

A STUDY OF EPOXY NANOCOMPOSITES INSULATING MATERIALS
AND ITS EFFECTS ON ELECTRICAL TREE PROPAGATION

MOHD HAFIEZ IZZWAN BIN SAAD

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2013

Special dedicated to
My beloved parents (Ummi & Walid)
Haji Saad Bin Arifin
&
Hajjah Siti Esah Binti Yusoff

My Siblings
Muhammad Redzuan, Muhamad Adzahan, Mohd Faiez Sofwan,
Intan Fatim Munirah, Luqman Farhan, Syafiq Aiman

For your unwavering love, sacrifice, patience, encouragement and
inspiration

ACKNOWLEDGEMENT

ALHAMDULILLAH, with the helped from Allah (S.W.T) the Almighty, this project was completed successfully. All praises, my sincere and deepest thankful be to Allah (S.W.T), and may His peace and blessings be upon the Prophet Muhammad S.A.W (peace be upon him).

First and foremost, in particular, I wish to express my special appreciation to my master's project supervisor, Dr. Yanuar Zulardiansyah Arief for his encouragement, guidance, friendly advice and motivation I received from him especially in my master programme and as my lecturer. I am very grateful to have him as my supervisor in helping me for the completion of this project and thesis. May Allah (S.W.T.) reward and bless him greatly.

Special thanks are dedicated to all who have helped me in this project from any kind of angle: Mr. Mohd Hafizi Ahmad, Mr. Aulia, Mr. Abdul Azim, Miss Wan Akmal Izzati, all lecturers, supporting staffs from IVAT, faculty managements and also my colleagues who always act as my backbone when I needed them most during my trouble.

Last but not least, I would like to express my sincere appreciation to my beloved family and siblings for their financial support and encouragement that made me strong and motivated enough to accomplish my master degree. Finally, thank you for all the people that contribute direct or indirectly to finish this thesis. May Allah bless and return your good deeds.

ABSTRACT

Polymeric insulating materials have attracted wide interest especially in high voltage equipments due to its potential properties enhancement. One of the main phenomena of partial discharges occurred in polymeric insulating material is electrical treeing phenomena. This kind of phenomena will cause excessive electric field stress at points where void and defects located. This thesis presents the thorough analysis of electrical treeing phenomena in epoxy nanocomposites. Epoxy resin nanocomposites containing 1 wt% and 3 wt%, of nanofillers sized organically modified montmorillonite (OMMT) nanoclay and silicon dioxide (silica) nanofillers were prepared and investigated, with unfilled epoxy resin served as reference material. The nanocomposites were prepared by using leaf-like specimen's method and online monitoring method was used to test the samples. Electrical insulating properties, mainly the electrical tree resistance were investigated based on to IEC 1072:1991, "Methods of Test for Evaluating the Resistance of Insulation Materials against the Initiation of Electrical Trees". There are three main parameters were collected during experiment was conducted which are tree inception voltage (TIV), tree breakdown voltage (TBV) and tree propagation time (TPT). Field emission scanning electron microscope (FESEM) was performed to determine the dispersion state of nanoclay epoxy resin nanocomposites. Based on the results, it was found that the existence of OMMT and silica nanofillers in polymer matrix could exhibit electrical tree growth. Furthermore, the presence of OMMT nanoclay in epoxy resin make tree growth faster compared the presence of silica nanofillers in epoxy resin.

ABSTRAK

Polimer bahan penebat telah menarik minat yang luas terutamanya dalam peralatan voltan tinggi kerana potensinya untuk menambahbaik ciri-cirinya. Salah satu fenomena utama dalam pelepasan separa penebat pada bahan penebat polimer adalah fenomena elektrik treeing. Fenomena ini akan menyebabkan tekanan medan elektrik yang berlebihan di tempat-tempat di mana wujudnya ruang kecil dan kecacatan pada bahan tersebut. Tesis ini membentangkan analisis yang menyeluruh mengenai fenomena elektrik treeing pada epoksi nanokomposit. Epoksi nanokomposit yang mengandungi 1% dan 3% tanah liat bersaiz nano (nanoclay) dan silikon dioksida (silica) bersaiz nano telah disediakan dan disiasat, di mana epoksi tanpa nanoclay dijadikan sebagai bahan rujukan. Nanokomposit telah disediakan dengan menggunakan kaedah *leaf-like* spesimen dan kaedah pemantauan terus untuk menguji sampel. Sifat penebat elektrik, terutamanya rintangan elektrik treeing telah disiasat berdasarkan IEC 1072:1991, "Kaedah Ujian untuk Menilai Rintangan Bahan Penebat terhadap Permulaan Elektrik Treeing". Terdapat tiga parameter utama dikumpul semasa eksperimen dijalankan iaitu voltan penubuhan treeing (TIV), voltan pecahan treeing (TBV) dan masa perambatan treeing (TPT). *Field emission scanning electron microscope* (FESEM) telah dijalankan untuk mengkaji keadaan campuran nanoclay di dalam epoksi nanokomposit. Berdasarkan keputusan yang diperolehi melalui eksperimen dan analisa yang dibuat, telah didapati bahawa kewujudan nanoclay OMMT dan nano silica di dalam matriks polimer boleh menyekat pertumbuhan elektrik treeing. Tambahan pula, kehadiran nanoclay OMMT dalam epoksi membuatkan pertumbuhan elektrik treeing lebih cepat berbanding kehadiran nano silica di dalam epoksi nanokomposit.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF ABBREVIATIONS AND SYMBOLS	xiv
	LIST OF APPENDICES	xvi
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objectives	2
	1.4 Scope of the Project	3
	1.5 Research Flow Chart	4
	1.5.1 Research Flow Chart Part One	4
	1.5.2 Research Flow Chart Part Two	6
	1.6 Thesis Organization	8
2	LITERATURE REVIEW	10
	2.1 Introduction	10
	2.2 Partial Discharge	10
	2.3 Electrical Treeing	12

2.4	Polymer Nanocomposites	14
2.5	Research Materials	16
2.5.1	Base Resin – Epoxy Resin	16
2.5.2	Nanofiller	17
2.5.3	Nanofiller – Organically Modified Montmorillonite Clay	18
2.6	Morphological Analysis	19
2.7	Comparative Studies on previous research of polymer nanocomposites	19
3	METHODOLOGY	21
3.1	Introduction	21
3.2	Chemical Materials	21
3.3	Preparation of Samples	23
3.3.1	Preparation of Samples Prior to Casting Process	25
3.4	Needle Tip Formation	26
3.5	Sample Preparation Technique for Pure Epoxy Resin	28
3.6	Sample Preparation Technique for Epoxy Nanocomposites	29
3.6.1	Nanofillers Preparation	30
3.6.2	Weighing Process	30
3.6.3	Mixing and Stirring Process	31
3.6.4	Sonication Process	32
3.6.5	Mixing with Hardener	34
3.6.6	Degasification Process	34
3.6.7	Casting and Curing Process	35
3.6.8	Cleaning Process	35
3.7	Field Emission Scanning Electron Microscopy (FESEM) Characterization Technique	36
3.8	Experimental Setup	37
3.8.1	Treeing Testing Setup	38
3.8.2	Software Monitoring System	39

3.8.3	Treeing Testing Procedure	40
3.9	Conclusion	43
4	RESULTS AND DISCUSSIONS	44
4.1	Introduction	44
4.2	Electrical Tree Analysis	45
4.2.1	Tree Inception Voltage	46
4.2.2	Tree Breakdown Voltage	52
4.2.3	Tree Propagation Time	58
4.3	Morphological Analysis	65
4.3.1	Dispersion State of Nanofillers under Microscope	65
4.3.2	Dispersion State of Nanofillers under Field Emission Scanning Electron Microscopy (FESEM) Image	66
4.3.2.1	Dispersion State of Pure Epoxy Resin	66
4.3.2.2	Dispersion State of Epoxy/OMMT 1 wt%	67
4.3.2.3	Dispersion State of Epoxy/OMMT 3 wt%	68
4.3.2.4	Dispersion State of Epoxy/Silica 1 wt%	69
4.3.2.5	Dispersion State of Epoxy/Silica 3 wt%	70
4.4	Conclusion	71
5	CONCLUSION AND RECOMMENDATIONS	73
6.1	Conclusions	73
6.2	Recommendations	74
	REFERENCES	75
	APPENDICES A - F	80 - 92

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Classification of Some Commercial Synthetic Polymers [4]	15
2.2	Current development of polymer nanocomposites [20]	16
3.1	Details of Materials	22
3.2	Fraction distribution of test samples	25
4.1	TIV Value of Pure ER, ER-OMMT 1% and ER-OMMT 3%	47
4.2	TIV Value of Pure ER, ER-Silica 1% and ER-Silica 3%	48
4.3	TBV Value of Pure ER, ER-OMMT 1% and ER-OMMT 3%	54
4.4	TBV Value of Pure ER, ER-Silica 1% and ER-Silica 3%	54
4.5	Tabulated data of tree propagation time for pure epoxy resin, ER-OMMT 1% and ER-OMMT 3%	60
4.6	Tabulated data of tree propagation time for pure epoxy resin, ER-Silica 1% and ER-Silica 3%	61

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Flow Chart for part one	5
1.2	Flow Chart for part two	7
2.1	Partial Discharge within the insulation system [5]	11
2.2	Electrical Tree in Epoxy Resin	13
2.3	Electrical tree growth through the polymer nanocomposites: (a) without contacting the nanoparticles (b) make a contact with nanoparticles, without break in the fillers (c) contacting the nanoparticles, dwelling at their surfaces [6]	14
2.4	Illustrations of polymer nanocomposites [21]	17
3.1	Epoxy Resin	22
3.2	Epoxy Curing Agent	22
3.3	Hydrophobic OMMT	23
3.4	Fumed Silica	23
3.5	Configuration of leaf-like specimen with a) schematic diagram of side view, b) schematic diagram of top view and c) top view of real specimen after casting and curing process	24
3.6	Leaf like specimens prior to casting process	26
3.7	Schematic diagram for the needle tip formation processes using Sodium Hydroxide (NaOH) solution	27
3.8	Needle tip formation process	28
3.9	Process flow of epoxy nanocomposites samples preparation	29
3.10	Radwag ASX 220 analytical balance	31
3.11	Magnetic Stirrer	31

3.12	Compounds of (a) ER-OMMT 3% (b) ER-Silica 3%	32
3.13	(a) Fisher FB-705B ultrasonic dismembrator (b) display screen interface of FB-705B ultrasonic dismembrator control panel	33
3.14	a) Compounds of ER-OMMT 3% (b) Compounds of ER-Silica 3%	33
3.15	Vacuum pump system setup configuration	34
3.16	The compounds inside the small container	35
3.17	(a) Acetone (b) Air Compressor	36
3.18	(a) FESEM machine from Philips XL40 (b) Auto fine coater from JEOL	37
3.19	Set-up of camera-equipped online monitoring system for electrical treeing studies schematic diagram [14]	38
3.20	Treeing testing setup and monitoring system	39
3.21	Interface of “ <i>CellSens Standard</i> ”	40
3.22	Real time monitoring of electrical tree growth	40
3.23	Images of electrical tree initiation roughly exceeds 10 μm	41
3.24	Images of electrical tree successfully bridge the electrode gaps	41
3.25	The electrical tree growth reach 80 % of the electrode gap	42
3.26	Cellsens Standard’s Toolbar consists of main parameters for tree propagation time analysis	43
4.1	Branch-type tree	45
4.2	Bush-type tree	45
4.3	Bush-branch type tree	45
4.4	Tree Inception in (a) Pure Epoxy Resin (b) ER-OMMT 1% (c) ER-OMMT 3% (d) ER-Silica 1% (e) ER-Silica 3%	47
4.5	TIV of pure ER, ER-OMMT 1% and ER-OMMT 3%	49
4.6	TIV of Pure ER, ER-Silica 1% and ER-Silica 3%	49
4.7	TIV of Pure ER, ER-OMMT 1% and ER-Silica 1%	50
4.8	TIV of Pure ER, ER-OMMT 3% and ER-Silica 3%	51
4.9	TIV of Pure ER, ER-OMMT 1%, ER-OMMT 3%, ER-Silica 1% and ER-Silica 3%	52
4.10	Tree breakdown image in (a) Pure Epoxy Resin (b) ER-OMMT 1% (c) ER-OMMT 3% (d) ER-Silica 1% (e) ER-Silica 3%	53
4.11	TBV of Pure ER, ER-OMMT 1% and ER-OMMT 3%	55
4.12	TBV of Pure ER, ER-Silica 1% and ER-Silica 3%	56

4.13	TBV of Pure ER, ER-OMMT 1% and ER-Silica 1%	57
4.14	TBV of Pure ER, ER-OMMT 3% and ER-Silica 3%	57
4.15	TBV of Pure ER, ER-OMMT 1%, ER-OMMT 3%, ER-Silica 1% and ER-Silica 3%	58
4.16	Tree propagation image in (a) Pure Epoxy Resin (b) ER-OMMT 1% (c) ER-OMMT 3% (d) ER-Silica 1% (e) ER-Silica 3%	59
4.17	TPT vs. TIV of Pure ER, ER-OMMT 1% and ER-OMMT 3%	62
4.18	TPT vs. TIV of Pure ER, ER-Silica 1% and ER-Silica 3%	63
4.19	TPT vs. TIV of Pure ER, ER-OMMT 1% and ER-Silica 1%	63
4.20	TPT vs. TIV of Pure ER, ER-OMMT 3% and ER-Silica 3%	64
4.21	TPT vs. TIV of Pure ER, ER-OMMT 1%, ER-OMMT 3%, ER-Silica 1% and ER-Silica 3%	64
4.22	Dispersion image of ER-OMMT 3% under microscope (a) After stirring process (b) After sonication process	65
4.23	Dispersion image of ER-Silica 3% under microscope (a) After stirring process (b) After sonication process	66
4.24	FESEM Image of Pure Epoxy resin (a) 30X Magnification (b) 100X Magnification (c) 10000X Magnification	67
4.25	FESEM image of Filled ER-OMMT 1% (a) 30X Magnification (b) 100X Magnification (c) 10000X Magnification	68
4.26	FESEM Image of Filled ER-OMMT 3% (a) 30X Magnification (b) 100X Magnification (c) 20000X Magnification	69
4.27	SEM Image of Filled ER-Silica 1% (a) 50X Magnification (b) 100X Magnification (c) 5000X Magnification	70
4.28	SEM Image of Filled ER-Silica 3% (a) 35X Magnification (b) 1000X Magnification (c) 2000X Magnification	71

LIST OF ABBREVIATIONS AND SYMBOLS

ER	-	Epoxy Resin
OMMT	-	organo-Montmorillonite
SiO ₂	-	Silicon Dioxide/ Silica
TIV	-	Tree Inception Voltage
TBV	-	Tree Breakdown Voltage
TPT	-	Tree Propagation Time
DC	-	Direct Current
AC	-	Alternating Current
FESEM	-	Field Emission Scanning Electron Microscopy
SEM	-	Scanning Electron Microscopy
TEM	-	Transmission Electron Microscopy
NaOH	-	Sodium Hydroxide
wt%	-	weight percentage
CCD	-	Charge Coupled Device
IEC	-	International Electrotechnical Commission
kVA	-	kilo-Volt Ampere
kA	-	kilo-Ampere
kV	-	kilo-Volt
kg	-	kilogram
L	-	Litre
Mpa.s	-	Megapascal-second
lb/cu.ft	-	pounds per cubic foot
mm	-	mili-meter
μm	-	micro-meter
°C	-	degree celcius
±	-	tolerance plus minus

mmHg	-	millimeters of mercury
rpm	-	rounds per minute
Ω	-	ohm
W	-	watt

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Technical data sheet of Epikure Resin 1007	80
B	Technical data sheet of Epikure Curing Agent	82
C	Technical data sheet of Nanomer nanoclay 1.30P	86
D	Technical data sheet of Fumed Silica from Sigma Aldrich	88
E	Gantt Chart for semester 1 and semester 2	91
F	Certificate of paper publication in Asian Conference on Electrical Discharge (ACED) 2012	92

CHAPTER 1

INTRODUCTION

1.1 Introduction

Cables have been used in power system networks since the early day of the existence electrical power industry. Electrical power industry will transmit and distribute electricity either by overhead line cables or underground cables. Nowadays, in urban areas, it is become an essential to transmit the electricity by using high voltage underground cable due to safety, reliability, low maintenance cost, better general appearance and so on. As a result, the development of the insulating and manufacturing techniques has improved over the years.

The cable insulation usually consists of impregnated paper, synthetic polymers and compressed gases. Polymer insulated cables was first introduced in the 1960s [1]. At present, polymeric cable are widely used as insulating material in various industries. However, for long periods of time, polymeric cables may be exposed to the aging and degradation of electrical insulation system. This can happen when exposed to continuous high voltage excitation for a long time. Such phenomena cannot be tolerated and efficient steps should be taken to prevent any damage.

1.2 Problem Statement

Polymeric insulators are preferred in many applications as they are easy to fabricate in complicated shapes and also area tough, lightweight, and possess excellent dielectric properties. However, their service on high voltage networks is coupled with the processes of degradation due to erosion and defects. Early stage detection of ageing and degradation is very important parameter to measure the performance of insulator in various polymeric insulating materials.

Nowadays, it is found that, a variety of polymeric insulating material has been developed. This includes three classes of materials are in significant use: epoxy resin, hydrocarbon elastomers and silicone elastomers. Additionally, the usage of nanofillers mix with base resin attracted wide interest among researchers. It is proved that most of polymer nanocomposites are very good insulator to retard electrical treeing activity. However, in term of electrical properties, the partial discharges characteristics of epoxy resin mix with OMMT nanoclay as insulating material is not clear reported yet. Therefore, the investigation of electrical tree propagation in ER/OMMT polymer nanocomposites is really necessary and much remains to be explored.

1.3 Objectives

The objectives of this project have been classified as follows:

- i. To develop the polymer nanocomposite of epoxy resin (ER) with organo-Montmorillonite (OMMT) nanoclay for treeing phenomena analysis.
- ii. To develop the polymer nanocomposite of epoxy resin (ER) with silicon dioxide (SiO_2) nanofiller for treeing phenomena analysis.

- iii. To investigate the effects of nanofillers in polymer nanocomposites ER-OMMT and ER- SiO₂ based on the inception and propagation of electrical treeing under HVAC stress.
- iv. To make comparative analysis between ER-OMMT and ER- SiO₂ in term of electrical analysis and morphological analysis.

1.4 Scope of Project

Before doing any analysis and experiment setup, literature review is needed to provide a good theory and understanding. The input knowledge can be obtained in various resources such as books, journals, internet, and papers. This project is primarily focused on developing the new polymer nanocomposites ER-OMMT and make comparison in term of electrical performance with existing ER- SiO₂.

After all the leaf like specimens sample was developed, the experiment will conducted using online monitoring technique and the electrical data will be collected. Electrical treeing parameter such as tree inception voltage, tree breakdown voltage and tree propagation time will be analyzed and comparative results will be made between nanocomposites.

In addition, morphological analysis will also be taken to review the fractured surface structure of material. Results obtained will be discussed in detail and finally, the involvement of the conference paper is taken into account.

1.5 Research Flow Chart

The research flow chart can be divided by two parts. First is research flow chart part 1 which is a framework for first semester while research flow chart part 2 is work plan for the second semester.

1.5.1 Research Flow Chart Part One

First of all, an in-depth literature study will be carried-out on electrical treeing initiation and growth, electrical insulation material degradation caused by discharges, nanofillers and microfillers that has been used by researchers globally. After that, solid insulating materials for test sample (ER-OMMT and ER-SiO₂) with different concentrations of nanofiller were made by using leaf-like specimen's method. Then, experimental setup was constructed using online monitoring method and base epoxy resin leaf like specimens were tested. Lastly, electrical treeing parameters will observe and all data collected will be discussed. The flow chart for part one can be shown in Figure 1.1

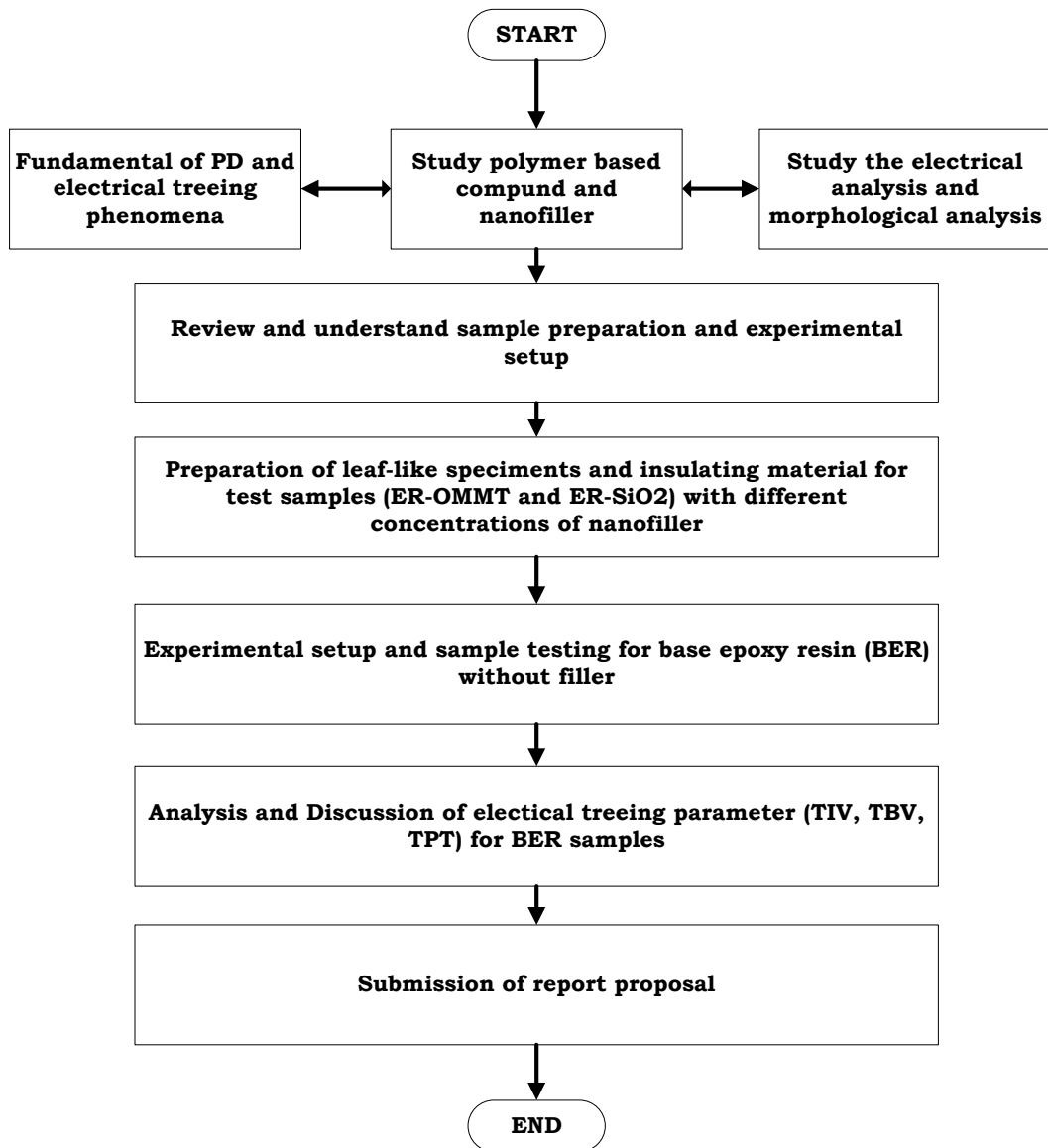


Figure 1.1: Flow Chart for part one.

1.5.2 Research Flow Chart Part Two

The work for part two will be started with experimental setup and testing for the remaining samples of filled ER/OMMT and filled ER/Silica. After that, electrical treeing parameters will observe and all data collected will be discussed. Then, the sample will observe using FESEM for dispersion state characterization purpose. With this characterization technique used, the condition of the prepare nanocomposites can be carefully observed, especially dispersion of nanoparticles in base polymer resin. After that, all data collected will be discussed and summarized. Lastly, preparation for paper or related publications will be made based on result obtained during experiment. Figure 1.2 shows the flow chart for part two.

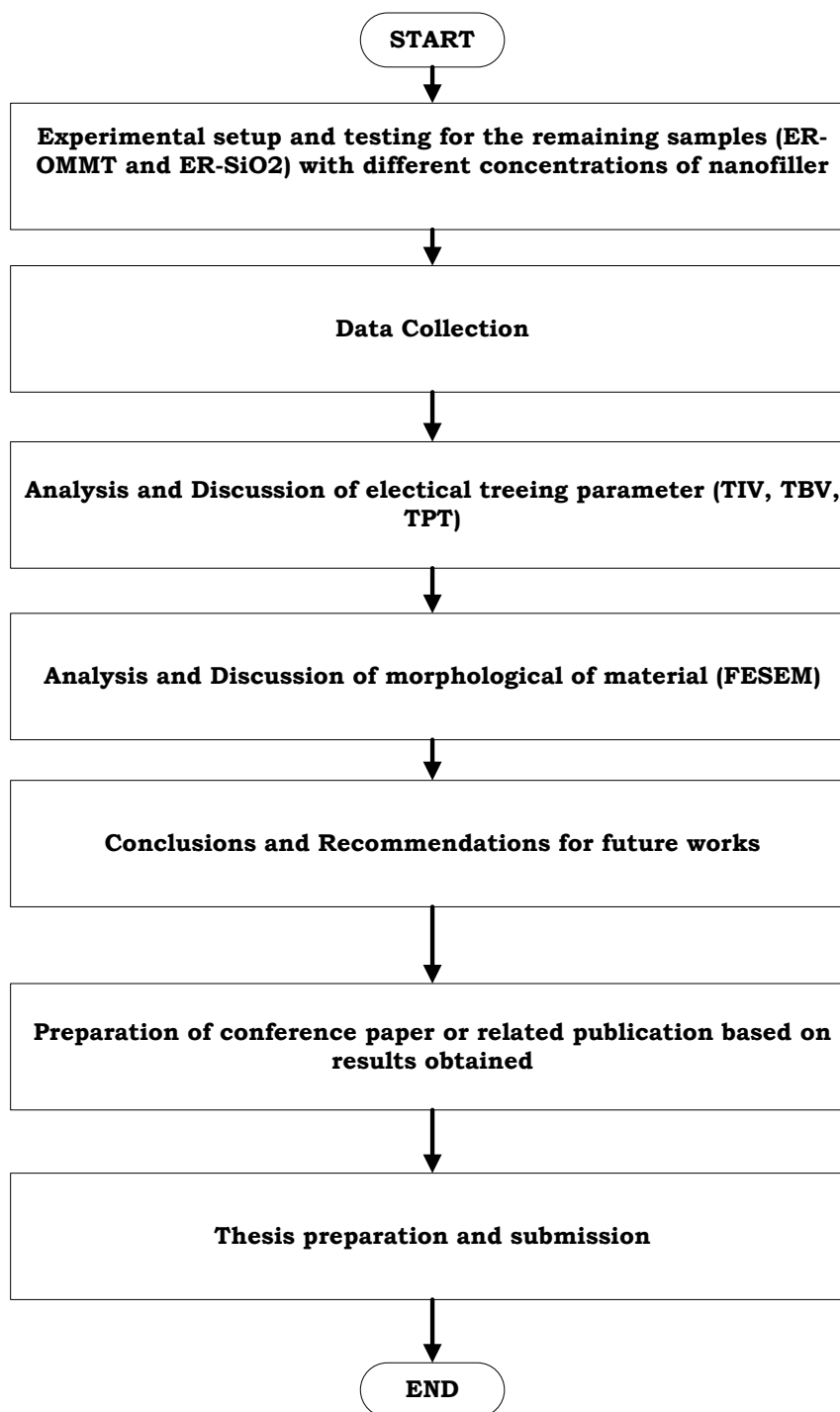


Figure 1.2: Flow Chart for part two.

1.6 Thesis Organization

Chapter 1: Introduction

This chapter describes the overview of this project. Besides that, problem statement of this project mainly described earlier at this chapter followed by objectives and the scope of project and lastly the research flow chart for both part 1 and part 2.

Chapter 2: Literature Review

Literature review contained all the basic information about partial discharge, and electrical treeing phenomena. Apart from that, there are also brief concept and context regarding research materials. This chapter also gives a brief introduction about morphological analysis in this project. Lastly, comparative studies were made based on previous research in polymer nanocomposites field.

Chapter 3: Methodology

This chapter describes about operation and methodology used in this project. The main content of this chapter is a details discussion on how the sample preparations were done and how the samples were characterized using FESEM. Lastly, this chapter also gives detail information on how the test and analysis were conducted in this project including the experimental setup and parameter used.

Chapter 4: Results and Discussions

The experimental results of electrical treeing test will be discussed thoroughly in this chapter. After that, the dispersion state obtained from under microscope observation and under FESEM equipments will be shown and discussed properly. Besides, discussion on data pattern will be displayed and comparisons between epoxy nanocomposites are then presented as well.

Chapter 5: Conclusions and Recommendations

Chapter 5 will concluded the work based on the result and discussion obtained from this project and suggested some recommendation for future work improvement and development related from this project.

REFERENCES

1. T. Miyashita (1969). "Deterioration of Water-Immersed Polyethylene Coated Wire by Treeing" *Proceedings 1969 IEEE-NEMA Electrical Insulation Conference*. September. Boston , 131-135.
2. IEC Publication 60270, Ed 3.0. "*High Voltage Test Techniques – Partial Discharge Measurement*", Ed. 2, 2000.
3. Hugh M. Ryan, "*High Voltage Engineering and Testing*", 2nd Edition, The Institution of Electrical Engineers, London, 2001.
4. N. H. Malik, A. A. Al-Arainy, and M. I. Qureshi, "*Electrical Insulation in Power Systems*", ed. Marcel Dekker INC, New York, 1998.
5. G. Paoletti and A. Golubev," Partial Discharge Theory and Applications to Electrical Systems", *TAPPI Conference 1999*.
6. M.G.Danikas and T. Tanaka, " Nanocomposites - A review of Electrical Treeing and Breakdown", *IEEE electrical Insulating Magazine*, Vol. 25, 2012, pg 19-25.
7. N.H. MALik, A.A.Al-Abdullah,A.A.AL-Arainy and M.I.Qureisy, "Factors Influencing Electrical Treeing in XLPE Insulation" *European Transactions on Electrical Power*. Vol 16, pp. 205-208, 2006.
8. M. H. Ahmad, A. A. A. Jamil, M. Kamarol, Y. Z. Arief, M. Mariatti,M. U. Wahit, M.A.M Piah, H. Ahmad, "Comparative Studies of Nanofiller in High Voltage Electrical Insulation." *Elsevier*. 2012
9. M.H. Ahmad, M. F. Dolmat, N. Bashir, H. Ahmad, A.A.A. Jamil," Effects of Oil Palm Empty Fruit Bunch Filler on the Electrical Tree Propagation in Silicone Rubber" *2nd International Conference on Chemistry and Chemical Process*, 2012.

10. M. H. Ahmad, H. Ahmad, Y. Z. Arief, R. Kurnianto, "Effects of Oil Palm Shell Filler on Inception and Propagation of Electrical Treeing in Silicone Rubber Composite Material Under AC Voltage," *IREE* Vol. 4 No. 2 2011.
11. J.H. Mason, "The deterioration and Breakdown of dielectrics resulting from internal discharges", *Proc. IEE* 98; 1951: 44-59.
12. L. A. Dissado and J. C. Fothergill, "*Electrical Degradation and Breakdown in Polymers*", ed. G. C. Stevens, Peter Peregrines, London, 1992.
13. A.L. Barclay and G.C. Stevens, "Statistical and Fractal Characteristics of Simulated Electrical Tree Growth", *Dielectric Materials, Measurements and Applications, Sixth International Conference*, 1992, pp. 17-20.
14. M. H. Ahmad, H. Ahmad, N. Bashir, Z. A. Malek, Y. Z. Arief, R. Kurnianto, "Statistical Study on Tree Inception Voltage of Silicone Rubber and Epoxy Resin", *Conference on Electrical Engineering and Informatics*, 2011, Bandung, Indonesia.
15. K.Y. Lau and M.A.M Piah, "Polymer Nanocomposites in High Voltage Electrical Insulation Perspective: A Review", *Malaysian Polymer Journal*, Vol. 6, No. 1, 2011, 58-69.
16. Hussain, F., Hojjati, M., Okamoto, M., and Gorga, R. E., "Review article: Polymermatrix nanocomposites, processing, manufacturing, and application: An overview", *Journal of Composite Materials*, 40 (17), 1511-1575 (2006).
17. Lewis, T. J., "Nanometric Dielectrics", *IEEE Transactions on Dielectrics and Electrical Insulation*. 1994. 1(5): 812-825.
18. Henk, P. O., Kortsens, T. W. and Kvarts, T., "Increasing the Electrical Discharge Endurance of Acid Anhydride Cured DGEBA Epoxy Resin by Dispersion of Nanoparticle Silica", *High Performance Polymers*. 1999. 11(3): 281-296.
19. Nelson, J. K. and Fothergill, J. C., "Internal Charge Behaviour in Nanocomposites", *Nanotechnology*, 2004. 15(5): 586-595.
20. Nelson, J. K., "Overview of Nanodielectrics: Insulating Materials of the Future", *2007 Electrical Insulation Conference and Electrical Manufacturing Expo*. Nashville, TN. 2007. 229-235.

21. Lau Kwan Yiew (2010). *Electrical insulating characteristics of polymer nanocomposites for high voltage applications*. Master of Electrical Engineering, Universiti Teknologi Malaysia, Skudai.
22. Tanaka, T., Montanari, G. C., and Mülhaupt, R., "Polymer nanocomposites as dielectrics and electrical insulation- perspectives for processing technologies, material characterization and future applications". *IEEE Transactions on Dielectrics and Electrical Insulation*, 11 (5), 763-784 (2004).
23. M. Nagao, K. Oda, K. Nishioka, Y. Muramoto and N. Hozumi, "Effect of filler on treeing phenomenon in epoxy resin under AC voltage", *Electrical Insulating Materials*, 2001. (ISEIM 2001). *Proceedings of 2001 International Symposium*", 2001, 611-614.
24. R. Kurnianto, Y. Murakami and M. Nagao (2008). "Investigation of Filler Effect on Treeing Phenomenon in Epoxy Resin under ac Voltage". *IEEE Transactions on Dielectrics and Electrical Insulation*. 15 (4) 1112- 1119.
25. Y. Chen, T. Imai, Y. Ohki, T. Tanaka, "Tree Initiation Phenomena in Nanostructured Epoxy Composites," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 17, no. 5, pp. 1509–1515, 2010.
26. Bhattacharya, S. N., Gupta, R. K., and Kamal, M. R. "Polymeric Nanocomposites: Theory and Practice." Germany: Carl Hanser Verlag. 2008.
27. Alexandre, M. and Dubois, P., "Polymer-layered Silicate Nanocomposites: Preparation, Properties and Uses of New Class of Materials", *Material Science Engineering*. 2000. 28: pp 1-63.
28. R. Kurnianto, Y. Murakami, N. Hozumi and M. Nagao (2007). "Characterization of Tree Growth in Filled Epoxy Resin: The Effect of Filler and Moisture Contents". *IEEE Transactions on Dielectrics and Electrical Insulation* 14 (2) 427-435.
29. S. Alapati and M. Joy Thomas (2008). "Electrical Treeing in Polymer Nanocomposites". *Fifteenth National Power Systems Conference (NPSC)*, IIT Bombay 351-355.

30. S. Raetzke, Y. Ohki, T. Imai, T. Tanaka and J. Kindersberger (2009). "Tree Initiation Characteristics of Epoxy Resin and Epoxy/Clay Nanocomposite". *IEEE Transactions on Dielectrics and Electrical Insulation*. 16 (5) 1473-1480.
31. Huicheng Shi, Naikui Gao, Haiyun Jin, Gang Zhang, Zongren Peng, "Investigation of the Effects of Nano-filler on Dielectric Properties of Epoxy Based Composites" ,*Proceedings of the 9th International Conference on Properties and Applications of Dielectric Materials* July 19-23,2009, H-19.
32. H. Z. Ding and B. R. Varlow (2004). "Effect of Nano-Fillers on Electrical Treeing in Epoxy Resin Subjected to AC Voltage". *Annual Report Conference on Electrical Insulation and Dielectric Phenomena*. 332-335.
33. F. Guastavino, A. Dardano, G.C. Montanari, L. Testa, F. Bellucci, "Electrical Treeing in EVA-Boehmite and EVA-Montmorillonite Nanocomposites" ,*IEEE Electrical Insulation Conference*, Montreal, QC, Canada (2009) 382-386.
34. Zhang Jinmei, Gao Junguo, Liu Jiayin, Ji Quanquan, Zhang Mingyan, Zhang Xiaohong. "Studies on Electrical Tree and Partial Discharge Properties of PE/MMT Nanocomposites", *Proceedings of 2008 International Symposium on Electrical Insulating Materials*, Japan (2008), pg 311-314.
35. IEC 1072:1991, "Methods Of Test For Evaluating The Resistance Of Insulating Materials Against The Initiation Of Electrical Trees", 1995.
36. M. H. Ahmad, H. Ahmad, N. Bashir, A. A. A. Jamil, M. A. M. Piah, Z. A. Malek, "Electrical Treeing In Silicone Rubber/Organo- Montmorillonite", *IEEE Conference on Electrical Insulation and Dielectric Phenomena*, Montreal, QC, Canada (2012), pg. 898-901.
37. Qi Wang, Peter Curtis, and George Chen, "Effect of Nano-Fillers on Electrical Breakdown Behavior of Epoxy Resin", *2010 Annual Report Conference on Electrical Insulation and Dielectric Phenomena*.

38. M. Kurimoto, H. Okubo, K. Kato, M. Hanai, Y. Hoshina and M. Takei, "Permittivity characteristics of epoxy/alumina nanocomposite with high Particle dispersibility by combining ultrasonic wave and centrifugal force", *IEEE Trans. Dielectr. Electr. Insul.*, Vol. 17, pp.1268-1275, 2010.
39. M. Kurimoto, H. Watanabe, K. Kato, M. Hanai, Y. Hoshina, M. Takei, and H. Okubo, "Dielectric Properties of Epoxy/Alumina Nanocomposite Influenced by Particle Dispersibility", *IEEE Conf. Electr. Insul. Dielectr. Phenomena (CEIDP)*, pp. 706-709, 2008.
40. R. Kochetov, T. Andritsch, U. Lafont, P. H. F. Morshuis and J. J. Smit, "Thermal conductivity of nano-filled epoxy systems", *IEEE Conf. Electr. Insul. Dielectr. Phenomena (CEIDP)*, pp. 658–661, 2009.