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EFFECT OF TiO_2 NANOFILLER ON THE AC AND IMPULSE CHARACTERISTIC FOR HV APPLICATION

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ABSTRACT

Research on polymer nanocomposite has achieved great contribution in many fields. This research is about to determine the electrical insulation strength of the Linear Low Density Poly-Ethylene Nanocomposite/Natural Rubber, LLDPE/NR with different percentages of titanium oxide, TiO_2. At the end of this research, the optimum percentage of nanofillers that can enhance the insulation performance can be known. Since the insulation strength has become the main concern on the application of high voltage, the samples of LLDPE/NR are more suitable to be tested using High Voltage Test as being practiced by all of other researchers and scholars. The tests involved in this research is HVAC testing and Lightning Impulse Test. Lightning has being the common causes of fault to the power system in Malaysia. The samples are varied up to 4 percentages of TiO_2 nanofillers which are 1%, 3%, 5% and 7%. At the earliest stage, the samples are compressed using hot compressor within specifics time for heating and cooling. The time for both heating and cooling must be precise to make sure the morphological structure of the samples are at the best condition. All samples are designed with thickness of 1.5 millimetres. Then, the samples are tested using both HVAC and Lightning Impulse Test. The samples are tested until they experiencing breakdown. Based on the result of the tests, 7weight % of nanofillers is the optimum percentage of nanofillers that enhance the electrical insulation.

Keywords: polymer nanocomposites, LLDPE-NR, TiO_2, HVAC, impulse.

INTRODUCTION

Polymer nanocomposite has been widely used in the industrial. This nanocomposite technology has emerged from the field of engineering plastics, and potentially expended its application to structural materials, coatings, and packaging to medical/biomedical and electronic and photonic devices (Tanaka *et al.*, 2004). In electrical field area, polymer nanocomposite also has been used as insulator. An electrical insulator is a material whose internal electric charges do not flow freely, and therefore make it very hard to conduct an electric current under the influence of an electric field.

Characteristic that should be taken into account in making insulators are dieletric properties, mechanical properties, thermal properties and environment properties. In general, insulator should have mechanical strength in order to withstand load and also wind. To avoid leakage current to earth, it should have high electrical resistance material and to make sure that dieletric strength is high, it should have high relative permittivity of insulator material. The insulator material also should be non-porous; free from impurities and cracks otherwise the permittivity is lowered.

Usually, the materials used for high-voltage power transmission are made from glass, porcelain or LLDPE composite polymer material. The examples of composite polymer material that have been used are titanium oxide, TiO2, silicon oxide, SiO2 and also MMT, clay. With further comparison among the PE materials, they found that the LLDPE is most compatible to natural rubber (NR) where the rubber particles are dispersed in the continuous phase of thermoplastic components (Jamail *et al.*, 2014).

Polymer nanocomposite

Nanocomposite is a matrix to which nanoparticles have been added in order to improve and enhance the particular properties of a material. This innovative materials have attracted a lot of attentions. Examples of particular properties that are improved are mechanical strength and insulation strength (for electrical insulation purpose).

While, polymer nanocomposite is a material that consist of polymer or also known as copolymer and nanoparticles which is also called as nanofillers. Both of these substances are dispersed in the polymer matrix to form polymer nanocomposite. Polymer molecular composites and polymer nanocomposites have been a target for R&D since 1970's. Much effort has been made to develop and apply polymer nanocomposites in transportation, electrical and electronics engineering, food package, and building industries since 1990 (Tanaka, 2005).

Linear low density polyethylene (LLDPE)

Basically, polyethylene is most common plastic. Most having chemical formula for polyethylene is $(C_2H_4)_nH_2$. Polyethylene such as linear low-density polyethylene (LLDPE) is obtained via the copolymerization of ethylene with various alpha olefins. In general, LLDPE is produced at lower temperatures and pressures. Examples of olefins are butene, hexene or octane.

Linear Low Density Polyethylene (LLDPE) is a kind of important plastic that is widely used in areas of agro-films, vessels and pipes due to its good softness and processing abilities. Instead of being used in agro-films, LLDPE also preferred for electrical insulation. To achieve

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specific electrical, mechanical and thermal properties, this LLDPE have been loaded with polymer nanocomposite. To better use the nanocomposites, a thorough understanding of interaction between nanoparticles and their matrix is important (Jamail, Piah and Muhamad, 2012). These studies are very important to improve their performance and widening their utilities.

HVAC test

In HVAC test, higher voltage alternating current is used. This test also known as low frequency tests. In these tests, the insulation system required to have the capability to withstand higher than usual alternating voltages (AC) that represent on the power system during abnormal conditions. The abnormal conditions could be in the form of continuous power frequency or temporary overvoltages or TOV. The frequency range of the voltage is at 50 or 60 Hz (countries depended) for continuous and from $10 < f < 500$ Hz for TOV tests (BS EN 60060-1:2010)

Lightning impulse test

Lightning impulse can be defined as intentionally applied aperiodic transient voltage, which usually rises rapidly to a peak value and then falls more slowly to zero, with impulse voltage front time less than 20µs (Wang, 2012). Figure-1 shows graph represent lightning impulse voltage;

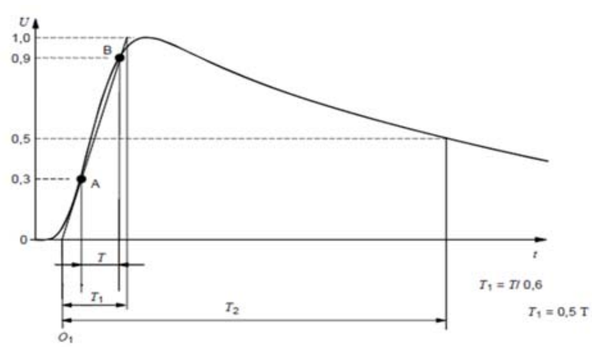

Figure-1. Lightning impulse voltage.

SAMPLE'S PREPARATION

Specimen for HVAC Test and Impulse Test, LLDPE polymer is moulded using Hydraulic Hot Press Genesis brand manufactured by Wabash MPI USA. At first, the LLDPE polymer prepared into square shape with the thickness of 1.5 mm by hot melt pressing at 1 ton pressure at 170°C for 10 min (Jamail *et al*., 2014). After the moulding process using the Hydraulic Hot Press Genesis, the specimens need to go through cooling process for another 10 min. This process is very important since it can influence the morphological features of the sample which may alter the dielectric characteristics. Four types of polyethylene nanocomposite square shape with a dimension of 10 cm × 10 cm were prepared, with concentrations of nanofiller of 1, 3, 5, and 7 wt%, respectively.

The mass of the LLDPE/NR must be calculated first before being moulded. The calculation below shows how the mass of the LLDPE/NR is determined.

Sample thickness = 1.5 mm

Mould volume, $V = length \times width \times height$ (1)

= 24 cm x 24 cm x 0.15 cm

= 86 cm^3

LLDPE density, $\rho = 0.918$ g/cm^3

Then,

$\rho = m/V\ g/cm^3$ (2)

Therefore,

$m = \rho Vg$ (3)

= 0.918 g/cm^3 x 86.4 cm^3 = 79.3152 g

Before putting the sample into the compressor, silicone spray is sprayed onto the moulder surface to make sure that the surface is not sticky and to make the samples easier to be pulled off after heating and cooling process. Figure-2 shows the silicone spray that has been used during the moulding process.

Figure-2. Silicone spray.

EXPERIMENTAL PROCEDURE

HVAC test

For HVAC test, the voltage is increased using the voltage knob on the control desk. The voltage is increased until breakdown occurs. For each percentage of nanofillers, six reading are taken to get the average voltage breakdown. After taking data, the voltage is decrease until it reach zero voltage by using the same knob. Figure-3 shows the flowchart of HVAC Test.

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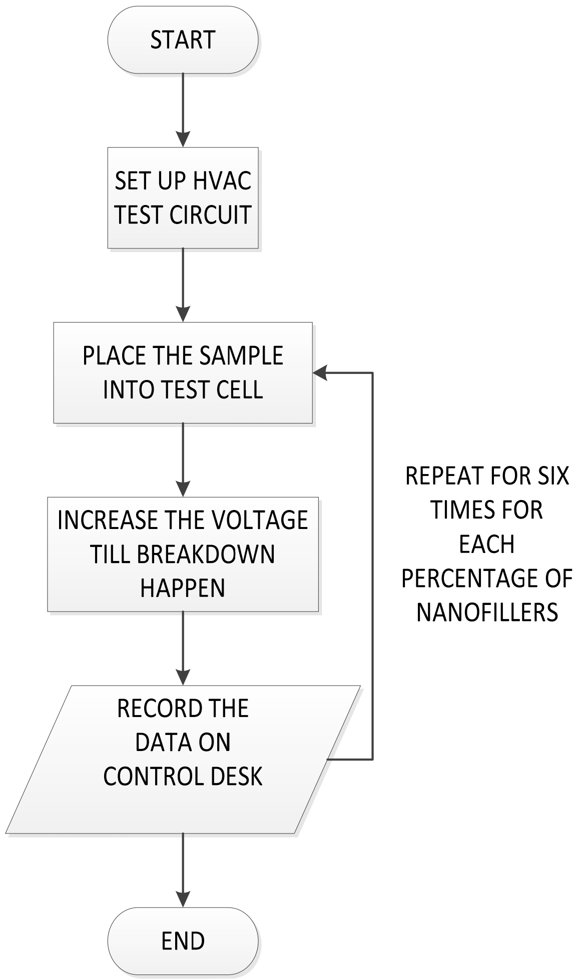

Figure-3. Flowchart of the HVAC test procedure.

Lightning impulse test

For Lightning Impulse Test, the procedures are a bit different compared to HVAC Test. After setting up the impulse test circuit and placed the insulator into the test cell, the sphere gap is adjusted. This is to make sure that the sphere gap distance is enough for the breakdown to happen. As the sphere gap is determined, the distance of the sphere gap is fix to same position throughout the experiment. Figure-4 shows the flowchart of the Lightning Impulse Test procedures.

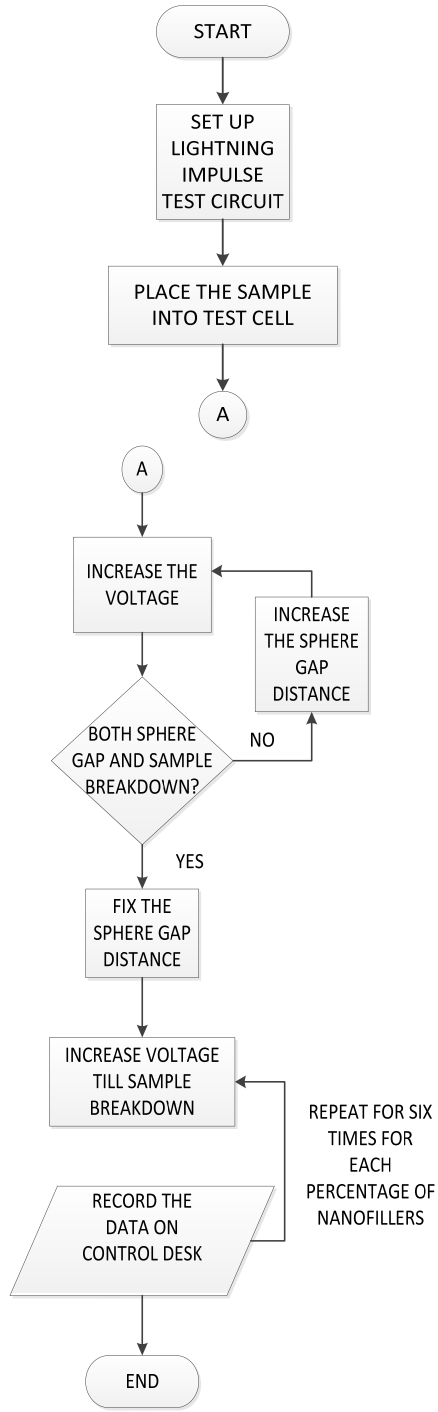

Figure-4. Flowchart of the HVAC test procedure.

Both HVAC Test and Impulse Test is conducted in a test cell with two fixed electrodes. The upper and lower electrode are sphere electrodes and the dielectric materials is the LLDPE Nanocomposite with different percentage of TiO_2 nanofillers which are 1%, 3%, 5% and 7%. Figure-5 shows the arrangement of sphere-sphere electrodes with the samples at the middle.

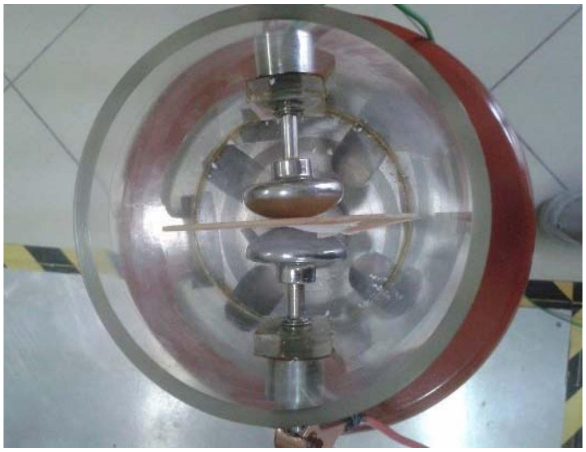

Figure-5. Arrangement of sphere-sphere electrodes with the samples at the middle.

Maximum allowable voltage for this experiment is 80KV. This is to ensure the safety of the equipment. The high voltage was connected to the upper electrode through current-limiting resistor to avoid excessive current that can cause damage to the electrodes, sample and the other equipment. Piece of paper is cut with the same size of the samples. The paper act as a film to see whether the samples is already breakdown or not. As the breakdown happen, the paper become torn and there are holes that can be seen on the paper.

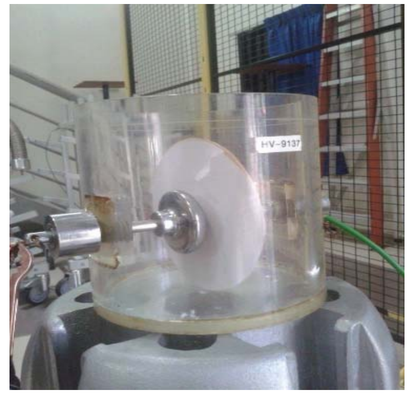

Figure-6. Paper act as a film being place together with the samples.

The thickness, the type and size of the electrode will remain constant as well as the voltage which is only allowed up until 80 kV and its frequency is 50 Hz. For each percentage of nanofillers, there will be six different readings and the total of the reading will be added to get the average readings. For each reading, the damaged paper will be replaced.

RESULT AND DISCUSSIONS

HVAC test result

In HVAC test, to analyse the data, all the values from the control desk will be recorded in the tables. For each percentage of nanofillers, six readings are taken and the average of the readings are the final result of the testing. Table-1 to Table-4 show the data that are being recorded.

Table-1. Data reading for 1% of TiO_2 nanofillers (AC test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
1%	1	36.17	87	1.2
	2	35.14	88	1.2
	3	36.84	86	1.2
	4	35.18	88	1.2
	5	36.93	93	1.3
	6	35.19	82	1.1
	Average	35.9	87.3	1.2

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Table-2. Data reading for 3% of TiO_2 nanofillers (AC test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
3%	1	37.9	84	1.1
	2	37.00	84	1.1
	3	35.50	81	1.0
	4	38.33	83	1.1
	5	37.79	88	1.2
	6	37.69	85	1.1
	Average	37.37	84.17	1.1

Table-3. Data reading for 5% of TiO_2 nanofillers (AC test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
5%	1	40.17	86	1.2
	2	39.07	87	1.2
	3	38.79	85	1.1
	4	37.29	83	1.1
	5	38.88	88	1.2
	6	37.08	86	1.1
	Average	38.55	85.83	1.2

Table-4. Data reading for 7% of TiO_2 nanofillers (AC test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
7%	1	39.76	87	1.2
	2	40.36	88	1.2
	3	41.14	91	1.2
	4	41.63	88	1.2
	5	38.49	84	1.1
	6	39.00	85	1.1
	Average	40.06	87.17	1.2

Lightning impulse test result

For Lightning Impulse Test, the data obtained from the control desk is recorded in the Table-5 until Table-8. For each percentage of nanofillers, six readings are taken and the averages of the readings are the final result of the testing. Table-5 to Table-8 show the data that are being recorded.

Table-5. Data reading for 1% of TiO_2 nanofillers (Lightning impulse test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
1%	1	49.50	101	0.8
	2	48.00	118	0.7
	3	47.46	108	0.6
	4	40.38	107	0.6
	5	50.00	112	0.9
	6	50.36	116	0.9
	Average	47.62	110	4.5

Table-6. Data reading for 3% of TiO_2 nanofillers (Lightning impulse test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
3%	1	49.33	110	0.9
	2	48.74	106	0.8
	3	49.03	109	0.8
	4	49.61	107	0.9
	5	52.20	114	0.9
	6	37.12	112	0.8
	Average	47.65	109	0.9

Table-7. Data reading for 5% of TiO_2 nanofillers (Lightning impulse test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
5%	1	48.70	107	0.6
	2	50.30	109	0.8
	3	50.80	110	0.7
	4	50.01	110	0.6
	5	50.14	114	1.0
	6	50.73	114	1.0
	Average	49.13	110	0.8

Table-8. Data reading for 7% of TiO_2 nanofillers (Lightning Impulse Test).

Percentage of TiO_2 nanofillers	No. of data	Breakdown voltage (kV)	Primary voltage (V)	Current, I
7%	1	49.80	111	0.8
	2	45.84	111	0.8
	3	48.10	109	0.6
	4	48.98	108	0.9
	5	50.19	114	0.9
	6	50.83	111	1.0
	Average	48.96	110	0.8

HVAC and lightning impulse test analysis

Table-9. The average breakdown voltage for impulse and ac tests.

Percentage	1wt %	3wt %	5wt %	7wt %
Impulse	47.62kV	47.65kV	49.13kV	48.96kV
HVAC	35.9kV	37.37kV	38.55kV	40.06kV

Table-5 shows the average breakdown voltage for both tests. The breakdown voltages for impulse test are higher compared to the HVAC test.

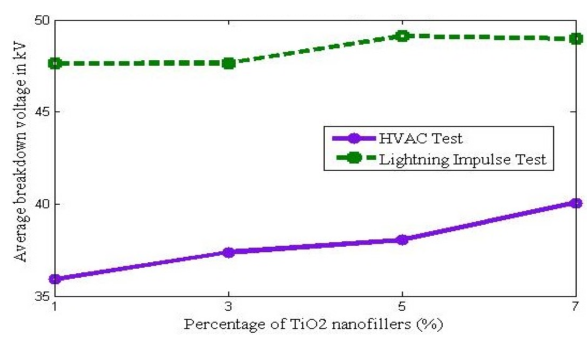

Figure-7. Average data value for all percentages of TiO_2 nanofillers for HVAC and Lightning Impulse Test.

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Based on the graph of the average voltage breakdown versus the percentage of nanofillers, the increment of percentage of TiO_2 nanofillers can increase the performance of electrical insulation of LLDPE/NR (80:20). It can be seen clearly in the graph that as the percentage of nanofillers increase, the voltage breakdown of the sample also increase.

Although the graph behaviour for the Lightning Impulse Test and HVAC Test show a little different in breakdown voltage, but the percentage of nanofillers with 7wt % still cause the breakdown voltage happen at the highest value compared to the other percentage of nanofillers.

Microstructure observation

Figures below show the sample's surface after undergoing high voltage test.

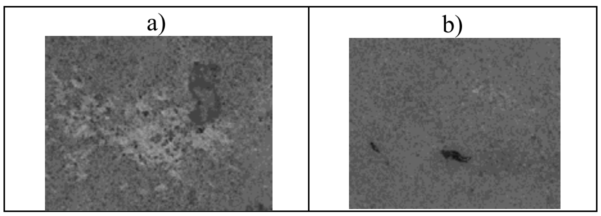

Figure-8. a) 1% LLDPE/NR TiO_2 sample's surface b) 3% LLDPE/NR TiO_2 sample's surface.

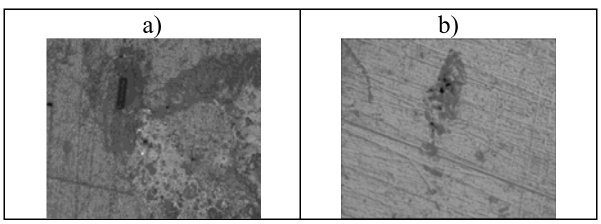

Figure-9. a) 5% LLDPE/NR TiO_2 sample's surface b) 7% LLDPE/NR TiO_2 sample's surface.

The difference between the microstructure of samples before and after undergoing high voltage tests can be seen clearly in the figures below. Sample with 1% of TiO_2 nanofillers, Figure-8(a) shows damage on its surface structure. Carbon track can be seen on the surface of the sample and the surfaces become sputtered due to the high voltage that had been applied to it.

Figure-8(b) which displays the microstructure surface of LLDPE/NR with 3% TiO_2 nanofillers shows less damage compared to LLDPE/NR with 1% TiO_2 nanofillers. Still, the carbon track still can be seen on the sputtered section of the sample's surface.

Figure-9(a) shows the microstructure surface of 5% LLDPE/NR TiO_2 while Figure-9(b) shows the sample's surface of 7% LLDPE/NR TiO_2. Sample's surface with 5% nanofillers is sputtered because of the breakdown happen and although the sample with 7% nanofillers shows a little damage, the carbon still can be seen on the surface.

CONCLUSIONS

After completing this project, it can be concluded that the percentage of nanofillers does effect the electrical insulating performance in high voltage application. The breakdown voltage of the samples is determined by two testings which are HVAC Test and Lightning Impulse Test. The breakdown voltage of the samples is determined by taking the average of the data.

From the graph, it is found that as the percentage of the nanofillers increase, the breakdown voltage for the samples also increases. The breakdown voltage for HVAC ranging from 35.90 kV with 1wt % of TiO_2 nanofillers while the highest breakdown voltage is 40.06 kV which belongs to samples with 7wt % of TiO_2 nanofillers. For Lightning Impulse Test, the lowest breakdown voltage belongs to lowest percentage of nanofillers, 1wt % which is 47.62 kV and the highest breakdown voltage belongs to 5wt % 49.13 kV

Based on researcher (Ibrahim, 1998), that has done a research on roles of fillers on properties of nano-TiO_2 and micro-SiO_2 filler mixed composites, he found that the breakdown strength of the nano-and-micro mixed composite (NMMC) increases with increasing nano-TiO_2 filler. However, the impulse test results show that the highest breakdown voltage is for 5wt %. This is maybe because of the fault of the equipment. Therefore, it can be conclude that the optimum percentage of nanofillers that enhance the electrical insulation performance is 7wt % of TiO2 nanofillers.

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