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Dielectric properties of Blending Nano zeolite for polymer using the least square method

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Abstract: The advancement of the isolation field is regarded as one of the most important processes and research that occupies all minds of workers in the field of high voltage, as each advancement results in isolators with a higher degree of insulation and a lower cost. Ethylene Propylene Rubber (EPR) is widely used in high and medium voltage cable insulation due to its low dielectric losses and its ability to improve cable properties in high temperatures. This paper aims to improve EPR electrical properties (dielectric strength) for high voltage and medium voltage cables by adding inorganic Nano fillers with different concentrations .Blends of the powder Nano fillers that have been used are Nano Zeolite ($Na2Al2Si3O10.2H2O$) With particle sizes (0.5, 1, 2.5, and 4 gm.) respectively.

The dielectric strength of the blends was tested at different temperatures ranging from room temperature to 120ºC.

Results were analyzed using the least squareMethod to determine the optimum mixing EPR /Nano zeolite blend which gives the best of electrical properties.

Keywords: Polymers; EPR / Zeolite fillers; dielectric strength; least square method.

I. Introduction

"Polymer" This word consists of two syllables the first is (poly) mean numerous and the second (mers) mean units or bilateral molecules. The process of converting these units to the polymer is called polymerization.

Polymers are chemical compounds characterized by the chain length but the length of the string that causes the large molecular weight of the compound resulting from repeating units in the similar same order along the chain, and therefore called composite polymer and maybe the basic constituent unit is composed of a polymer of one or more material and so-called recurring polymer unit in the name of Monomer[1, 2].

Filler" is a form of a material, typically particulate, that is embedded in a polymeric matrix toConstitute composite materials. Usually, the fillers are incorporated in the composite materials inorder to improve or add various properties, e.g., mechanical, thermal, optical, dielectric, electric, Magnetic, etc. the Chemical structure and amount of the fillers are just a part of factors that determinethe properties of the composites. The other important the factors include morphological factors such

As Shape, size, and state of dispersion of the fillers. The Interface between the filler and the matrix polymer isalso crucial for composite properties. Any kind of materials can be considered as fillers; they can beinorganic, organic, carbonaceous, or metallic and in solid, liquid, or even in the gas phase[3, 4] .

Dielectric strength is one of the most important electrical characteristics that must be taken into account when designing any cable and it defined as the ability of a material to withstand electrical breakdown when a voltage is applied. It usually depends on the thickness of the material and on the method and conditions of the test. To calculate the dielectric strength the samples are placed between two electrodes and applying a voltage across these two electrodes and increasing the voltage until the break down occurs. It can be expressed as the higher the dielectric strength of the material the better an electrical insulator it makes. Dielectric strength can be tested according to standards such as ASTM D149[5, 6].

The current work has been devoted to studying the dielectric strength under different temperatures, and different ratios of Nano-zeolite to determine the filler mixing ratio of EPR that gives a good performance as an insulating material.

II. METHODOLOGY

A. Blend Preparation

The chemical ingredients of the materials used in the present investigation are as follows:

1-Ethylene Propylene Rubber (EPR)

It was supplied by EGYPT AFRICA S.A.E.

2-Nano Zeolite.

Nano fillers were supplied by nanotech Egypt

The samples were made by mixing the Nano zeolite filler with the base polymer (EPR). Various grams of Nano-zeolite have been added to the EPR polymer. A pure EPR sample without Nano-zeolite filler was considered as a reference .

five blend samples have been prepared as :pure EPR without Nano zeolite,{0.5,1,2.5,4 }gram Nano zeolite Which represents {0.5%,1%,2.5%,4%} of the weight EPR filled.

One of the main problems of Nanoparticles is to obtain an optimal dispersion, otherwise, large particle aggregates or large regions in the matrix that are devoid of Nano particles can be achieved .

The samples were applied in a laboratory model of two roll mill (470 mm diameter and 300mm operating distance). The samples were cut and prepared with dimensions to suit the dielectric strength testing method according to ASTM[7].

B. Dielectric Breakdown Strength Test.

Dielectric strength is one of the most important electrical characteristics that must be considered when designing any cable and it defined as the ability of a material to withstand electrical breakdown when a voltage is applied .

It usually depends on the thickness of the material and on the method and conditions of the test. The results are expressed in kV/mm[8].

Sets of blend samples have been prepared and tested using A.C voltage. Samples are in the form of a disc with 5 cm diameter and 1 mm thickness for the dielectric strength test and the test is carried out according to ASTM [9].

The procedures and precautions required during the dielectric strength test are as follows:

- Test samples should be clean and dry before starting high voltage tests.
- The electrodes should be fixed into the samples, one at the top and the other on the bottom end.
- Circuit links should be correct before applying the electrical test to ensure safety. Fig. 1 shows the schematic diagram which represents the dielectric strength testing circuit.
- The voltage is gradually increased at an almost constant rate of 2 kV/sec until the voltage breakdown occurs.

The arc shown in Fig.2 illustrates the process of the dielectric breakdown strength test for a sample of the blend.

The relation (equation) between different dielectric strength values and the content of Nano zeolite percentage in the blend was interpreted by the least square method using MATLAB Each sample has been tested several .times to ensure the results and the average is taken to minimize the error

All of the practical results have been precisely gathered and recorded in tabulated forms and then plotted to be easy for discussion and analysis.

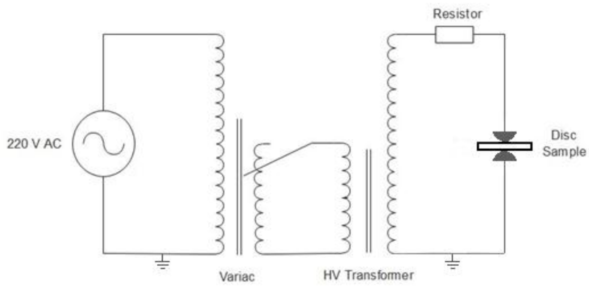

Fig. 1. Schematic diagram for the dielectric strength testing circuit

Fig. 2.Dielectric breakdown strength test in high voltage laboratory.

III. Least Square Method

Experimental data is exact about specific points but it is needed to predict intermediate values which can't be easily carried out. A convenient method for these cases is to derive a mathematical model or a function that fits the shape of the data without the necessity of matching all points

Least square method is used to minimize the discrepancy between the data points and the curve, which will be used in analyzing the obtained results[10].

A. Problem statement.

The main objective of the method is to adjust the parameters of a model function to find the best fit of a data set. A simple data set consists of n points (xi, yi), i = 1 n, where xi is an independent variable and yi is a dependent variable.

A regression line is defined as a straight line that describes how a dependent variable y changes when an independent variable x changes. It is used to predict the value of y for a given value of x[11].If this fit is a straight line, then

(x)=ax+b (1)

$$Error = \sum d_i^2$$

$$Error = [y_1 - f(x_1)]^2 + [y_2 - f(x_2)]^2 + [y_3 - f(x_3)]^2 + [y_4 - f(x_4)]^2 (2)$$

$$Error = \sum_{i=1}^{N} [y_i - f(x_i)]^2 = \sum_{i=1}^{N} [y_i - (ax_i + b)]^2 (3)$$

The best line has minimum error between line and data points, this is called the least squares approach.

$$Minimize\ \{Error\} = \sum_{i=1}^{N} [y_i - (ax_i + b)]^2 (4)$$

Taking the derivative of the error with respect to a, set the equation to zero.

$$\frac{\partial (Error)}{\partial a} = \frac{\partial \left(\sum_{i=1}^{N} [y_i - (ax_i + b)]^2 \right)}{\partial a} = 0 \qquad (5)$$

$$\frac{\partial (Error)}{\partial a} = -2 \left(\sum_{i=1}^{N} x_i [y_i - (ax_i + b)] \right) = 0 \quad (6)$$

Making the same with respect to b.

$$\frac{\partial (Error)}{\partial b} = \frac{\partial (\sum_{i=1}^{N} [y_i - (ax_i + b)]^2)}{\partial b} = 0 \qquad (7)$$

$$\frac{\partial (Error)}{\partial b} = -2 \left(\sum_{i=1}^{N} [y_i - (ax_i + b)] \right) = 0 \qquad (8)$$

Solve for a and b so that equations (4.6) and (4.8) both equal zero

$a\sum_{i=1}^{N} x_i^2 + b\sum_{i=1}^{N} x_i = \sum_{i=1}^{N} x_i y_i$ (9)

$a\sum_{i=1}^{N} x_i + bN = \sum_{i=1}^{N} y_i$ (10)

Put these equations into matrix form

$$\begin{bmatrix} \sum_{i=1}^{N} x_i^2 & \sum_{i=1}^{N} x_i \\ \sum_{i=1}^{N} x_i & N \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{N} x_i y_i \\ \sum_{i=1}^{N} y_i \end{bmatrix} \quad (11)$$

$$a = \frac{N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N\sum_{i=1}^{N} x_i^2 - [\sum_{i=1}^{N} x_i]} \quad (12)$$

$$b = \frac{\sum_{i=1}^{N} y_i \sum_{i=1}^{N} x_i^2 - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} x_i y_i}{N\sum_{i=1}^{N} x_i^2 - [\sum_{i=1}^{N} x_i]} \quad (13)$$

B. Polynomial Regression.

Representing engineering data by a line isn't convenient for many cases so, it would be preferable to fit the data by a curve using polynomial regression.

The least square procedure can be extended to fit the data to a higher-order polynomial. So, fitting a second-order polynomial as [30]:

Suppose that we fit a second-order polynomial or quadratic:

$y = a_0 + a_1 x + a_2 x^2 + e$ (14)

$$Error = \sum_{i=1}^{n} d_i^2 = \sum_{i=1}^{n} (y_i - a_0 - a_1 x - a_2 x^2)^2$$

$Error = \sum_{i=1}^{n} (y_i - a_0 - a_1 x - a_2 x^2)^2$ (15)

Applying the same procedure of the previous section, taking the derivative of equation (4.15) with respect to each of unknown coefficients of the polynomial $a_0, a_1 and a_2$ as:

$\frac{\partial Error}{\partial a_0} = -2\sum (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$ (16)

$\frac{\partial Error}{\partial a_1} = -2\sum x_i (y_i - a_0 - a_1 x_i - a_2 x_i^2)$ (17)

$\frac{\partial Error}{\partial a_2} = -2\sum x_i^2 (y_i - a_0 - a_1 x_i - a_2 x_i^2)$ (18)

The equations are then set equal to zero and rearranged to develop the following set of normal equations:

$(n)a_0 + (\sum x_i)a_1 + (\sum x_i^2)a_2 = \sum y_i$ (19)

$(\sum x_i)a_0 + (\sum x_i^2)a_1 + (\sum x_i^3)a_2 = \sum x_i y_i$ (20)

$(\sum x_i^2)a_0 + (\sum x_i^3)a_1 + (\sum x_i^4)a_2 = \sum x_i^2 y_i$ (21)

Where all summations are from i=1 through n.

Putting these equations into matrix and using the following method:

$AX = B$ (22)

$X = A^{-1} * B$(23)

Where:

$$A = \begin{bmatrix} n & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix}, X = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} and B = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \end{bmatrix} (24)$$

The coefficients a_0, a_1 and a_2 can be then easily calculated from the measured data. The two-dimensional case can be easily extended to an mth order polynomial as:

$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_m x^m + e (25)$$

C. Coefficient of determination (R2).

Coefficient of determination (R2) is the square of multiple correlation coefficient between y and x1, x2,…,xn .

Its value describes how well the regression line fits to the actual measured data. Which is considered a measure of goodness of the fitting for the model.

Then

$$R^2 = 1 - \frac{SS_{res}}{SS_T} \qquad (26)$$

Where:

R2 is the Coefficient of determination,

SS_{res} is the sum of squares due to residuals and

SS_T is the total sum of squares[12].

IV. Results and Analysis

1. at 25ºc Calculations(room temperature)

10 samples were made for each mixture

The average was taken for each (10 samples) mixture.

This is to obtain 5 readings from a total of 50 test samples at room temperature.

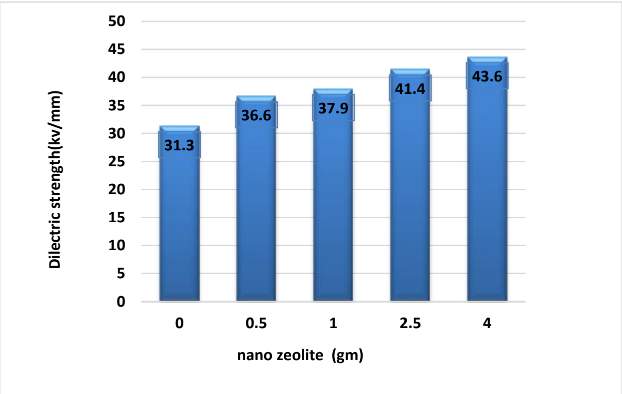

Fig. 3. Dielectric strength (kV/mm) of blend samples at 25ºc

material	Nano zeolite(gm)	Dielectric strength(kv/mm)
Ethylene propylene rubber (EPR)	0	31.3
	0.5	36.6
	1	37.9
	2.5	41.4
	4	43.6

The samples are tested at room temperature. Fig. 3 shows that pure EPR (1st sample) has the minimum value of dielectric strength of 31.3 kV/mm.

While when adding 4 grams of nano zeolite to the EPR (5th sample) has the maximum value of dielectric strength of 43.6 kV/mm. The blend samples have values in between.

As the amount of nano zeolite increases, the dielectric strength increase

Applying the least-square criterion using the MATLAB program (curve fitting toolbox), the best curve fitting for the obtained results from the test is shown in Fig. 4. Representing the data by a 3rd degree polynomial equation to minimize the error as possible:

$$y = a_1x^3 + a_2x^2 + a_3\text{x} + a_4 \qquad (27)$$

Where

y is the dielectric strength value,

x is the value of Nano zeolite in the blend,

$a1$ is a constant = 0.48752,

$a2$ is a constant = -3.7476,

$a3$ is a constant = 10.201,

$a4$ is a constant = 31.579, and

R^2 = 0.9876

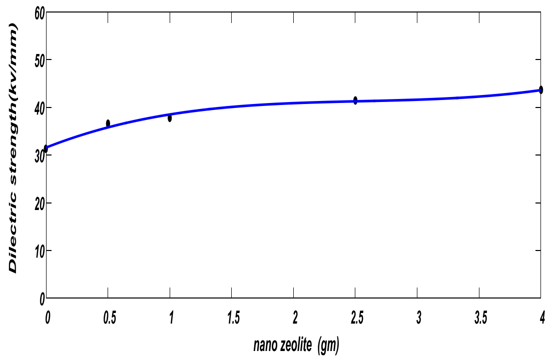

Fig. 4. Curve fitting results for the dielectric strength of blend samplesat 25ºc

2-at 50ºc Calculations

samples were made for each mixture 10

The samples were placed in a hot air oven at 50 ° C for 24 hours thereafterThe average was taken for each

This is to obtain 5 readings from a total of 50 test samples at a temperature of 50 ° C..(10 samples) mixture

material	Nano zeolite(gm)	Dielectric strength(kv/mm)
Ethylene propylene rubber (EPR)	0	30.2
	0.5	33.5
	1	36.2
	2.5	38.2
	4	41.1

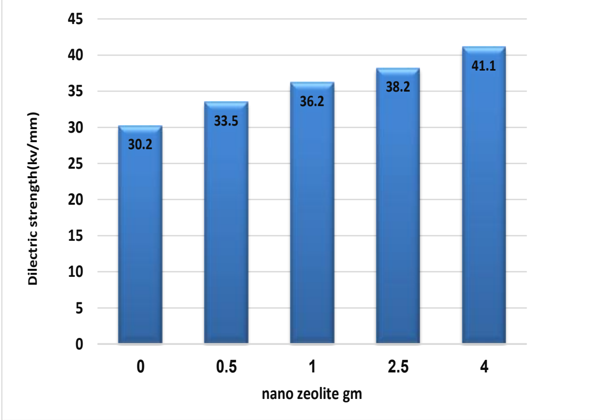

Fig.5. Dielectric strength (kV/mm) of blend samples at 50ºc

The samples are tested at 50ºC. Fig.5.shows that pure EPR (1st sample) has the minimum value of dielectric strength of 30.2 kV/mm.

While when adding 4 grams of nano zeolite to the EPR (5th sample) has the maximum value of dielectric strength of 41.1kV/mm. The blend samples have values in between.

As the amount of nano zeolite increases, the dielectric strength increaseApplying the least-square criterion using the Matlab program (curve fitting toolbox), the best curve fitting for the obtained results from the test is shown in Fig. 6. Representing the data by a 3rd degree polynomial equation to minimize the error as possible:

$$y = a_1x^3 + a_2x^2 + a_3\text{x} + a_4 \qquad (28)$$

Where

y is the dielectric strength value,

x is the value of Nano zeolite in the blend,

$a1$ is a constant = 0.47616,

$a2$ is a constant = -3.4314,

$a3$ is a constant = 8.8515,

$a4$ is a constant = 30.115, and

R^2 = 0.9985

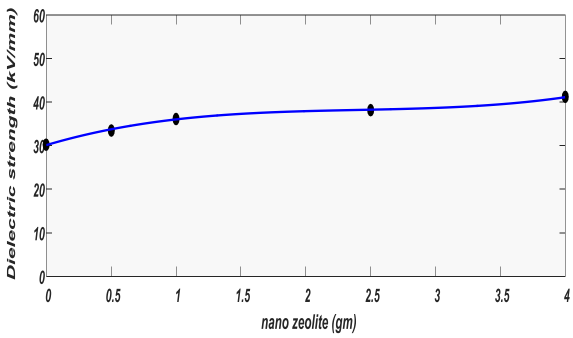

Fig. 6. Curve fitting results for the dielectric strength of blend samples at 50ºc

3-at 90ºc Calculations

samples were made for each mixture 10

The samples were placed in a hot air oven at 90 ° C for 24 hours thereafterthe average was taken for each (10 samples) mixture. This is to obtain 5 readings from a total of 50 test samples at a temperature of 90 ° C.

material	Nano zeolite(gm)	Dielectric strength(kv/mm)
Ethylene propylene rubber (EPR)	0	28.4
	0.5	32.3
	1	35.6
	2.5	35.7
	4	40.4

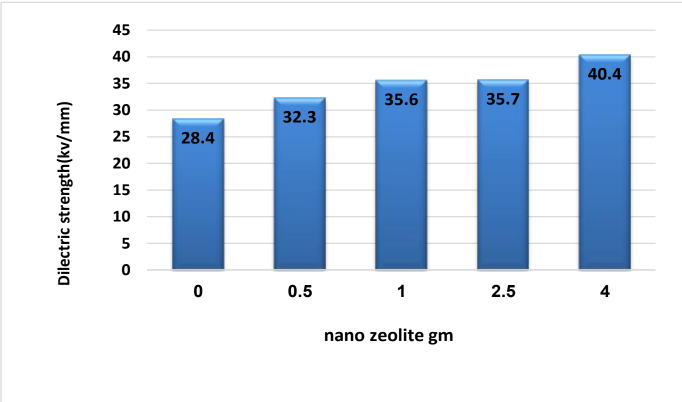

Fig.7. Dielectric strength (kV/mm) of blend samples at 90ºc

The samples are tested at 90ºC. Fig.5.shows that pure EPR (1st sample) has the minimum value of dielectric strength of 28.4kV/mm.

While when adding 4 grams of nano zeolite to the EPR (5th sample) has the maximum value of dielectric strength of 40.4kV/mm. The blend samples have values in between.

As the amount of nano zeolite increases, the dielectric strength increaseApplying the least-square criterion using the Matlab program (curve fitting toolbox), the best curve fitting for the obtained results from the test is shown in Fig. 6. Representing the data by a 3rd degree polynomial equation to minimize the error as possible:

$$y = a_1x^3 + a_2x^2 + a_3\text{x} + a_4 \qquad (21)$$

Where

y is the dielectric strength value,

x is the value of Nano zeolite in the blend,

$a1$ is a constant = 0.88331,

$a2$ is a constant = -5.7298,

$a3$ is a constant = 11.827,

$a4$ is a constant = 28.221, and

R^2 = 0.9985

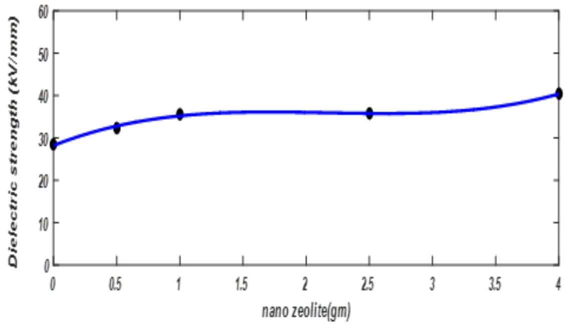

Fig. 8. Curve fitting results for the dielectric strength of blend samples at 90ºc

4-at 120ºc Calculations

10 samples were made for each mixture

The samples were placed in a hot air oven at 120 ° C for 24 hours thereafterthe average was taken for each (10 samples) mixture.This is to obtain 5 readings from a total of 50 test samples at a temperature of 120 ° C

material	Nano zeolite(gm)	Dielectric strength(kv/mm)
Ethylene propylene rubber (EPR)	0	26.6
	0.5	28.9
	1	30.3
	2.5	32.8
	4	34.4

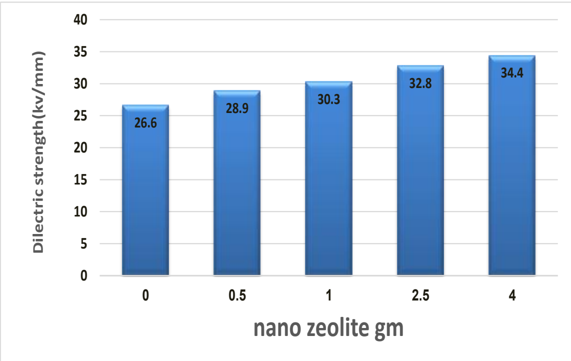

Fig.9. Dielectric strength (kV/mm) of blend samples at 120ºc

The samples are tested at 120ºC. Fig.5.shows that pure EPR (1st sample) has the minimum value of dielectric strength of 30.2kV/mm.

While when adding 4 grams of nano zeolite to the EPR (5th sample) has the maximum value of dielectric strength of 41.1kV/mm. The blend samples have values in between.

As the amount of nano zeolite increases, the dielectric strength increase

Applying the least-square criterion using the MATLAB program (curve fitting toolbox), the best curve fitting for the obtained results from the test is shown in Fig. 6. Representing the data by a 3rd degree polynomial equation to minimize the error as possible:

$$y = a_1x^3 + a_2x^2 + a_3x + a_4 \quad (21)$$

Where

y is the dielectric strength value,

x is the value of Nano zeolite in the blend,

$a1$ is a constant = 0.16954,

$a2$ is a constant = -1.4475,

$a3$ is a constant = 5.0194,

$a4$ is a constant = 26.634, and

R^2 = 0.9996

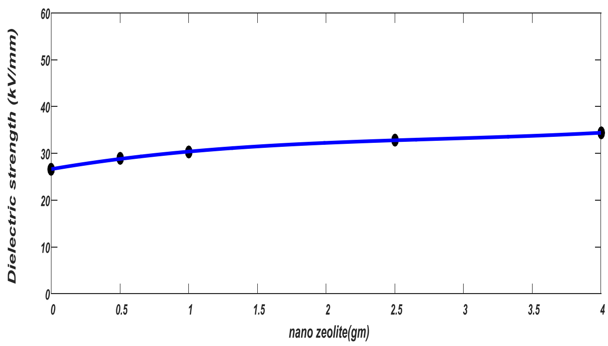

Fig. 10. Curve fitting results for the dielectric strength of blends samples at 120ºc

V. Conclusion

It can be concluded that,

1-Samples were evaluated by electrical insulation test.
2-The nano-reinforced manufactured samples showed the best performance when compared to the nano-free samples
3- As the amount of nanostructures added to the sample increases, the dielectric strength is improved.

Acknowledgment

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