

# Dielectric Strength of Polypropylene/Copolymer Blends

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**Abstract:** Presently, polypropylene (PP), a type of thermoplastic polymer, becomes favorable for use in power cable insulation owing to its better electrical properties over the thermoset crosslinked polyethylene (XLPE). However, PP has a significant issue in term of mechanical properties. Specifically, standalone PP has high stiffness and brittleness. Therefore, adding copolymers into PP is an effective approach to tailor the flexibility of standalone PP. Nevertheless, this often comes with degraded dielectric strength of PP/copolymer blends, particularly with increasing loadings of copolymers. Therefore, this paper investigates the chemical structure and AC and DC breakdown performance of PP with 20 wt% of ethylene-based copolymer (EBC) and 20 wt% of propylene-based copolymer (PBC). The results reveal that the presence of methyl groups of PP/EBC is more pronounced compared to PP/PBC. Meanwhile, the AC breakdown strengths of PP with 20 wt% of EBC and 20 wt% of PBC are comparable at 151 kV/mm and 153 kV/mm respectively, compared to that of XLPE (148 kV/mm). Additionally, PP with 20 wt% of EBC has a comparable DC breakdown strength (317 kV/mm) to XLPE (324 kV/mm) while PP with 20 wt% of PBC has a higher DC breakdown strength (338 kV/mm) over XLPE. Therefore, both the AC and DC breakdown performance of PP with 20 wt% of EBC and 20 wt% of PBC are not inferior over XLPE. These suggest that 20 wt% of EBC and 20 wt% of PBC are appropriate for formulating PP/EBC blend and PP/PBC blend as alternatives to XLPE.

**Keywords:** crosslinked-polyethylene, polypropylene, elastomers, breakdown strength

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## 1. INTRODUCTION

Polymer-based materials are widely used in high voltage insulation systems owing to their excellent electrical properties, including high dielectric strength and low loss [1]. In the power cable industry, crosslinked polyethylene (XLPE) is commonly utilized because of its excellent electrical characteristics, including high electrical strength, low relative permittivity, minimal loss, durable mechanical stability, high solvent resistance, and excellent thermo-mechanical performance [2]. By end of its lifespan, however, recycling of XLPE is challenging because of its thermosetting nature. Its crosslinking process also produces by-products that can be environmentally harmful [3]. Additionally, XLPE's low melting temperature at 110 °C and limited operational temperature at 90 °C make it unsuitable for high-capacity voltage transmission applications [4].

Polypropylene (PP), a thermoplastic material, is currently being explored for high voltage applications due to its advantages over XLPE. PP offers a high melting temperature (170 °C), high mechanical strength, low dielectric loss, and better volume resistivity, allowing cables to carry higher currents and operate at higher voltage levels [5-8]. Unlike XLPE, PP can be easily recycled and does not require crosslinking or degassing processes, leading to more efficient manufacturing. As a result, PP is seen as a promising alternative to XLPE for

insulating power cables.

Nonetheless, PP alone is not appropriate for cable insulation as a consequence of its stiff and brittle mechanical properties. Additionally, PP has a high tensile yield strength and modulus of elasticity, making it unsuitable for cable extrusion [9]. Similarly, isotactic polypropylene (iPP) shares these limitations, despite having a high melting point of around 170 °C [10]. As a result, iPP is also too stiff and brittle for insulation applications. To address these issues, polymer blending with copolymers has been identified as an effective method to enhance the flexibility and overall characteristics of PP [11].

Currently, blending copolymers like propylene-based copolymer (PBC), ethylene-based copolymer (EBC), and ethylene propylene diene monomer (EPDM) with PP has demonstrated potential in reducing PP's mechanical stiffness and brittleness. According to Andritsch et al. [4], blending copolymers with PP increases the maximum operating temperature to as high as 150 °C, which allows for a higher voltage limit compared to the approximately 100 °C limit of XLPE. Similarly, Zhou et al. [12] reported that PP/EBC and PP/PBC blends used for cable insulation have a higher operating temperature than those made from low density polyethylene (LDPE) and high density polyethylene (HDPE). Furthermore, Green et al. [10] reported that a blend containing 50 wt% PP and 50 wt%

ethylene-based copolymer exhibited comparable flexibility at low temperatures and excellent mechanical strength at high temperatures compared to XLPE. Moreover, Gao et al. [13] supported the advantages of PP blends by examining the electro-mechanical characteristics of PP combined with up to 30 wt% polyolefin copolymer. The author found that blending PP with 10 wt% copolymer was effective in producing a PP/copolymer blend with significantly improved flexibility and excellent breakdown strength. In this paper, the effect of blending PP with 20 wt% of copolymers, i.e., EBC and PBC, in term of chemical structure and AC and DC breakdown strength, is discussed for developing potential insulation materials for power cable applications.

## 2. EXPERIMENTAL

### 2.1 Materials

The reference material utilized in this research comprised XLPE, consisting of 98 wt% LDPE grade Titanlene LDF200YZ, produced by Lotte Chemical Titan, and 2 wt% dicumyl peroxide (DCP) grade 329541, manufactured by Sigma Aldrich. PP homopolymer (Titanpro 6531M), sourced from Lotte Chemical Titan, was selected as the base material for the PP blend. EBC (Queo 6800LA grade), produced by Borealis and PBC (Vistamaxx 6202 grade), produced by ExxonMobil, were utilized as copolymers. 20 wt% of each copolymer was selected as the optimal quantity to be blended with the PP base polymer. Table 1, Table 2, and Table 3 specify the properties of XLPE, PP homopolymer, and copolymers, respectively.

Table 1. Properties of XLPE

Properties	Unit	LDPE	DCP
Melting point	°C	>100	39-41
Flash point	°C	260	110
Density	$g/cm^3$	0.922	1.56

Table 2. Properties of PP Homopolymer

Properties	Unit	PP
Melt flow index, MFR (230 °C)	g/10 min	3.5
Density	$g/cm^3$	0.9
Tensile strength at yield	$kg/cm^2$	360
Elongation at yield	%	10

Table 3. Properties of elastomers

Properties	Unit	PBC	EBC
Density	$g/cm^3$	0.862	0.868
Melt flow index	g/10min	20	0.5
Softening temperature	°C	45.2	38

### 2.2 Samples Preparation

Each raw material was initially heated under vacuum at 70 °C for 24 h before being blended with a Brabender mixer to minimize the moisture impact on the raw materials. The Brabender melt mixer operated at a rotational speed of 50

rpm, a temperature of 130 °C, and a duration of 10 min for the preparation of XLPE. Meanwhile, a temperature of 180 °C, a rotational speed of 50 rpm, and a duration of 10 min were used for the preparation of the PP, PP/EBC blend, and PP/PBC blend samples. A Carver laboratory hot press was then employed to fabricate thin films of the samples. To achieve a thickness of approximately 100 µm, PP, PP/EBC, and PP/PBC samples were subjected to heat pressing at 180 °C and 2.5 tons of pressure. Meanwhile, XLPE was subjected to heat pressing at 130 °C at a pressure of 3 tons. Subsequent to heat-pressing, the temperature was elevated to 180 °C and remained for 10 min to facilitate crosslinking. XLPE samples were subjected to a degassing process in a vacuum oven at 70 °C for 72 h to remove crosslinking residues. The sample designations are presented in Table 4.

Table 4. Sample designations

Sample	Elastomer type	Elastomer content
XLPE	-	-
PP	-	-
PP/PBC	PBC	20 wt%
PP/EBC	EBC	20 wt%

### 2.3 Fourier Transform Infrared Spectroscopy

The Fourier transform infrared spectroscopy (FTIR) spectrometer is an efficient instrument for collecting chemical spectra of materials. The infrared spectrum is a specific pattern that indicates the frequencies at which atomic bonds in a material oscillate, functioning as a unique identifier for that sample. A Perkin Elmer Spectrum One Fourier transform infrared (FTIR) spectrometer, fitted with a standard mid-infrared triglycine sulphate (MIRTGS) detector, was utilized to identify chemical content on XLPE, PP, PP/EBC, and PP/PBC. The data are collected within a spectral range of 500  $cm^{-1}$  to 4000  $cm^{-1}$ . This was accomplished by conducting 16 scans at 4  $cm^{-1}$  resolution; the selected parameters were sufficient to identify the presence of chemical contents in the materials. The specimen possessed a thickness of around 100 µm.

### 2.4 AC and DC Breakdown Strength

The AC and DC breakdown tests were performed in line with the specifications detailed in the American Society for Testing and Materials (ASTM) D149 [14] and ASTM D3755 [15] standards, respectively. This study employed BAUR AC/DC high-voltage test equipment rated for 80 kV AC voltage and 110 kV DC voltage for breakdown testing. For each breakdown measurement, AC voltage in step of 1 kV was applied every 20 s until the specimen experienced breakdown, and DC voltage in step of 2 kV was applied every 20 s until the specimen experienced breakdown. The test samples possessed a nominal thickness of 100 µm. The specimen was inserted between two steel-ball terminals, each with 6.3 mm diameter, and submerged in silicone oil to mitigate surface discharge. The minimum distance between two breakdown points was 10 mm to prevent surface flashover. Figure 1 and Figure 2 demonstrate the representative circuit diagram of the AC and DC breakdown test setups, respectively. The setup for AC breakdown included a transformer, a

regulator, a capacitive voltage divider, and a current-limiting resistor. For DC breakdown, an additional rectifying circuit was included.

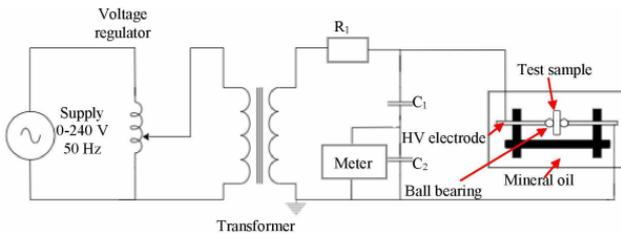


Figure 1. Representative circuit diagram of AC breakdown setup

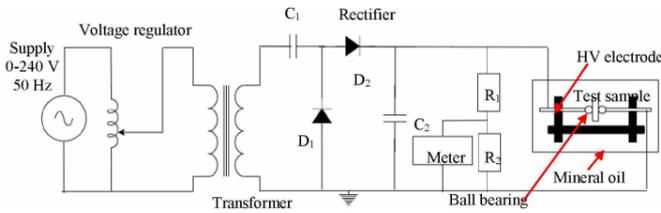


Figure 2. Representative circuit diagram of DC breakdown setup

15 breakdown readings were obtained for each sample according to Equation (1), where  $E$  represents breakdown strength in kV/mm,  $V_{bd}$  indicates breakdown voltage in kV, and  $d$  represents sample thickness in mm. The breakdown performance of XLPE, PP, PP/EBC, and PP/PBC were assessed using the Weibull distribution, as outlined in Equation (2), where  $E$  represents the breakdown strength,  $\alpha$  denotes the scale parameter representing the breakdown strength determined at 63.2% probability of failure, and  $\beta$  signifies the shape parameter representing the distribution of the experimental breakdown data. The Weibull distribution was used due to its ability to perform reliability data analysis from breakdown strength test.

$$E = \frac{V_{bd}}{d} \quad (1)$$

$$P(E) = 1 - e^{-\left(\frac{E}{\alpha}\right)^\beta} \quad (2)$$

### 3. RESULTS AND DISCUSSION

#### 3.1 Chemical Analysis

Figure 3 shows the FTIR spectra of XLPE, PP, and PP/copolymer blends containing EBC and PBC. As a reference material, XLPE exhibited absorption bands at  $723 \text{ cm}^{-1}$  and  $1461 \text{ cm}^{-1}$ , indicating the bending vibration of -CH group reaction with crosslinking agent in polyethylene chains. The absorption bands between  $2832 \text{ cm}^{-1}$  and  $2964 \text{ cm}^{-1}$  demonstrated the stretching vibration of methylene groups of polyethylene chains [16, 17]. Based on previous research [18], the absorption bands of PP from  $2823 \text{ cm}^{-1}$  until  $2970 \text{ cm}^{-1}$  indicated the stretching vibration of -CH groups of PP while the absorption peak from  $809 \text{ cm}^{-1}$  to  $1454 \text{ cm}^{-1}$  pointed out the bending vibration of -CH groups of PP. The blending of EBC or PBC on PP did not significantly affect the FTIR spectra

obtained from the resulting blend. For instance, it can be seen that stretching vibrations of -CH groups in PP at absorption bands between  $2823 \text{ cm}^{-1}$  and  $2970 \text{ cm}^{-1}$  is similar with PP/EBC and PP/PBC. However, the presence of EBC and PBC on PP can be observed through absorption peaks at  $720 \text{ cm}^{-1}$  indicating bending vibration of -CH groups. This observation corresponds to the previous research [19, 20], in which the absorption band at  $720 \text{ cm}^{-1}$  could be ascribed to -CH groups of copolymers.

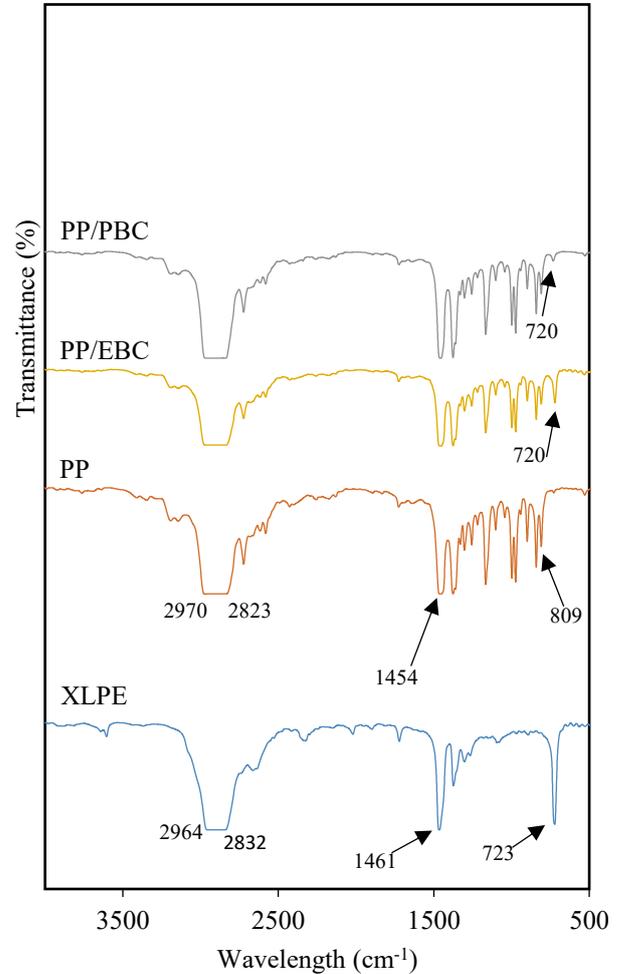


Figure 3. FTIR spectra for XLPE, PP, and PP/copolymer blends

#### 3.2 AC Breakdown Strength

Figure 4 compares the AC breakdown strength of XLPE, PP, and PP/copolymer blends containing EBC and PBC. Their Weibull parameters are listed in Table 5. As a reference material, the AC breakdown value of XLPE was  $148 \pm 9 \text{ kV/mm}$ . Unfilled PP showed the highest AC breakdown value at  $162 \pm 8 \text{ kV/mm}$ . By adding 20 wt% of EBC and PBC to PP, the AC breakdown value increased slightly to  $151 \pm 8 \text{ kV/mm}$  and  $153 \pm 8 \text{ kV/mm}$ , respectively, compared to XLPE. By taking into account the Weibull uncertainties, the AC breakdown values of PP/EBC and PP/PBC are comparable to that of XLPE.

Table 5. Weibull AC breakdown parameters

Sample	$\alpha$ (kV/mm)	$\beta$
XLPE	$148 \pm 9$	$7 \pm 3$
PP	$162 \pm 8$	$10 \pm 4$
PP/PBC20	$153 \pm 8$	$10 \pm 3$
PP/EBC20	$151 \pm 8$	$9 \pm 4$

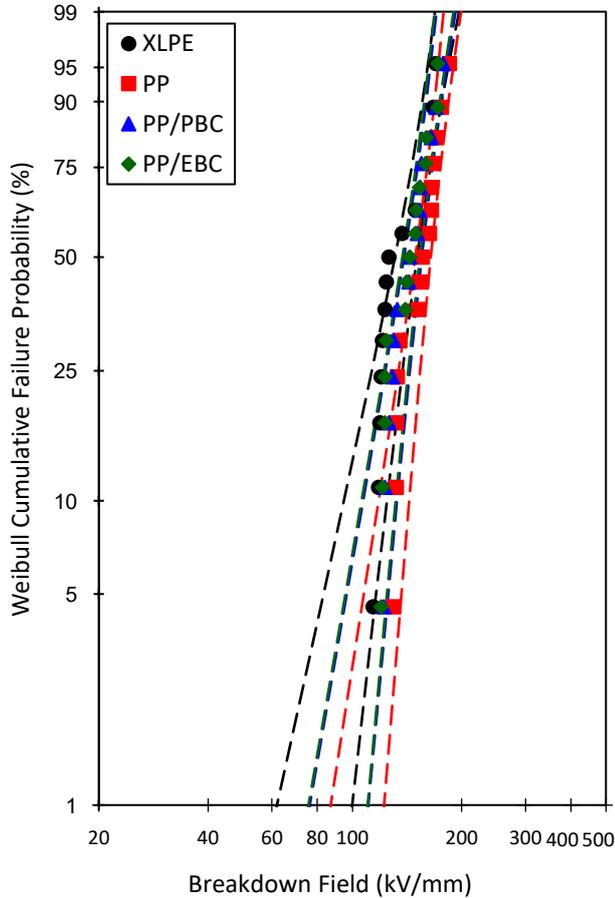


Figure 4. Weibull breakdown plots under AC field

### 3.3 DC Breakdown Strength

Figure 5 compares the DC breakdown strengths of XLPE, PP, and PP/copolymer blends containing EBC and PBC. Their Weibull parameters are listed in Table 6. As a reference material, the DC breakdown strength of XLPE was  $324 \pm 11$  kV/mm. Unfilled PP showed the highest DC breakdown strength at  $367 \pm 13$  kV/mm; similar results are reported by Kamarudin et al. [21]. The DC breakdown strength of PP containing 20 wt% of EBC was slightly lowered at  $317 \pm 9$  kV/mm. This could be due to the presence of high ethylene-based content in PP/EBC, which affected the compatibility of the blend material, thus reducing the breakdown strength [17]. Blending 20 wt% of PBC into PP improved DC breakdown strength to  $338 \pm 24$  kV/mm compared to XLPE. According to Azrin et al. [22], PBC, dominated by the propylene-based content, had better compatibility with PP. This led to better breakdown performance of PP/PBC. Notably, by taking into account the Weibull uncertainties, the DC breakdown strengths of PP/EBC blend and PP/PBC blend are comparable with that of XLPE.

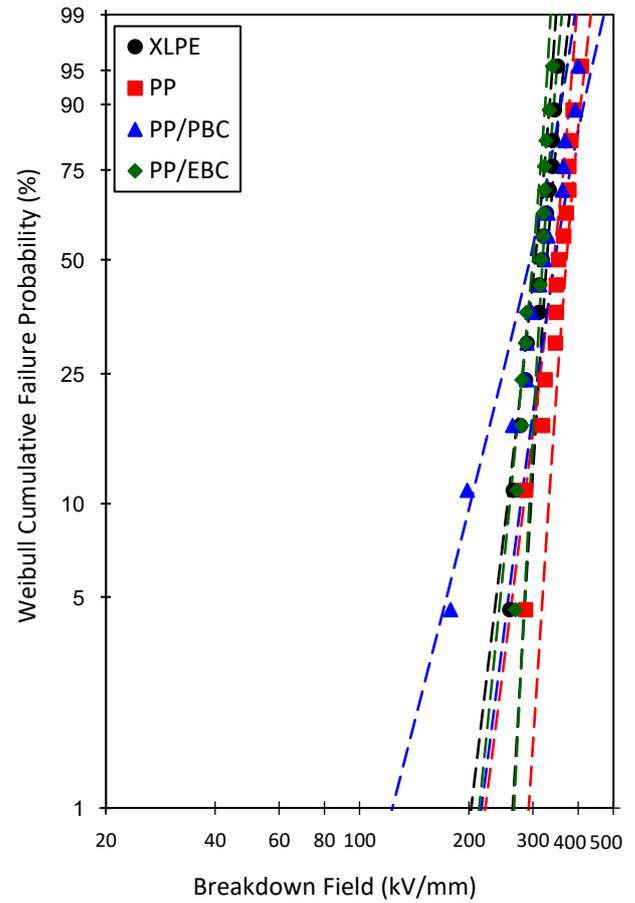


Figure 5. Weibull breakdown plots under DC field

Table 6. Weibull DC breakdown parameters

Sample	$\alpha$ (kV/mm)	$\beta$
XLPE	$324 \pm 11$	$14 \pm 5$
PP	$367 \pm 13$	$13 \pm 5$
PP/PBC20	$338 \pm 24$	$6 \pm 3$
PP/EBC20	$317 \pm 9$	$16 \pm 7$

### 4. CONCLUSIONS

The current study examines the effect of different copolymer types, namely, EBC and PBC, with a 20 wt% addition to PP. The chemical and electrical properties of XLPE, PP, and PP/copolymer containing 20 wt% of EBC and PBC are presented. In term of chemical analysis, the presence of methyl groups in PP/EBC blend is more apparent compared to PP/PBC blend. The result of chemical analysis aligns with the breakdown strength performance, indicating that the higher content of methyl groups significantly reduces the breakdown strength, in which PP/PBC blend demonstrating a slightly higher breakdown strength over PP/EBC blend. Although PP/PBC blend has higher breakdown strength over PP/EBC blend, the breakdown behaviors of PP/EBC blend and PP/PBC blend still demonstrates an adequate dielectric breakdown strength in comparison to XLPE. This indicates that the utilization of 20 wt% of EBC and PBC is suitable for AC and DC breakdown performance consideration. To ensure the possible use of PP/copolymer blends in high voltage cable insulation, further investigation into the

thermal and morphology of PP/EBC and PP/PBC blends is currently ongoing.

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## REFERENCES

- [1] S. Z. Ahmed Dabbak, H. A. Illias, B. C. Ang, N. A. Abdul Latiff, and M. Z. Makmud, "Electrical Properties of Polyethylene/Polypropylene Compounds for High-Voltage Insulation," *Energies*, vol. 11, no. 6, 2018.
- [2] J. Mohammed, S. S. Refaat, H. Abu-Rub, M. Olesz, and J. Guzinski, "The Impact of Thermal Stresses on Volume Resistivity: Performance Comparison between TR-XLPE and XLPE Cables," in *2021 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 12-15 Dec. 2021, pp. 263-268.
- [3] Y. Gao, J. Li, Y. Li, Y. Q. Yuan, S. H. Huang, and B. X. Du, "Effect of elastomer type on electrical and mechanical properties of polypropylene/elastomer blends," in *2017 International Symposium on Electrical Insulating Materials (ISEIM)*, 11-15 Sept. 2017, vol. 2, pp. 574-577.
- [4] T. Andritsch, A. Vaughan, and G. C. Stevens, "Novel insulation materials for high voltage cable systems," *IEEE Electrical Insulation Magazine*, vol. 33, no. 4, pp. 27-33, 2017.
- [5] C. J. Zheng, J. M. Yang, H. Zhao, and Q. C. Chen, "AC performance, physical and mechanical properties of polypropylene/polyolefin elastomers blends," in *2018 12th International Conference on the Properties and Applications of Dielectric Materials (ICPADM)*, 20-24 May 2018, pp. 910-913.
- [6] Y. Zhou, J. Hu, B. Dang, and J. He, "Effect of different nanoparticles on tuning electrical properties of polypropylene nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 24, no. 3, pp. 1380-1389, 2017.
- [7] X. Huang, Y. Fan, J. Zhang, and P. Jiang, "Polypropylene based thermoplastic polymers for potential recyclable HVDC cable insulation applications," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 24, no. 3, pp. 1446-1456, 2017.
- [8] N. A. Johari, K. Y. Lau, Z. Abdul-Malek, M. R. M. Esa, C. W. Tan, and R. Ayop, "Structure of Polypropylene, Ethylene-Propylene-Diene-Monomer and Magnesium Oxide for the Formulation of PP Blend Nanocomposites," in *2023 IEEE 3rd International Conference in Power Engineering Applications (ICPEA)*, 6-7 March 2023, pp. 221-224.
- [9] L. Y. Chen, Y. F. Zhu, G. K. Xu, Y. X. Yun, X. Li, and W. W. Zhang, "Effect of Elastomer Content on Interface Discharge Behavior Between Polypropylene and Silicone Rubber Under AC Voltage," in *2019 2nd International Conference on Electrical Materials and Power Equipment (ICEMPE)*, 7-10 April 2019, pp. 222-225.
- [10] C. D. Green *et al.*, "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.
- [11] J. W. Zha, H. D. Yan, W. K. Li, and Z. M. Dang, "Environmentally friendly polypropylene/thermoplastic elastomer composites with modified graphene oxide for HVDC application," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 25, no. 3, pp. 1088-1094, 2018.
- [12] Y. Zhou, J. He, J. Hu, X. Huang, and P. Jiang, "Evaluation of polypropylene/polyolefin elastomer blends for potential recyclable HVDC cable insulation applications," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 22, no. 2, pp. 673-681, 2015.
- [13] Y. Gao, J. Li, Y. Yuan, S. Huang, and B. Du, "Trap Distribution and Dielectric Breakdown of Isotactic Polypropylene/Propylene Based Elastomer With Improved Flexibility for DC Cable Insulation," *IEEE Access*, vol. 6, pp. 58645-58661, 2018.
- [14] *American Society for Testing and Materials. ASTM D149: Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies*, 2013.
- [15] *American Society for Testing and Materials. ASTM D3755: Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Under Direct-Voltage Stress*, 2020.
- [16] J. V. Gulmine and L. Akcelrud, "FTIR characterization of aged XLPE," *Polymer Testing*, vol. 25, no. 7, pp. 932-942, 2006/10/01/ 2006.
- [17] P. Hu, P.-P. Zhao, G. W. Zhang, and X.-H. Wang, "Thermal properties of 60Co irradiated crosslinked high density polyethylene," *Solar Energy Materials and Solar Cells*, vol. 149, pp. 55-59, 2016.
- [18] A. Gopanna, R. N. Mandapati, S. P. Thomas, K. P. Rajan, and M. Chavali, "Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy and wide-angle X-ray scattering (WAXS) of polypropylene (PP)/cyclic olefin copolymer (COC) blends for qualitative and quantitative analysis," *Polymer Bulletin*, vol. 76, pp. 4259-4274, 2018.
- [19] K. Yang *et al.*, "Enhanced Morphology-Dependent Tensile Property and Breakdown Strength of Impact Polypropylene Copolymer for Cable Insulation," *Materials*, vol. 13, no. 18, 2020.
- [20] J. Wang, J. Guo, C. Li, S. Yang, H. Wu, and S. Guo, "Crystallization kinetics behavior, molecular interaction, and impact-induced morphological evolution of polypropylene/poly(ethylene-co-octene) blends: insight into toughening mechanism," *Journal of Polymer Research*, vol. 21, 11/23 2014.
- [21] S. N. H. Kamarudin, K. Y. Lau, N. A. Ahmad, N. A. Azrin, C. W. Tan, and K. Y. Ching, "Structure and DC Breakdown Properties of Polypropylene/Elastomer Blends," in *2023 IEEE 3rd*

*International Conference in Power Engineering Applications (ICPEA)*, 6-7 March 2023, pp. 214-216.

- [22] N. Azrin, A. Ahmad, K. Y. Lau, and N. Kamarudin, "Structure, mechanical, and dielectric properties of polypropylene blended with ethylene and propylene-based elastomers," *Journal of Applied Polymer Science*, vol. 141, 2024.