Thermal and Breakdown Properties of Polypropylene Homopolymer, Copolymer, and Blend

A. Azmi[1,*] , K. Y. Lau[1], N. A. Ahmad[1], Z. Abdul-Malek[1], W. A. W. A. Rahman[2]
[1]*Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310*
[2]*Biopolymer Research Group, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310*
Johor Bahru, Malaysia
Email: aizat.azmi.1987@gmail.com

***Abstract*— Polypropylene has been widely used in high voltage insulation. This material has recently been regarded as to potentially compensate conventional limitations of XLPE such as being difficult to recycle and having significant space charge accumulation and poor thermal conductivity. Currently, there are various types of polypropylene produced in the market. Therefore, this research attempts to investigate the breakdown performance of several types of polypropylene, namely, polypropylene homopolymer, polypropylene impact copolymer, and the combination of both in 50:50 ratio. The thermal behaviors of the samples were characterized using scanning calorimetry (DSC). The thermal characterization demonstrates that all types of polypropylene have a similar melting temperature of about 162 °C. Besides that, the breakdown test reveals that polypropylene homopolymer has the highest DC breakdown of 278 kV/mm. Meanwhile, polypropylene impact copolymer has the lowest breakdown strength of 109 kV/mm and 239 kV/mm under the applied AC and DC fields, respectively.**

Keywords—polypropylene, AC breakdown, DC breakdown

I. INTRODUCTION

Polymeric insulation material has been widely used as high voltage cable insulation. Various advantages of the material have been identified such as low dielectric constant and dielectric losses, excellent mechanical flexibility, and low cost. Currently, the most popular polymeric material used are low density polyethylene (LDPE), high density polyethylene (HDPE), combinations of LDPE and HDPE with certain compositions [1][2], and cross-linked polyethylene (XLPE). XLPE is introduced as to improve the mechanical properties of LDPE. The cross-linked macromolecular network characteristic of XLPE is employed for the improvement. However, several disadvantages of XLPE have been reported, such as its difficulty to recycle due to its thermoset nature resulted from the crosslinking process, long-term deterioration in its performance due to the presence of crosslinking byproducts, significant space charge accumulation, and thermal expansion that reduces its thermal conductivity. Therefore, polypropylene (PP) has recently been highlighted as a potential alternative that can compensate the aforementioned issues with XLPE.

PP is a commercial plastic extensively used in high voltage insulation. The demand of this material increased significantly due to its high melting temperature (commonly above 150°C), high mechanical strength, low dielectric loss, and high volume resistivity compared to XLPE, HDPE, and LDPE [3][4]. Moreover, PP is classified as a thermoplastic material that can be recycled with ease [5][6]. Presently there are several types of polypropylene polymer available in the market, such as isotactic PP, PP homopolymer, and PP copolymer. Each type of propylene has different characteristics. Therefore, it is essential to investigate the thermal and electrical properties of different types of polypropylene. In this research, three types of polypropylene samples, namely, PP homopolymer (PPh), PP impact copolymer (PPi), and PP blend (a composition of PP homopolymer and PP impact copolymer with the ratio of 50:50) were employed to study their breakdown strength characteristic and thermal behavior. The DC and AC breakdown strength of each type of sample was compared.

II. EXPERIMENT

A. Material Preparation

PP homopolymer grade TITANPRO 6531M and PP impact copolymer grade TITANPRO SM340 from Lotte Chemical Titan were used in this research. These PPs are prepared by means of Brabender melt mixer. The rotational speed and temperature were set to 50 rpm and 180°C respectively. The time for completing the blending process was set to 10 minutes. Figure 1 demonstrates the PPh, PPi, and PP blend sample after completing the mixing process. After that, the samples were hot pressed using hydraulic laboratory hot press at a temperature of 180°C and a load of 3 ton in order to produce disc shape films. The melt pressed samples were then left to cool non-isothermally. Table I summarizes the features of the PPs based on the manufacturer's datasheet. Meanwhile Figure 2 demonstrates the hydraulic laboratory hot press machine used in this research.

B. Characterization

Thermal melting traces of the investigated samples were obtained by means of Perkin Elmer's differential scanning calorimeter (DSC) 7. 5 mg of PP sample was prepared. The sample was sealed using aluminum pan before being subjected to nitrogen atmosphere. The sample was first run from 30°C to 220°C at a scan rate of 10°C/min to remove its thermal history. Next, the sample was cooled from 220°C to 30°C at the same scan rate of 10°C/min to determine its cooling behavior. Finally, the same heating procedure was

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

repeated for the second heating process. Perkin Elmer's Pyris software was used for analyzing the thermal data.

DC and AC breakdown tests were performed using a dielectric strength tester. The test was carried out based on the guidelines set out in the American Standard for Testing Material (ASTM) D149. The thickness of the test samples was approximately 100 µm. The samples were sandwiched between two ball bearing electrodes (~6.3 mm diameter) and immersed in mineral oil (to prevent the surface discharge). An AC step voltage and a DC step voltage of 1 kV every 20 s and 2 kV every 20 s, respectively, were applied. The voltage was continuously applied until the samples breakdown. 15 breakdown points were taken for each sample. The measured data was then analyzed using the Weibull statistical distribution method. The experiment setup for AC and DC breakdown strength is illustrated in Figure 3.


(a)

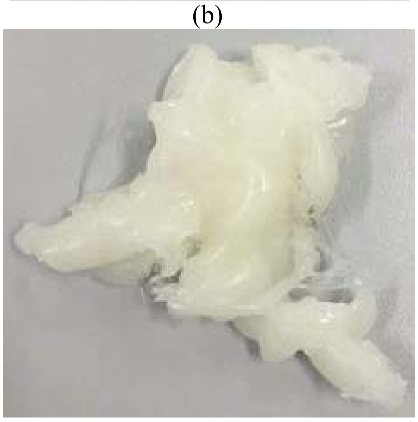
(b)

(c)

Fig. 1. Polypropylene sample prepared by means of brabender melt mixer (a) PPh (b) PPi and (c) PP Blend

TABLE I. POLYPROPYLENE FEATURES

Properties	**Unit**	**PP homopolymer**	**PP impact copolymer**
Tensile strength	kg/cm^2	360	290
Flexural Modulus	kg/cm^2	17000	13500
Melt flow rate, at 230 °C	g/10 minutes	3.5	4.0
Heat deflection temperature at 4.6 kg/cm^2	°C	86	85
Water absorption after 24 hours	%	0.02	0.02

Fig. 2. Hydraulic laboratory hot press machine

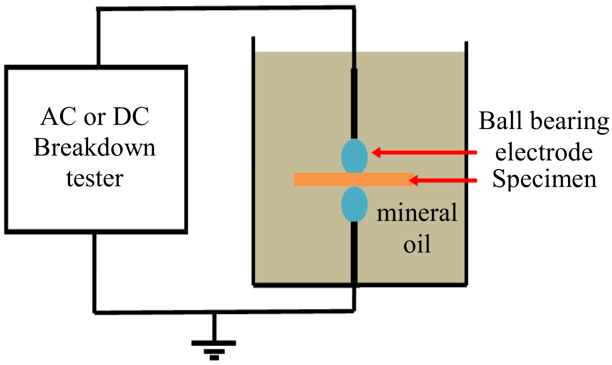


Fig. 3. Experimental setup for breakdown test

III. RESULTS AND DISCUSSION

A. Thermal Analysis

The melting and cooling behaviors of PPh, PPi, and PP blend are demonstrated in Figure 4 and Figure 5, respectively. The obtained results demonstrated that, PPh, PPi, and PP blend had similar values of melting temperature where the melting peak was observed at around 162°C. Meanwhile, the cooling peak for PPh, PPi, and PP blend was observed at around 117°C. These values are in close proximity with the values in [7][8].

B. Breakdown Strength Analysis

Weibull analysis was used to analyze the breakdown data of polypropylene. These data were fitted into two-parameter of Weibull distribution with its cumulative distribution function given by the equation (1):

$$F(x) = 1 - \exp\left\{-\left(\frac{x}{\alpha}\right)^{\beta}\right\} \quad (1)$$

where *F(x)* is the probability of breakdown at an electric field strength of x (kV/mm). The scale parameter (α) is related to the 63.2% probability of breakdown at field strength, and the shape parameter (β) describes the shape of the distribution.

Figure 6 and Figure 7 show the Weibull plots of PPh, PPi and PP blend for AC and DC breakdown strength respectively with derived parameter values listed in Table II. The breakdown fields for AC and DC of the measured polypropylene samples ranged from 109-122 kV/mm and 239-278 kV/mm respectively. Besides that, PPh had the highest breakdown strength compared to PPi and PP blend. Meanwhile, PPi had the lowest breakdown strength for both AC and DC. Significantly, PP blend showed breakdown strength that was commensurate with PPh.

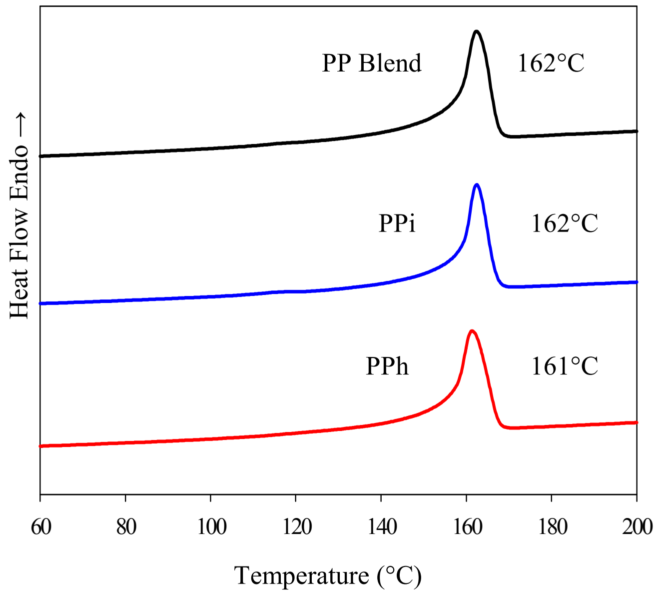


Fig. 4. DSC heating thermograms of PPh, PPi, and PP blend

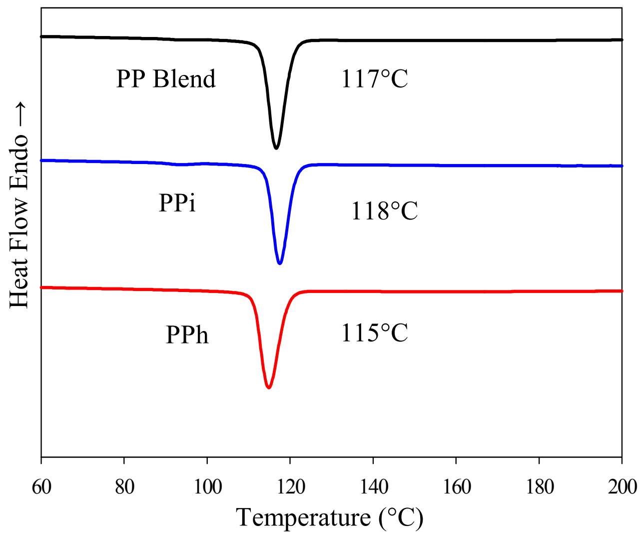


Fig. 5. DSC cooling thermograms of PPh, PPi, and PP blend

Apart from that, the overall performance of breakdown test in this research demonstrated that the DC breakdown strength for all samples was significantly greater than the AC breakdown strength. This finding is consistent with the data presented elsewhere [9].

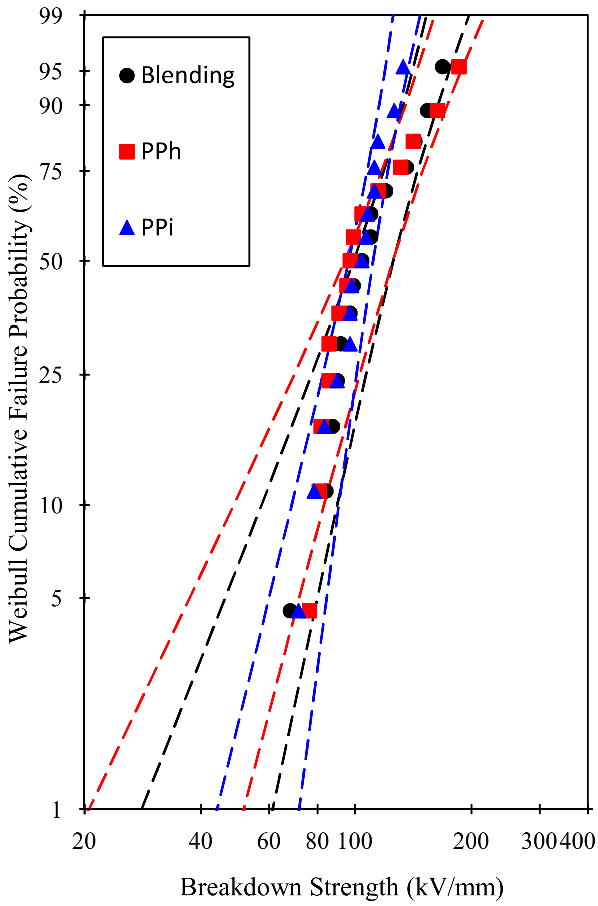


Fig. 6. Weibull plots comparing the AC breakdown strength of PPh, PPi, and PP blend

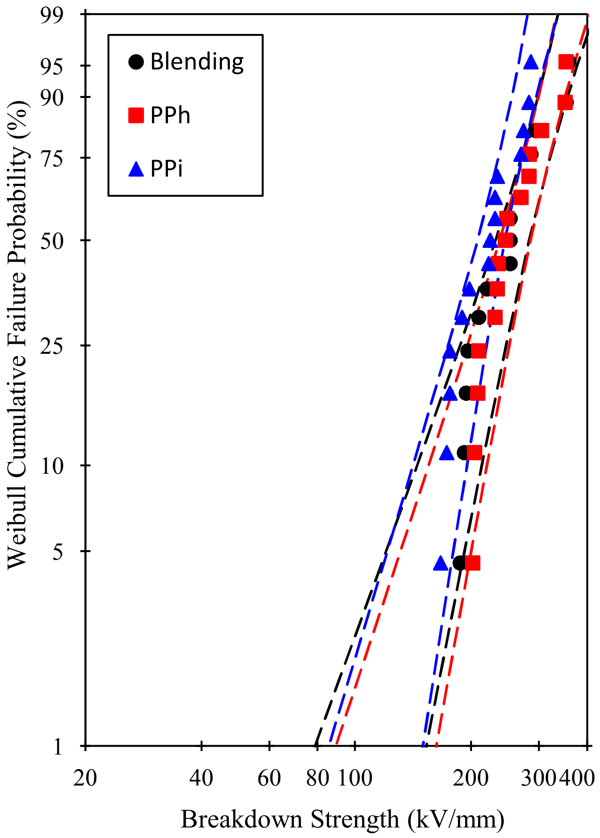


Fig. 7. Weibull plots comparing the DC breakdown strength of PPh, PPi, and PP blend

TABLE II. AC AND DC BREAKDOWN DATA FROM WEIBULL ANALYSIS. THE UNCERTAINTIES CORRESPOND TO 90% CONFIDENCE BOUNDS

Breakdown	Sample	α (kV/mm)	β
AC	PPh PPi PP blend	121 ± 16 109 ± 7 122 ± 13	4 ± 1 7 ± 3 4 ± 2
DC	PPh PPi PP blend	278 ± 24 239 ± 18 275 ± 26	5 ± 3 6 ± 3 5 ± 2

IV. CONCLUSION

The investigation on the effect of different types of polypropylene on the thermal and electrical properties of the materials was carried out. All the polypropylene samples had similar melting behavior. Meanwhile, PPh shows excellent breakdown property with higher breakdown strength than PPi and PP blend. However, the use of PP blend showed that blending PPh and PPi could result in breakdown strength that was commensurate with PPh.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia for their financial sponsorships and the grants 03G66 and 13H12.

REFERENCES

[1] S. N. H. Kamarudin, K. Y. Lau, and W. A. W. A. Rahman, "The Effect of Non-Isothermal Crystallization on the AC Breakdown Performance of Polyethylene/Silicon Dioxide Nanocomposites," in *IEEE Conference on Energy Conversion (CENCON)*, 2017, pp. 7–10.

[2] K. Lau, A. Vaughan, G. Chen, I. Hosier, A. Holt, and K. Ching, "On the Space Charge and DC Breakdown Behavior of Polyethylene/Silica Nanocomposites," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. 1, pp. 340–351, 2014.

[3] T. Andritsch, A. Vaughan, and G. C. Stevens, "Novel Insulation Materials for High Voltage Cable Systems," *IEEE Electr. Insul. Mag.*, vol. 33, no. 4, pp. 27–33, 2017.

[4] Y. Zhou, J. Hu, B. Dang, and J. He, "Effect of Different Nanoparticles on Tuning Electrical Properties of Polypropylene Nanocomposites," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 24, no. 3, pp. 1380–1389, 2017.

[5] G. C. Montanari, D. Fabiani, F. Palmieri, D. Kaempfer, R. Thomann, and R. Mülhaupt, "Modification of Electrical Properties and Performance of EVA and PP insulation through Nanostructure by Organophilic Silicates," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 11, no. 5, pp. 754–762, 2004.

[6] C. D. Green, A. S. Vaughan, G. C. Stevens, A. Pye, S. J. Sutton, T. Geussens, and M. J. Fairhurst, "Thermoplastic Cable Insulation Comprising a Blend of Isotactic Polypropylene and a Propylene-Ethylene Copolymer," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 22, no. 2, pp. 639–648, 2015.

[7] C. Ou, "The crystallization characteristics of polypropylene and low ethylene content polypropylene copolymer with copolyesters," *Eur. Polym. J.*, vol. 38, pp. 467–473, 2002.

[8] H. H. S. Corporation, "DSC Measurement of Polypropylene," 2008.

[9] K. Y. Lau, M. A. M. Piah, and K. Y. Ching, "Correlating the Breakdown Strength with Electric Field Analysis for Polyethylene/Silica Nanocomposites," *J. Electrostat.*, vol. 86, pp. 1–11, 2017.