system.

4. Conclusion

The effects of Al_2O_3, AlN and organoclay nanofillers with various loading on dielectric properties and resistance and erosion to tracking of PP/EPDM blends were experimentally investigated.

The dielectric strength of PP/EPDM with three types of nanofillers was compared. The dielectric strength of PP/EPDM with 2 vol% Al_2O_3 and organoclay nanofillers composites were increased 4.31% and 4.33% from the unfilled, respectively. However, the dielectric strength of PP/EPDM between 2 vol% AlN and unfilled composites is 0.54%, which is slightly small and did not show significant improvement. The addition of the nanofiller in PP/EPDM was also affected to the increment of dielectric constant of the nanocomposite compare to the unfilled composites material. The 2 vol% of Al_2O_3 nanocomposites has slightly same dielectric constant and higher dielectric strength with the unfilled PP/EPDM which has potential as solid insulator in high voltage power system.

The resistance to tracking and erosion result was significantly improved by addition of nanofiller. The mass loss and erosion depth of the PP/EPDM nanocomposites decreased with the increasing of filler loading. The PP/EPDM filled with 4 vol% organoclay and 6 vol% Al_2O_3 onwards was considered has hydrophilic surfaces. The PP/EPDM with AlN nanofiller slightly drops the hydrophobicity condition of the material when the concentrations of the filler increases and maintains the hydrophobic surface condition at 8 vol%. As a conclusion, AlN gives the optimum results in all testing and can be considered as better nanocomposite in high voltage insulator system.

5. Recommendations

Some recommendations for the future work are suggested as follows based on the results and conclusions in this present research work:

1. The leakage current measurement should be developed for resistance to tracking test using computer with LabView software to investigate the behavior of leakage current signals related to the filler concentration.

2. Further research should be conducted on the types of nanofillers that can enhance dielectric strength.

3. Advanced research on samples that exposed to the weather (tropical weather) for a month and upwards and analyse the tracking behavior.

4. Conducted the resistance to tracking study on XLPE material for underground and overhead weather sheet high voltage system application.

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List of Publications

1. I.N. Hidayah, Mariatti Jaafar, Hanafi Ismail and Mohamad Kamarol, "Evaluation of PP/EPDM nanocomposites filled with SiO2, TiO2 and ZnO nanofillers as thermoplastic elastomeric insulators", Plastics Rubber and Composites, Vol.44, No.7,pp.259-264, September, **2015** (DOI: 10.1179/1743289815Y.0000000014) (ISI; IF:0.58)

2. MS Hamzah, M Mariatti and ***M. Kamarol***, "Tensile Properties and Melt Flow Index of Polypropylene/Ethylene Propylene Diene Monomer Nanocomposites", Advanced Materials Research, Vol. 1107, pp 125-130, **2015** (doi:10.4028/www.scientific.net/AMR.1107.125).

3. MS Hamzah, IN Hidayah, M Mariatti and ***M Kamarol***, "Dielectric and thermal properties of flame retardant fillers in polypropylene/ethylene propylene diene monomer composites", Journal of Reinforced Plastics and Composites,pp.1-11, Sept. 2014 (DOI:10.1177/0731684414553381). (ISI; IF: 1.188)

4. M. Hafiz, M. Fairus, Noor Syazwani Mansor, M. Mariatti and ***M. Kamarol***, "Investigation of Electrical Treeing Structures in SiR/Alumina Nanocomposites", IEEE Conference on Energy Conversion (CENCON), 19-20th October, **2015**

5. M. Hafiz, M. Fairus, Noor Syazwani Mansor, M. Mariatti and ***M. Kamarol***, "Electrical Tree Characteristics with the Addition of Alumina in Silicone Rubber", International Conference on the Properties and Applications of Dielectric Materials (ICPADM), 19-22 July, **2015** (ISBN:978-1-4799-8902-7).

6. M. Fairus, Noor Syazwani Mansor, M. Hafiz, M. Mariatti and ***M. Kamarol***, "Investigation on Dielectric Strength of Alumina Nanofiller with SiR/EPDM Composites for HV Insulator", International Conference on the Properties and Applications of Dielectric Materials (ICPADM), 19-22 July, **2015** (ISBN:978-1-4799-8902-7).

7. Noor Syazwani Mansor, ***M. Kamarol*** and M. Mariatti, "Effect of Nanofiller on Resistance to Tracking and Hydrophobicity of PP/EPDM Blends", School of Electrical and Electronic Engineering 5th Postgraduate Colloquium/EEPC, pp.366-369, **2015** (eISBN: 978-983-52-1012-9).

8. M. Fairus, M. Hafiz, Noor Syazwani Mansor, M. Mariatti and ***M. Kamarol***, "SiR/EPDM Solid Polymeric Blends for AC High Voltage Insulation: A Review of Specimen Preparation Techniques and Dielectric Strength", School of Electrical and Electronic Engineering 5th Postgraduate Colloquium/EEPC, pp.222-227, **2015** (eISBN: 978-983-52-1012-9).

9. M. Hafiz, M. Fairus, M. Mariatti and ***M. Kamarol***, "A Review of Electrical Treeing Trends in Solid Insulators with AC Stress", School of Electrical and Electronic Engineering 5th Postgraduate Colloquium/EEPC, pp.144-148, **2015** (eISBN: 978-983-52-1012-9).

10. Noor Syazwani Mansor, M. Mariatti, ***M. Kamarol***, "Effect of Nanofiller on Resistance to Tracking and Hydrophobicity of PP/EPDM Blends", International Conference on Condition Monitoring and Diagnosis, PE16, pp.217-220, 2014.