Electrical Breakdown Strength of Boron Nitride Polyethylene Nanocomposites

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Introduction

There is a growing demand for the design of high-performance insulators for high voltage applications. It was proposed that the addition of nanofillers to a polymer could potentially enhance the electrical properties of insulators when compared to the conventional unfilled or microfilled polymers. These materials have captured the interest of many researchers worldwide since then, as present dielectric materials could benefit from improvements in dielectric strength, dielectric loss, electrical and thermal conductivity, and permittivity that nanodielectrics offer. However, many of the underlying principles remain uncertain, such as the polymer/nanofiller interface, and researchers are still exploring solutions to common challenges faced by nanodielectrics such as nanoparticle agglomeration.

Material and Sample Preparation

The host polymer consisted of a polyethylene blend composed of 80 wt% LDPE and 20 wt% HDPE. Hexagonal boron nitride (h-BN) is chosen as the nanofiller. The nanocomposites were prepared using a solution blending method.

The desired amount of the polymer blend and h-BN were added to 200 ml of xylene. This mixture was mixed inside a round bottomed flask and heated to the boiling point xylene while simultaneously being stirred by a magnetic stirrer bar.

After all the polymer pellets had dissolved, the hot mixture was poured into 300 ml of methanol with simultaneous, vigorous stirring resulting in the precipitation of the nanocomposite as a white mass.

This material was then filtered using a funnel to remove most of the solvent followed by drying in a ventilated box for five days at room temperature. The material was then placed in a vacuum oven at 60 ⁰C for 3 days followed by melt pressing at 150 ⁰C to remove the remaining xylene from the nanocomposite.

Materials produced consisted of an unfilled PE blend, nanocomposites containing 2 wt%, 5 wt%, and 10wt% h-BN.

To prepare samples for suitable for AC breakdown tests, 140 mg of the material was pressed at a temperature of 150 ⁰C and a load of 3 ton. This produced disks with a thickness ranging from 50 – 100 µm.

The materials were crystallised in two ways:

i)   Rapid crystallisation: directly quenched in water.

ii) Slow crystallisation: crystallised in an oil bath for an hour at a temperature of 115 ⁰C.

The h-BN was also examined using a field emission gun scanning electron microscope (FEG-SEM) in the form of the as-received powder and following xylene processing.

For the h-BN powder, a semiconductor tape was stuck onto an SEM stub, which was dipped in h-BN powder followed by gold coating to create a conductive surface suitable for the FEG-SEM.

For the h-BN solution, a round glass slide was stuck onto an SEM stub using double sided tape. Drops of a solution consisting of xylene and h-BN were transferred to this slide followed by gold coating.

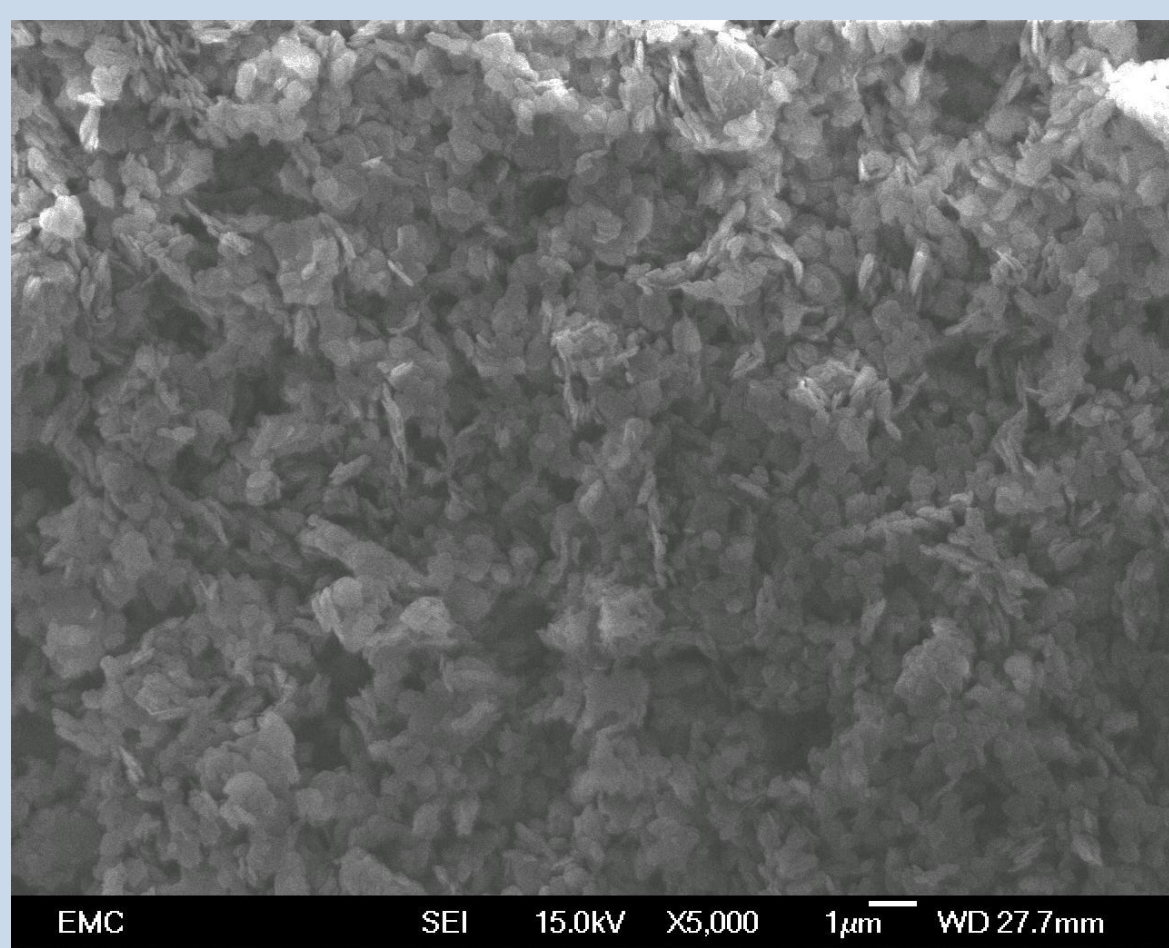## Structural Characterization using the FEG-SEM

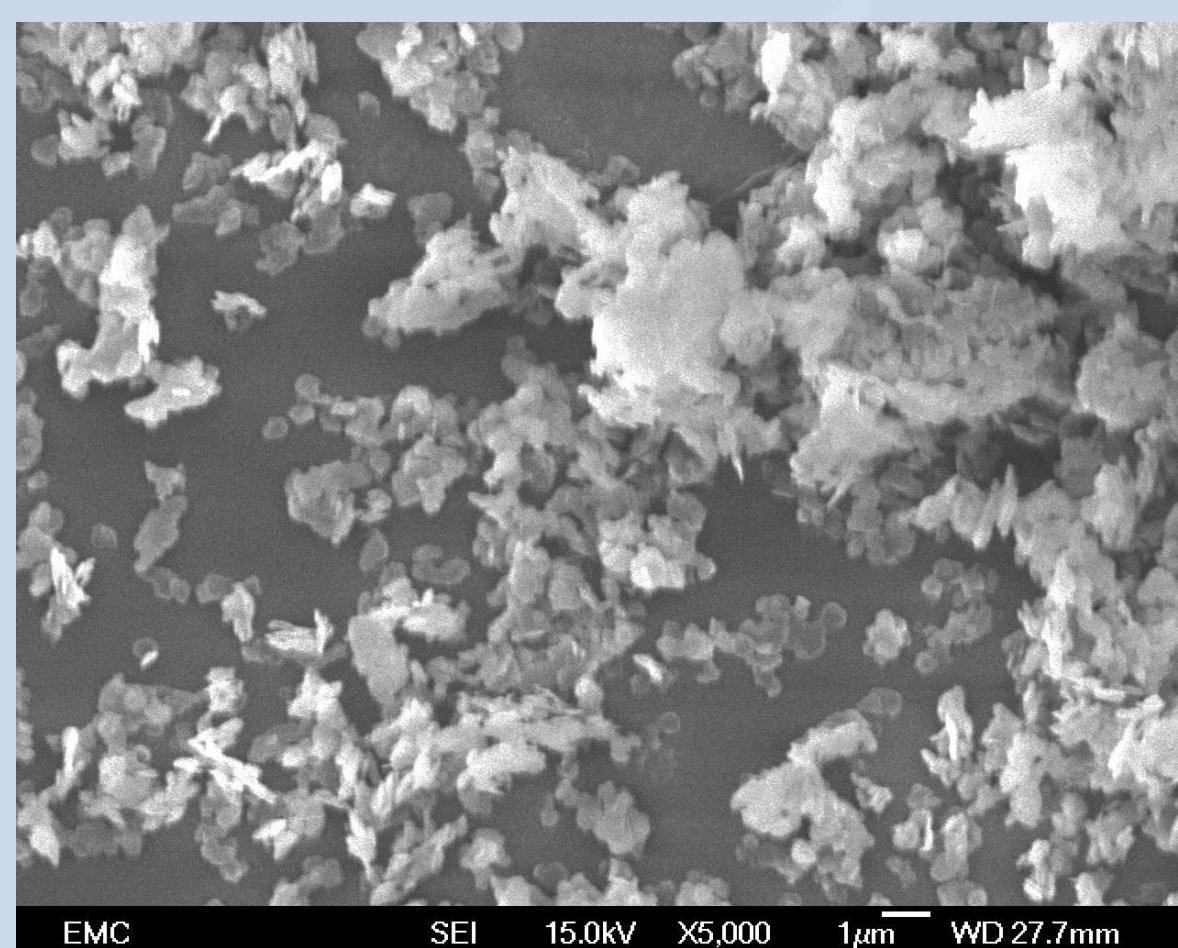Figure 1: Image showing the state of h-BN as powder

Figure 2: Image showing the h-BN state following solution processing

The hexagonal shape of the boron nitride can be observed in these images.

Figure 1 shows a cluster of h-BN particles in the powder so there is a considerable amount of agglomeration in the system with a size in the micrometer range.

Figure 2 shows some dispersion of h-BN particles in xylene as expected. However, the filler is still largely present as agglomerates, suggesting little exfoliation in this solvent.

No efforts have been made to disperse these particles yet as this system is used as a reference to compare with systems that will be prepared in the future that have gone through exfoliation and surface modification.

Electrical Breakdown Testing

The samples were placed between two ball bearings immersed in silicone oil with two electrodes: the upper electrode connected to the high voltage supply while the lower electrode connected to the ground.

An alternating voltage with 50 Hz frequency and a ramp rate of 50 V/s was applied until the sample failed. The breakdown data were then analysed using the two parameter Weibull distribution.

The following Weibull plots are all for different materials crystallised at 115 ⁰C.
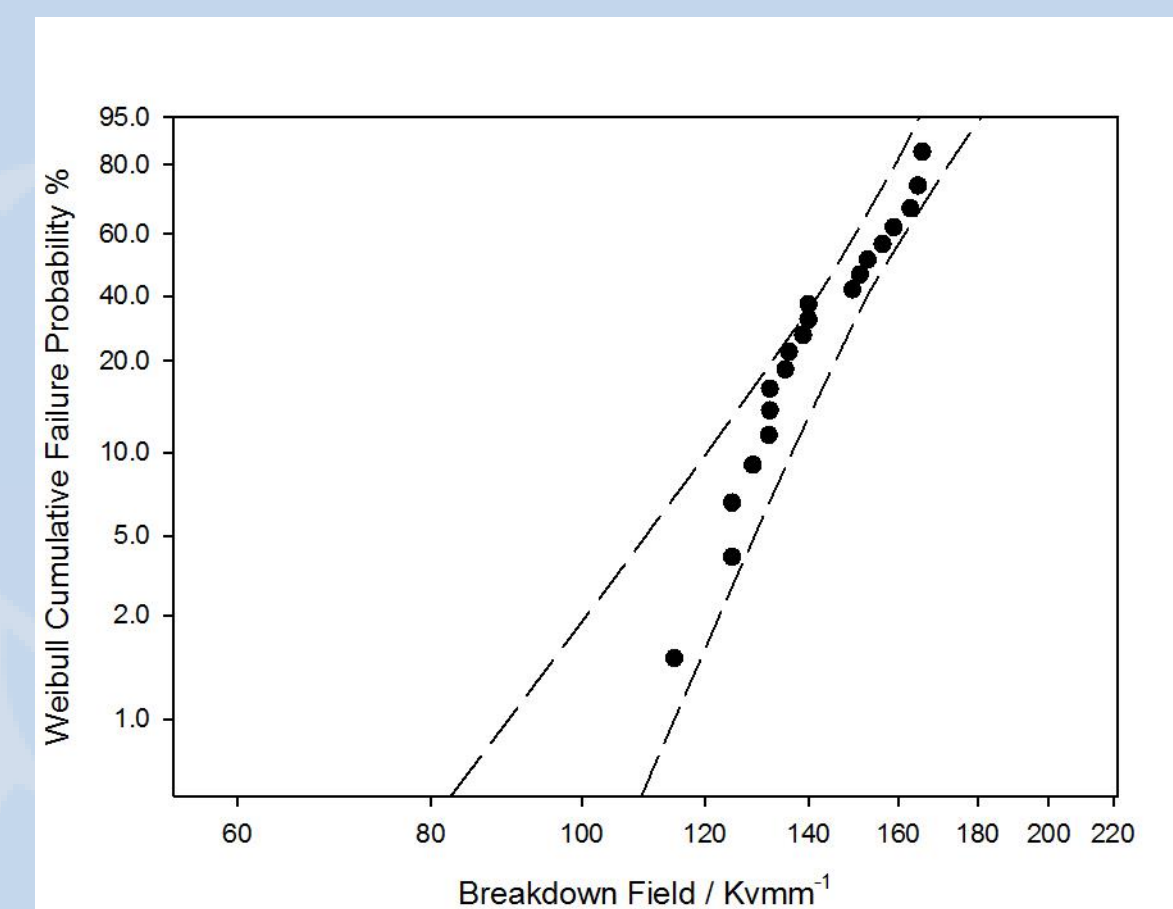

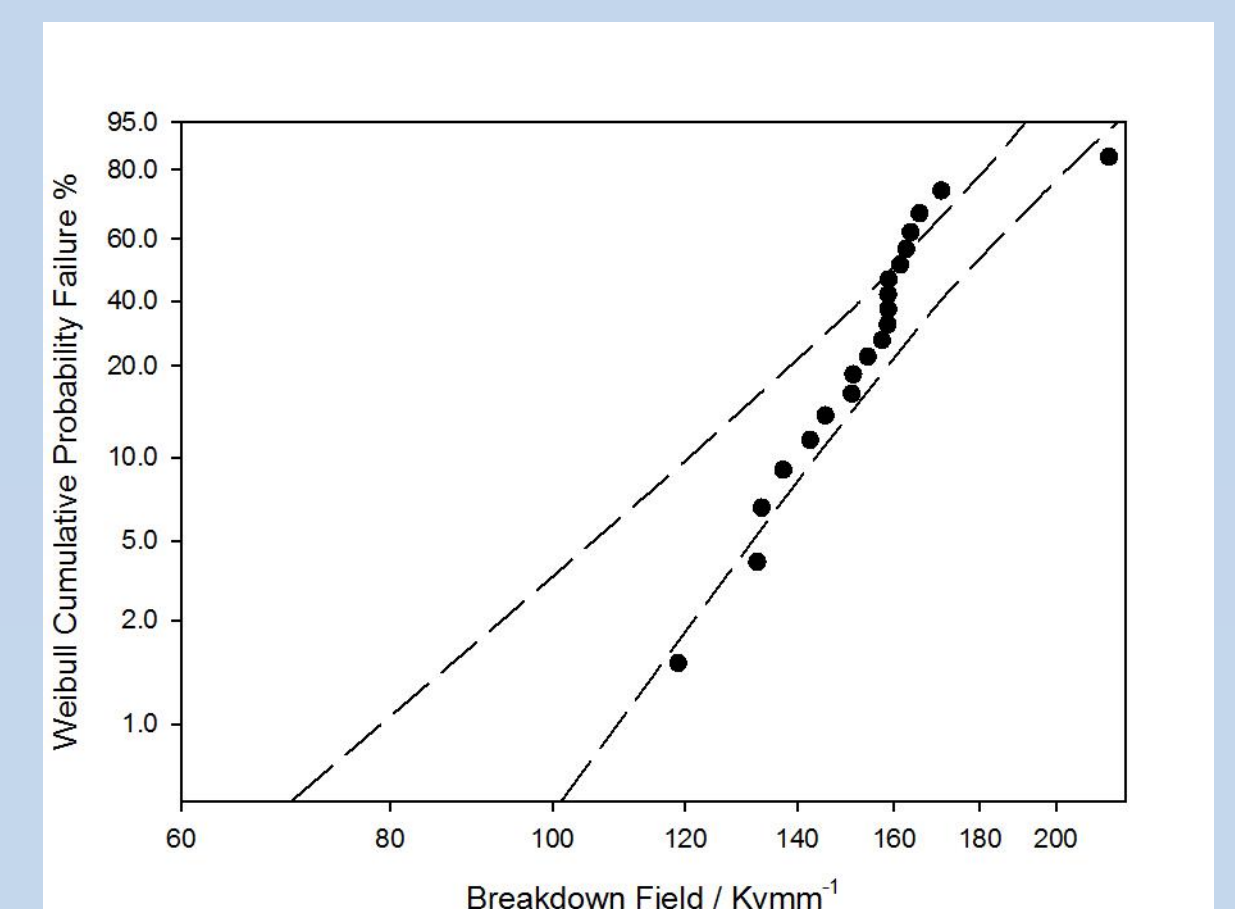Figure 3: Weibull plot of unfilled PE blend crystallized 115 ⁰C

Figure 4: Weibull plot of 2 wt% h-BN/PE blend nanocomposite crystallized 115 ⁰C
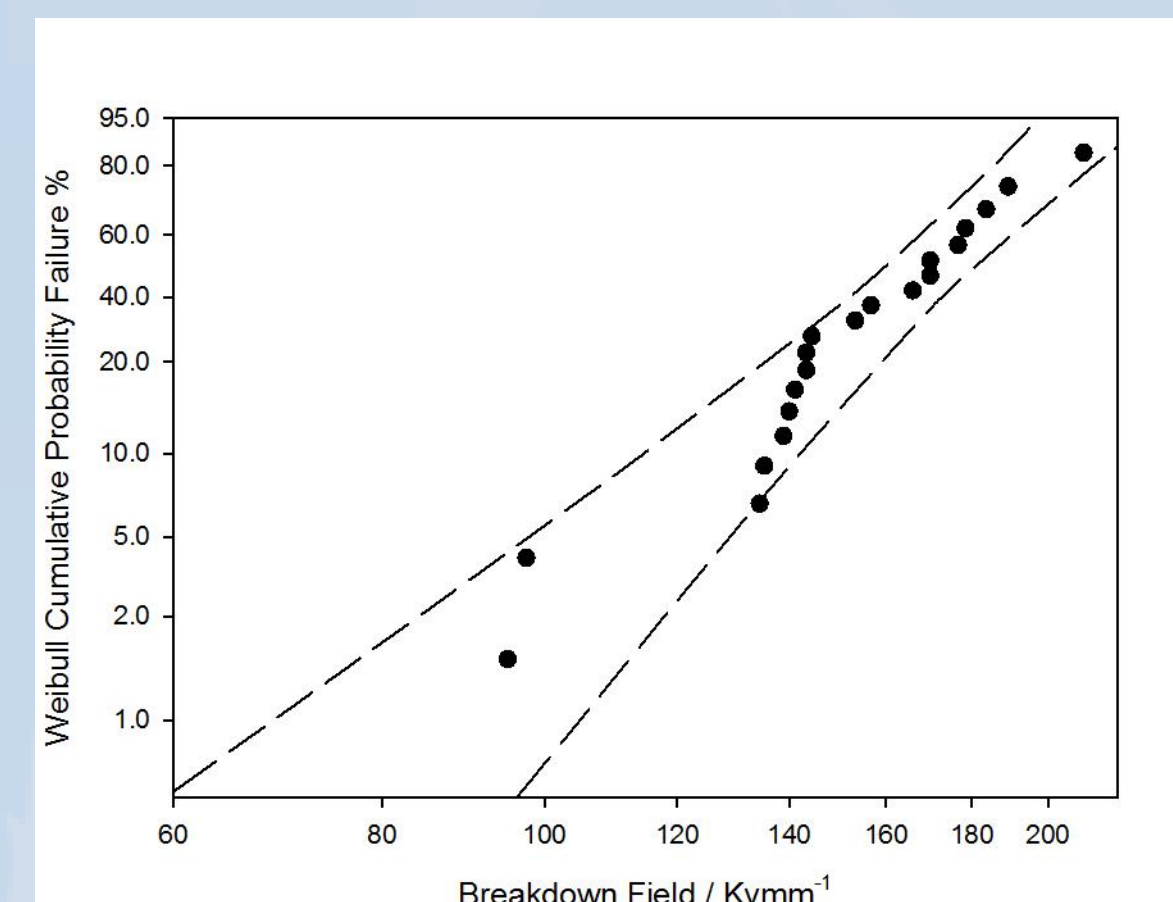

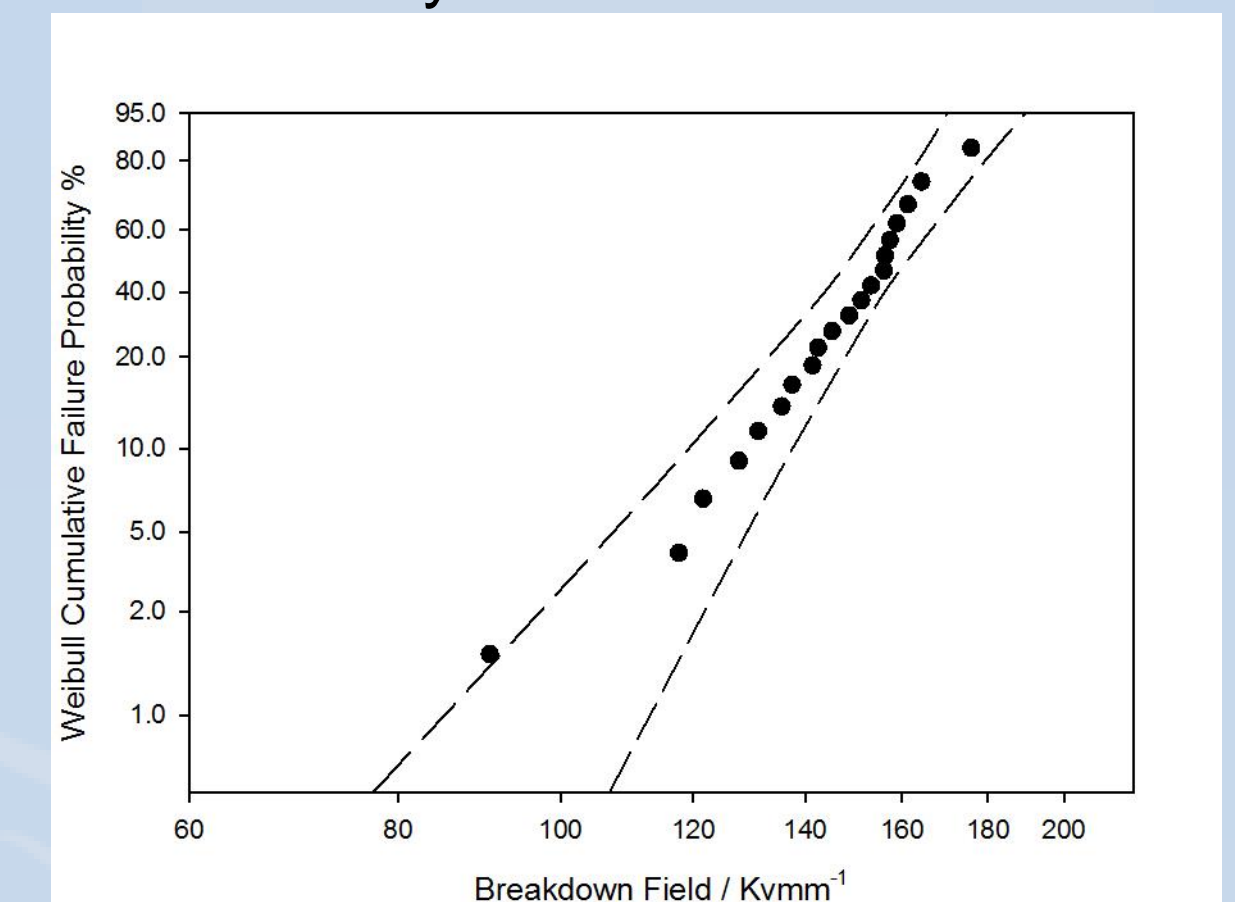Figure 5: Weibull plot of 5 wt% h-BN/PE blend nanocomposite crystallized 115 ⁰C

Figure 6: Weibull plot of 10 wt% h-BN/PE blend nanocomposite crystallized 115 ⁰C

Material	α (kV/mm)	β
Unfilled PE blend	148.7	10.9
2 wt% h-BN/PE blend nanocomposite	163.5	7.3
5 wt% h-BN/PE blend nanocomposite	164.7	6.3
10 wt% h-BN/PE blend nanocomposite	158.3	8.7

Table 1: Weibull parameters obtained from breakdown tests for each sample

Discussion of Results

The breakdown results indicate that the addition of h-BN increases the electrical breakdown strength. The breakdown strength of the 10 wt% nanocomposite is lower than the 2 wt% and 5 wt% nanocomposites, yet still higher than the unfilled PE blend. This could be due to the larger agglomerates in the matrix at such a high loading level. The increase in breakdown strength could be attributed to the high dielectric strength of h-BN as compared to polyethylene. The β value, which represents the slope and the spread of breakdown strength, is considerable low for all materials. This could be because the prepared samples have a thickness range of 50 – 100 µm which might produce inaccurate or inconsistent results.

Conclusions and Future Work

Four different materials were prepared using a solution blending method: 0 wt%, 2 wt%, 5 wt%, and 10 wt% h-BN/PE blend nanocomposites.

The state of the nanofiller was examined using a FEG-SEM as a powder and in solution phase, which showed a considerable amount of agglomeration.

The breakdown strength of the nanocomposites is higher than the unfilled PE blend, even though the h-BN is aggregated.

The next step is to prepare samples under controlled conditions to produce samples with uniform thickness to obtain more accurate results. Materials containing exfoliated and surface modified h-BN will be prepared and compared to the current nanocomposites.

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