BREAKDOWN PROPERTIES OF HIGH DENSITY POLYETHYLENE AND POLYPROPYLENE BLENDS

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DEDICATION

This project report is dedicated to my husband and my kids, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

In high voltage (HV) applications, thermoplastic polymers are preferred to be used as insulators especially in cable technology. Polyethylene (PE) and polypropylene (PP) have been widely used due to their advantages of having good mechanical strength, thermal properties and electrical properties. However, there are weaknesses for each type of polymer (either PE or PP) that can be improved. Degradations and failures of insulators may cause a big impact to high voltage equipment when flashover occurred, thus damaging the equipment. The use of polymer blends may compensate the weaknesses of each polymer. In this paper, thermoplastic polymer blends composed of high density polyethylene (HDPE) and polypropylene (PP) homopolymer were formulated through melt blending method. The breakdown properties of the polymer blends with different compositions were investigated and analysed. Five samples of polymers composed of 100% HDPE, 80% HDPE and 20% PP, 50% HDPE and 50% PP, 20% HDPE and 80% PP, and 100% PP were chosen for investigation purposes. The breakdown results obtained were analysed using Weibull software. The results showed that thermoplastic blends revealed good breakdown performance. These improvements can be transformed into favourable choices and cost effective solutions in electrical power systems.

ABSTRAK

Dalam aplikasi voltan tinggi (HV), polimer lebih disukai untuk digunakan sebagai penebat terutamanya dalam teknologi kabel. Polietilena (PE) dan polipropilena (PP) telah digunakan secara meluas kerana kelebihannya mempunyai kekuatan mekanikal, sifat terma dan sifat elektrik yang baik. Walau bagaimanapun, terdapat kelemahan untuk setiap jenis polimer (sama ada PE atau PP) yang perlu diberi perhatian. Degradasi dan kegagalan penebat boleh menyebabkan kesan besar terhadap peralatan voltan tinggi apabila sambaran voltan berlaku, sekali gus merosakkan peralatan. Penggunaan campuran polimer boleh mengimbangi kelemahan setiap polimer. Di dalam projek ini, campuran polimer termoplastik yang terdiri daripada homopolimer polietilena ketumpatan tinggi (HDPE) dan polipropilena (PP) telah diformulasikan melalui kaedah campuran pencairan. Sifat pecah tebat campuran polimer dengan komposisi yang berbeza telah disiasat dan dianalisis. Lima sampel polimer terdiri daripada 100% HDPE, 80% HDPE dan 20% PP, 50% HDPE dan 50% PP, 20% HDPE dan 80% PP, dan 100% PP telah dipilih untuk tujuan penyiasatan. Hasil kajian pecah tebat yang diperoleh dianalisis menggunakan perisian Weibull. Hasil tersebut menunjukkan bahawa campuran termoplastik menghasilkan kekuatan pecah tebat yang baik. Penambahbaikan ini boleh diubah menjadi pilihan yang baik dan memberikan kos efektif dalam sistem kuasa elektrik.

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LIST OF ABBREVIATIONS

AC	-	Alternating current
ASTM	-	American Society for Testing and Materials
CDF	-	Cumulative Distribution Function
DC	-	Direct current
DMI	-	Digital Measuring Instrument
EPR	-	Ethylene propylene rubber
FMEA	-	Failure mode and effect analysis
FRACAS	-	Failure reporting and analysis
FTA	-	Fault Tree Analysis
HDPE	-	High Density Polyethylene
HVAC	-	High voltage alternating current
HVDC	-	High voltage direct current
IVAT	-	High Voltage High Current
LDPE	-	Low Density Polyethylene
MgO	-	Magnesium oxide
MLE	-	Maximum Likelihood Estimation
MTTF	-	Mean time to failure
NR	-	Natural rubber
OT	-	Operating terminal
PCTFE	-	Polychlorotrifluoroethylene
PE	-	Polyethylene
POE	-	Polyolefin elastomer
PP	-	Polypropylene
PS	-	Polystyrene
PTFE	-	Polytetrafluoroethylene
PVC	-	Polyvinyl chloride
SEBS	-	Styrene Ethylene Butylene Styrene
s-PP	-	Syndiotactic polypropylene
SR	-	Silicone rubber

TPU	-	Thermoplastic polyurethanes
UV	-	Ultraviolet
XLPE	-	Cross-linked Polyethylene

LIST OF SYMBOLS

d	-	thickness
E	-	Breakdown strength
C_2H_6	-	Ethane gas
g	-	gram
Hz	-	Hertz
kV	-	kilovolt
mm	-	millimetre
V	-	Volt
wt	-	weight
%	-	Percentage
^oC	-	Celsius
°F	-	Fahrenheit
α	-	Scale parameter
β	-	Shape parameter
η	-	Characteristic life

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

The technology of insulation in electrical power systems has evolved drastically. The main purpose of an insulator in an electrical power system is to prevent the flow of electric current between two points of different potential and to hold the conductor or busbar at a certain distance from ground. The degradation and failure of solid insulating materials is the most common cause of problems in electrical equipment, which may then result in short circuit, arcing and up to the extent of flashover. This unwanted event is something that many industries wish would never occur. However, an insulator is never perfect and will somehow fail at some point of usage.

The application of many types of insulator in high voltage systems become important and many researchers have been exploring the enhancement of insulator's materials and blending techniques to increase the equipment's reliability. Therefore, polymers have emerged as the best of materials to meet the demand request as one of the power level increased [1]. Crosslinked Polyethylene (XLPE) has been widely used at the highest voltage of AC and DC power system up to 525kV [3]. However, XLPE cannot be recycled and may cause pollution to the environment during its aging end of life [4].

The similarity between all insulator technology study is the focus on the materials used for specific conditions and applications. The types and rates of insulator failures are depending on many contributing factors such as electrical, mechanical and environmental condition. The word "failure" signifies the unexpected or unwanted behaviour which lead to malfunctioning of equipment within the design life period and business upset.

In particular, the studies have been done to get a good breakdown strength with various type of insulator polymer materials such as Polyethylene (PE), Polypropylene (PP), Low Density Polyethylene (LDPE), Low Density Polyethylene (LDPE) and Polypropylene (PP) blends, Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) blends. It is also considered various blending techniques in relation to the influence of additives or metallic load incorporation, various temperature conditions and testing methods.

Through polymerization process of ethylene gas, a long chain polymer can be manufactured called Polyethylene (PE). Nowadays, thermoplastic PE was popular when it was compared with other material such as paper insulated materials because of low cost, good electrical properties and low temperature flexibility. HDPE is considered as one of the best polymers for dielectric applications. However, there are disadvantages of PE on its practical temperature limit of 70 °C [5].

Polypropylene (PP) has been proposed as an alternative material for HVDC cable insulators due to its high melting point and eco-friendly property, better than PE. The mechanical and electrical properties of PP can be further improved at low temperature condition by introducing polyolefin elastomer (POE) and MgO nanoparticles to PP [6].

There are many advantages and disadvantages of each material as insulators. The selection of an insulating material is very important to determine the integrity and lifespan of the insulator so as to achieve reliable and economic operation of a system. Many types of high voltage insulators have been used, such as inorganic (ceramic and glasses) or organic material such as Polyvinyl Chloride (PVC), Polyethylene (PE), Cross-linked Polyethylene (XLPE), Ethylene Propylene Rubber (EPR), Natural

Rubble (NR), Silicon Rubber (SR) and etc. Therefore, in this study, the breakdown strength for polymer blends insulator with different compositions of HDPE and PP was investigated.

1.2 Problem Statement

XLPE insulator has been widely used as a cable insulator of choice for many years. This material has many desirable characteristics but its thermomechanical properties have consequences for both continuous and emergency cable ratings. Many researchers made XLPE as a reference and benchmarking for better improvement in insulator technology.

In 2004, synthesized with homogeneous metallocene catalyst developed called stereoregular syndiotactic Polypropylene (s-PP), blend system based upon High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) [7]. Then research followed by compositional optimization of a propylene homopolymer/propylene-ethylene polymer blends in 2015 compared to Cross-linked Polyethylene (XLPE) breakdown strength [8]. In 2016, thermoplastic blend materials such as High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) blends, Polypropylene (PP) blends can reveal better thermal and electrical performance with respect to XLPE that has significant impact with continuous operating temperature of 90^{o}C [3]. The space charge injection and accumulation which can cause the breakdown and aging of materials are the main problem in development of HVDC cable although PP is known has a better prospect compared than XLPE [9]. Then, in 2017, the modified nanocomposite with addition of MgO effectively suppressed the space charge accumulation compared to PP/SEBS blends and improved the breakdown strength [10].

Although lots of work were done on the use of PP as good alternative to XLPE, little work was done on the breakdown strength of PP when blended with PE. Different compositions of PP/PE blends may result in different breakdown properties, but this is less explored as far as the author was aware.

1.3 Research Goal

1.3.1 Research Objectives

The objectives of the research are:

(a) To formulate thermoplastic polymer blends composed of Polyethylene and Polypropylene.

(b) To investigate the breakdown properties of Polyethylene and Polypropylene blends.

(c) To analyse the breakdown strength of Polyethylene and Polypropylene blends.

1.4 Research Scopes

Polyethylene (PE) and Polypropylene (PP) have been widely used due to its advantages either good mechanical strength, thermal properties or electrical properties. However, there are weaknesses for each homopolymer that need to be compensated. Polymer blending may compensate the weakness of each polymer to become a good insulator material. See in Appendix A for the thread block diagram of previous research paper on breakdown strength. In this paper, combinations Polyethylene and polypropylene with different compositions were used to investigate the breakdown strength of polymer blends.

This research focused on the breakdown properties of Polyethylene (PE) and polypropylene (PP) blends. The Polyethylene used was High Density Polyethylene (HDPE) while the polypropylene used was polypropylene homopolymer. Five types of polymer blends composed of 100% HDPE, 80% HDPE and 20% PP, 50% HDPE and 50% PP, 20% HDPE and 80% PP, and 100% PP were chosen for investigation purposes. The experimental setup based on HVAC and HVDC testing was carried out to observe and record the breakdown properties of each samples. The distribution of dielectric strength will be plotted and analysed using Weibull distribution analysis.

1.5 Contributions

The work gave the following contributions:

(a) Determination of the blending composition percentage between HDPE and PP through melt blending process.

(b) Improved understanding of the breakdown strength of polymer blends with different compositions of HDPE and PP.

(c) Evaluation of dielectric strength distribution using Weibull software.

1.6 Project Timeline

Figure 1.1 shows the project timeline for the project 1 and 2:

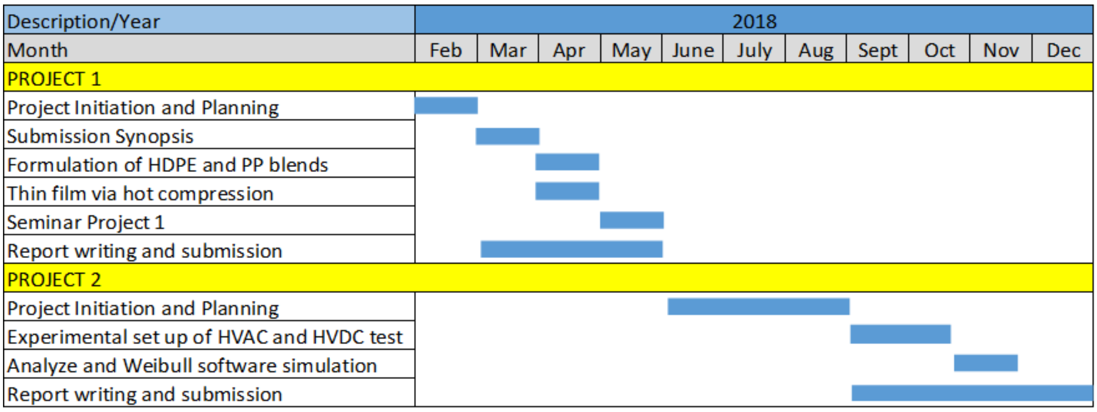

Figure 1.1 The planned schedule of project 1 and 2

REFERENCES

[1] Shengtao Li, Shihu Yu, Yang Feng, "Progress in and prospects for electrical insulating materials," vol. 1, no. 3, pp. 122-129, 2016.

[2] Hualong Zheng, Simon M. Rowland, Ibrahim Iddrissu and Zepeng Lv, "Electrical Treeing and Reverse Tree Growth in an Epoxy Resin," *IEE Transactions on Dielectric and Electrical Insulation,* vol. 24, no. 6, pp. 3966-3973, 2017.

[3] G. C. Stevens and A. Pye, A.s. Vaughan, C. D Green and J. Pilgrim, "High Performance Thermoplastic Cable Insulation Systems," *Proceedings of the 2016 IEEE International Conference on Dielectrics, ICD 2016,* no. IEEE, 2016.

[4] N. H. H. S. K. F. K. T. M. H. Y. T. Takeda, "Space Charge behavior in fullsize 250kV DC XLPE cables," *IEEE Trans. Power Delivery,* vol. 13, no. IEEE, pp. 28-39, 1998.

[5] Metwally, Ibrahim A., "The Evolution of Medium Voltage Power Cables," *IEEE,* vol. 31, no. 3, 2012.

[6] Y. Zhou, J. L. He, J. Hu and B. Dang, "Surface modified MgO nanoparticle enhances the mechanical and DC electrical characteristics of polypropylene/polyolefin elastomer nanodielectrics," *J. Appl. Polym.,* vol. 133, no. 1, 2016.

[7] Yoshino K., Demura T., Kawahigashi M., Miyashita Y., Kurahashi K., Matsuda Y., "Application of a novel polypropylene to the insulation of an electric power cable," vol. 146, no. 1, pp. 18-26.

[8] Green C.D., Vaughan A.S., Stevens G.C., Pye A., Sutton S.J., Geussens T., Fairhurst M.J., "Thermoplastic cable insulation comprising a blend of isotactic polypropylene and a propylene-ethylene copolymer," *IEEE Transactions on Dielectrics and Electrical Insulation,* vol. 22, no. 2, pp. 639-648, 2015.

[9] Zha J.-W., Wang Y., Li W.-K., Wang S.-J., Dang Z.-M., "Electrical properties of polypropylene/styrene-ethylene-butylene-styrene block copolymer/MgO

nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 24, no. 3, pp. 1457-1464, 2017.

[10] Jiang P., Sun X., Huang Y., Bo J., Zhang J., Wu C., "Preparation of MgO/polypropylene insulation nanocomposites and their properties," *Gaodianya Jishu/High Voltage Engineering*, vol. 43, no. 2, pp. 355-366, 2017.

[11] Eesaee M., David E., Demarquette N.R., Fabiani D, "Electrical Breakdown Properties of Clay-Based LDPE Blends and Nanocomposites," *Journal of Nanomaterials*, 2018.

[12] Chao Zhang, Mori Tatsuo, Mizutani Teruyoshi, Ishioka Mitsugu, "Electrical breakdown properties of blend polymers with low density polyethylene and polypropylene," *Proceedings of the IEEE International Conference on Properties and Applications of Dielectric Materials*, vol. 1, pp. 212-124, 2000.

[13] Zhang C., Mizutani T., Kaneko K., Mori T., Ishioka M., "Space charge and conduction in LDPE-polypropylene copolymer blends," *Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), Annual Report*, pp. 28-31, 2001.

[14] Zhang C., Mori T., Mizutani T., Ishioka M., Cheng Y., "Morphology and electrical breakdown properties of LDPE-polypropylene copolymer blends," *Journal of Polymer Science, Part B: Polymer Physics*, vol. 39, no. 15, pp. 1741-1748, 2001.

[15] Hassan A., Wahit M.U., Chee C.Y., "Mechanical and morphological properties of PP/NR/LLDPE ternary blend - Effect of HVA-2," *Polymer Testing*, vol. 22, no. 3, pp. 281-290, 2003.

[16] Zhang C., Mori T., Mizutani T., Ishioka M., "Effects of manufacturing technology on electrical breakdown and morphology of thin films of low density polyethylene blended with polypropylene copolymer," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 10, no. 3, pp. 435-443, 2003.

[17] Anzano J., Bonilla B., Montull-Ibor B., Casas-González J., "Plastic identification and comparison by multivariate techniques with laser-induced breakdown spectroscopy," *Journal of Applied Polymer Science*, vol. 12, no. 5, pp. 2710-2716, 2011.

[18] Ehsani M., Borsi H., Gockenbach E., Bakhshandeh G.R., Morshedian J., Abedi N., "Study of electrical, dynamic mechanical and surface properties of silicone-EPDM blends," *Proceedings of the 2004 IEEE International Conference on Solid Dielectrics ICSD 2004,* vol. 1, pp. 431-434, 2004.

[19] Sugumaran, Ramkumar. R and C. Pugazhendhi, "Investigation on Dielectric Properties of HDPE with Alumina Nano Fillers," 2016.

[20] ASTM D149 - 97a (2004), An American National Standard, "Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies," *Designation: D 149 – 97a (Reapproved 2004)*, 2004.

[21] M. Tsukiji, W. Bitoh, and J. Enomoto, "Thermal degradation and endurance," *IEEE Electr. Insul. Conf,* pp. 88-91, 1990.

[22] Zijing Wang, Robert Freer, Le Fang & Ian Cotton, "Development of Low Temperature Co-fired Ceramic (LTCC) Coatings for Electrical Conductor Wires," *IEEE Transactions on Dielectrics and Electrical Insulation,* vol. 23, no. 1, pp. 158-164, 2016.

[23] L. A. Dissado, "Understanding electrical trees in solids: from experiment to theory," *IEEE Trans. Dielectr. Electr. Insul,* vol. 9, pp. 483-497, 2002.

[24] L. A. Dissado and J. C. Fothergill, "Electrical Degradation and Breakdown in Polymers," *P. Peregrinus Press for IEE, London,* 1992.

[25] Dr. Robert B. Abernethy, "An Overview of Weibull Analysis" - The New Weibull Handbook,, North Palm Beach.

[26] A. P. a. J. L. T. A. S. C. D. G. a. I. L. H. G. C. Stevens, ""Thermoplastic High Performance Cable Insulation Systems for Flexible System Operation,"," *2015 Electrical Insulation Conference (EIC), Seattle, Washington, USA,* 7 -10 June 2015.

[27] R. G. A. Z. a. E. A. P. C. S. S. L. Casterllani, *US patent,* Vols. US-6410651, 2001.

[28] Y. Ohki, ""XLPE recycling technology in Japan"," *IEEE Electr. Insul. Mag,* vol. 25, pp. 48-49, Mar-Apr, 2009.

[29] J. J. B. Y. a. C. I.J.Seo, "“Experimental Investigation on the DC Breakdown of Silicone Polymer Composites Employable to 500kV HVDC Insulator," *1st*

International Conference on Electric Power Equipment and Switching Technology, pp. pp 697-700, 2011.

[30] S. A. Crud and M. Zanin, "“Evaluation of the Incorporation of Recycled Material in the Dielectric Properties of High Density Polyethylene”,," *Proceedings of the 7th Intemational Conference on Properties and Applications of Dielectric Materials* , vol. Nagoya, June 1-5, 2003.

[31] Standard, A, D149, "Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies," *ASTM International, West Conshohocken,PA,* 2009.

[32] Alhabill, F.N, T Andritch and A.S Vaugan, "Effect of the processing method on the electrical behaviour of silicon nitride/ epoxy naocomposites in Electrical Insulation Dielectric Phenomena (CEIDP)," *IEEE Confernce on 2015,* 2015.

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

[34] Tsekmes, IA, et al, "Breakdown strength and electrical conductvity of epoxy cubic boron nitride composites in Electrical Insulation and Dielectric Phenomena (CEIDP)," *IEEE Confernce on 2015,* 2015.

[35] A. M. Farouk, "“Mechanism of insulator flashover under artificial rain”,," *Proc. IEEE,* vol. 122, no. 4, pp. pp 449-454, Apr 1975.

[36] Gilbert Teyssedre and Christian Laurent, "Advances in High-Field Insulating Polymeric Materials Over the Past 50 Years," *IEEE Electrical Insulation Magazine,,* 2013.

[37] Ramkumar. R and C. Pugazhendhi Sugumaran, "Investigation on Dielectric Properties of HDPE with Alumina Nano Fillers," *IEEE,* 2016.