Original Research Article

Estimate Electrical Resistivity of Epoxy Insulators Using Artificial Neural Network

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Abstract: Epoxy resin represents a commonly used basis for insulation materials and has been used in many different electrical applications. In this paper, different micro fillers such as Silicone dioxide (SiO_2) and Barium iodate ($Ba (IO_3)_2$) were added to epoxy resin to improve electrical characteristics in different contaminated conditions. The electrical resistivity (ohm.cm) was carried out. The samples were prepared by mixing micro filler into epoxy with the content of 0, 5, 10, 15, 20 and 25 wt%. The artificial neural network (ANN) technique was used to evaluate electrical resistivity in different contaminated conditions and different fillers concentrations. The results show that the electrical resistivity of epoxy composites is increased with the increase of filler concentration. Maximum electrical resistivity (ohm.cm) value was obtained from micro Barium iodate composite with 25 wt% filler concentration.

Keywords: Epoxy resin, Silicone dioxide filler, Barium iodate filler, Electrical resistivity, Artificial neural network.

INTRODUCTION

Epoxy resin insulators have been successfully used in high voltage equipment for AC systems for more than 60 years. Epoxy resins are ideal for these applications because of their high specific stiffness, high specific strength, electrical insulating properties, corrosion resistance, chemical compatibility with reinforcing fibers, and relative ease of manufacture [1].

Fillers are often added to epoxy resin to enhance its mechanical, thermal and chemical properties. The addition of fillers can deteriorate electrical performance. With the new development in nanotechnology, it has been widely anticipated that the combination of nanoparticles with traditional resin systems may create nanocomposite materials with enhanced electrical, thermal and mechanical properties [2-6].

Epoxy resins were first commercialized from seventy years and are widely used in industry as protective coatings and for structural applications, such as laminates and composites, tooling, molding, casting, bonding and adhesives, and others. The ability of the epoxy ring to react with a variety of substrates gives the epoxy resins versatility [7].

EXPERIMENTAL

Samples Preparation

The filler is loaded to the resin/hardener mixture which is again stirred slowly till the particles have been uniformly mixed with the resin under the magnetic field and the air bubbles have escaped. The mixture is then poured carefully into a mold and left at room temperature (25℃±1) until curing after 24 hours and 7 days for material stability. The mixture of epoxy composite takes the mold shape. There are different ratios of each filler SiO2 and Ba (IO3)2 (5 up

to 25% by weight). The mixing formulation of epoxy composite samples at different types and concentrations of fillers is given in Table 1.

Table-1: The Mixing formulation of epoxy with different type and concentration of fillers

Filler concentration	Filler type	
	SiO_2	$Ba(IO_3)_2$
0	P	P
5	Si_5	Ba_5
10	Si_{10}	Ba_{10}
15	Si_{15}	Ba_{15}
20	Si_{20}	Ba_{20}
25	Si_{25}	Ba_{25}

Electrical Resistivity Test

Reading of resistance is recorded by meter as shown in Fig-1 and Fig-2 [8-9]. Resistivity depends on the value of resistance and the sample dimensions. The electrical resistivity (ρ) of a solid material is determined by passing an electric current through a specimen and then measuring the resultant voltage drop over a certain length. the electrical resistivity formula can be written as (1):
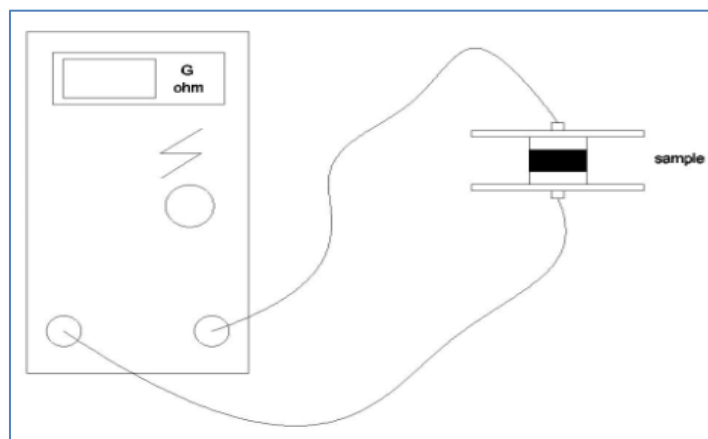
$$\rho = \frac{R.A}{L} \tag{1}$$

Where,

R: is the electrical resistance of a uniform specimen (ohms: Ω)

A is the cross-sectional area of the specimen (cm^2)

L is the length of the specimen (cm)

Fig-1: Electrical resistivity tester

Fig-2: Schematic diagram of resistivity test arrangement for insulator

Artificial Neural Network Simulation

In several fields artificial intelligence (AI) is used more and more frequently: for control, fail detection, or to predict variables. One of the most widely used AI tools is the neural network, and the most widely used neural network architecture is the multilayer feed forward Fig-3. As proved in the universal approximation theorem [10] a feed-forward network with a single hidden layer, is capable of approximating any continuous functions defined on compact training data sets. It is common to apply the classical training algorithm, based on the minimization of the mean squared error (MSE) cost function, with the process (training) data. A comprehensive fundamentals of ANN can be found in [11].
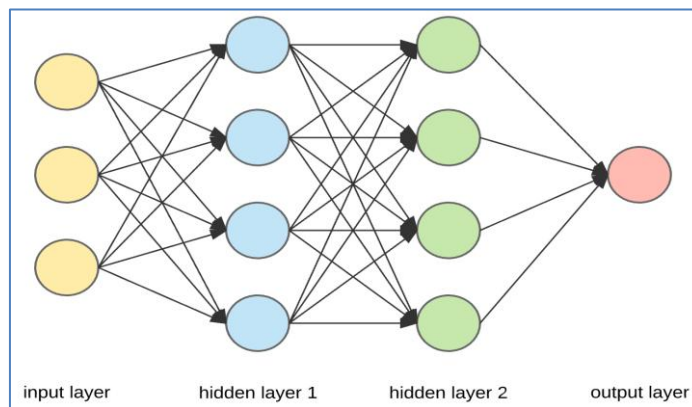

Fig-3: Full connected multilayer feed-forward neural network

RESULTS AND DISCUSSION

Electrical Resistivity Test Measurements at different contaminated conditions

Dry Condition

The electrical resistivity (ohm.cm) for epoxy has been investigated with different micro fillers type and concentration in dry condition. Fig-4 shows the relation of electrical resistivity and different percentages of micro SiO_2 and $Ba(IO_3)_2$ fillers added to epoxy in dry condition.
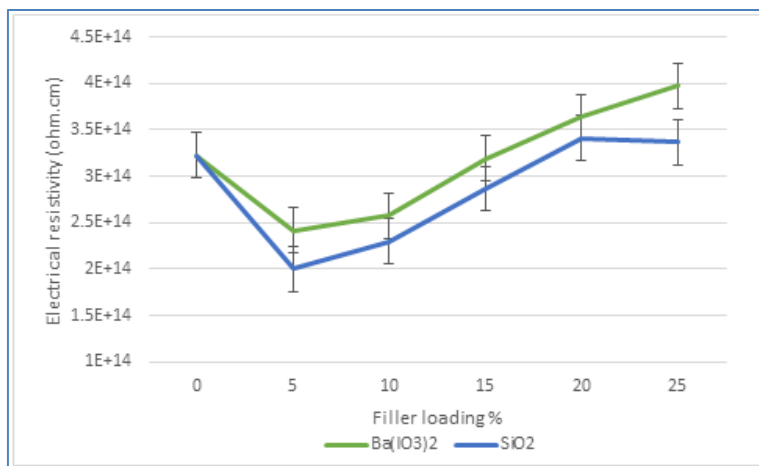

Fig-4: Electrical resistivity of micro composite loaded with different types and concentrations of fillers in dry condition

The electrical resistivity (ohm.cm) is measured for micro composite samples Fig-4. The increase of filler micro SiO_2 and $Ba(IO_3)_2$ fillers concentration results in increasing the electrical resistivity. Fig-4. shows that the epoxy composite with 25 wt% micro $Ba(IO_3)_2$ filler records maximum electrical resistivity at $3.98x10^{14}$ ohm.cm. When the filler type also changes, the electrical resistivity of composite material changes.

Wet Condition

After immersion in a container of distilled water as a simulation of wet weather and rains the samples are tested for electrical resistivity. Fig-5 shows the relation of electrical resistivity and different percentages of micro SiO_2 and $Ba(IO_3)_2$ fillers added to epoxy in wet condition.
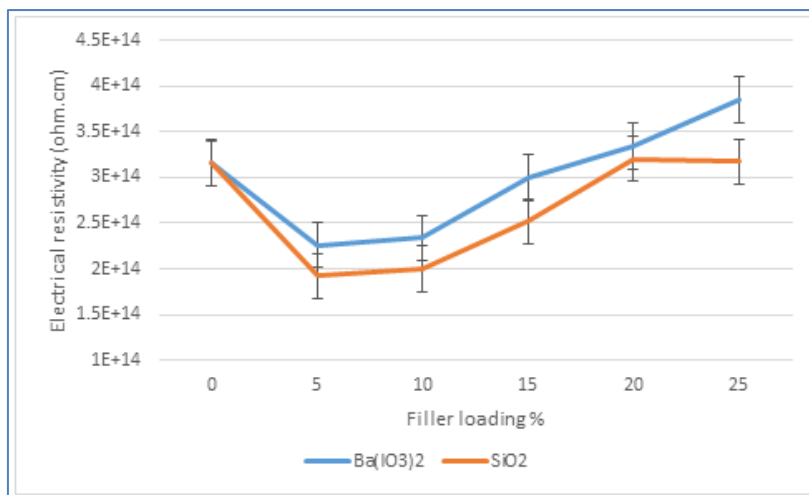
Fig-5: Electrical resistivity of micro composite loaded with different types and concentrations of fillers in wet condition

The results showed that after adding different fillers, the electrical resistivity (ohm.cm) of epoxy has been improved significantly. It is obviously shown in Fig-5. that with the increase of filler content (from 0% to 25%), the electrical resistivity (ohm.cm) of epoxy is increased. The electrical resistivity (ohm.cm) of micro Barium iodate composite is higher than micro silicon dioxide composite. The electrical resistivity (ohm.cm) of micro Barium iodate composite increases and reaches the highest value of $3.85 x 10^{14}$ ohm.cm at the percentage of 25 wt% as shown in Fig-5.

Salty Wet Condition
For a simulation of areas near to seas or coastal cities, samples are immersed into a container of NaCl solution and tested for electrical resistivity (ohm.cm). Fig-6 shows the relation of electrical resistivity (ohm.cm) and different percentages of micro SiO_2 and $Ba(IO_3)_2$ fillers added to epoxy in salty wet condition.
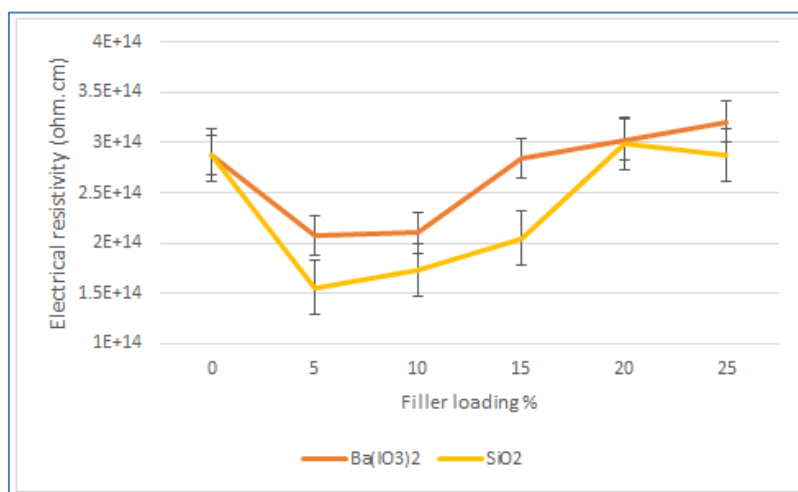

Fig-6: Electrical resistivity of micro composite loaded with different types and concentrations of fillers in salty wet condition

Clearly the presence of micro Barium iodate filler has offered appreciable electrical resistivity (ohm.cm) in comparison to pure epoxy. It can be shown from Fig-6 that, the maximum electrical resistivity (ohm.cm) is recorded for micro Barium iodate composites with the content of 25 wt%, but micro silicone dioxide composite has the maximum electrical resistivity (ohm.cm) when the filler concentration is 20 wt%. With increasing the concentration of micro silicone dioxide filler up to 20%, the electrical resistivity (ohm.cm) showed an enhanced performance as shown in Fig-6.

Artificial Neural Network Results
The experimental measurements of electrical resistivity (ohm.cm) of different epoxy composite samples were used to train the ANN model. The ANN model has two inputs (the content of SiO_2 and $Ba(IO_3)_2$ fillers in epoxy and the test condition); the output is the electrical resistivity(ohm.cm). The feed-forward neural network model that has been used was built by writing m-file code using MATLAB neural network toolbox [12].

ANN Model for Estimating Electrical Resistivity (ohm.cm) *of Micro Ba(IO₃)₂ Composites in Different Contaminated Condition*

Table-2, and Fig-7 show the test results of ANN model in different contaminated conditions such as dry, wet and salty wet.

Table-2: ANN and experimental results for electrical resistivity of micro Ba(IO₃)₂ /epoxy composites in different contaminated conditions

Composite code	Condition of test	Electrical Resistivity (ohm.cm)		
		Experimental results	ANN results	Residual ($O_{act.} - O_{NN}$) (%)
P	Dry	$3.23*10^{14}$	$3.1400*10^{14}$	2.7863
Ba₅		$2.42*10^{14}$	$2.4635*10^{14}$	1.7975
Ba₁₀		$2.58*10^{14}$	$2.5161*10^{14}$	2.4767
Ba₁₅		$3.19*10^{14}$	$3.0906*10^{14}$	3.1159
Ba₂₀		$3.64*10^{14}$	$3.5444*10^{14}$	2.6263
Ba₂₅		$3.98*10^{14}$	$3.8646*10^{14}$	2.8994
P	Wet	$3.16*10^{14}$	$3.1400*10^{14}$	0.6329
Ba₅		$2.26*10^{14}$	$2.4234*10^{14}$	7.2301
Ba₁₀		$2.34*10^{14}$	$2.5160*10^{14}$	7.5213
Ba₁₅		$3.00*10^{14}$	$3.0905*10^{14}$	3.0166
Ba₂₀		$3.34*10^{14}$	$3.5442*10^{14}$	6.1137
Ba₂₅		$3.85*10^{14}$	$3.8645*10^{14}$	0.3766
P	Salty wet	$2.58*10^{14}$	$2.5637*10^{14}$	0.6317
Ba₅		$2.07*10^{14}$	$2.2037*10^{14}$	6.4589
Ba₁₀		$2.1*10^{14}$	$2.1278*10^{14}$	1.3238
Ba₁₅		$2.84*10^{14}$	$2.7911*10^{14}$	1.7218
Ba₂₀		$3.03*10^{14}$	$2.9981*10^{14}$	1.0528
Ba₂₅		$3.21*10^{14}$	$3.0275*10^{14}$	5.6853
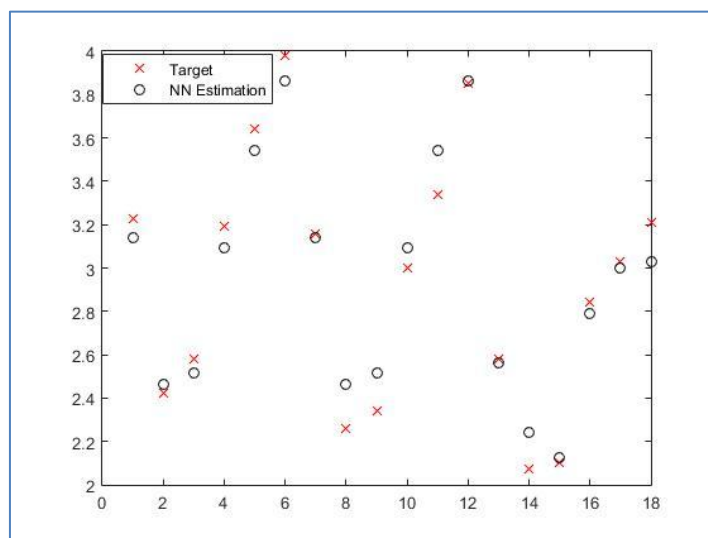
Fig-7: ANN results for the electrical resistivity of Ba (IO₃)₂ /epoxy composite samples under different contaminated conditions
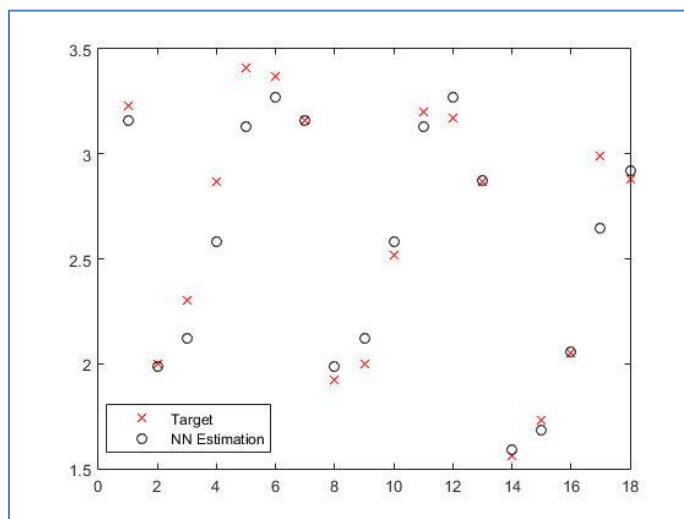
It can be noted from Table-2 and Fig-7 that ANN model has been trained which can evaluate the electrical resistivity (ohm.cm) of different concentrations of Ba(IO₃)₂ in epoxy composites. The average percentage of errors was evaluated for ANN model and ranging from 0.3766% for sample Ba₂₅ to 7.2301% for sample Ba₅ as shown in Table-2.

ANN Model for Estimating Electrical Resistivity of Micro SiO₂ Composites in Different Contaminated Conditions

Table-3, and Fig-8 show the test results of ANN model in different contaminated conditions such as dry, wet and salty wet.

Table-3: ANN and experimental results for electrical resistivity (ohm.cm) of micro SiO$_2$ /epoxy composites in different contaminated conditions

Composite code	Condition of test	Electrical Resistivity (ohm.cm)		
		Experimental results	ANN results	Residual ($O_{act.}$ -O_{NN}) (%)
P	Dry	$3.23*10^{14}$	$3.1600*10^{14}$	2.1671
Si$_5$		$2.00*10^{14}$	$1.9874*10^{14}$	0.6300
Si$_{10}$		$2.30*10^{14}$	$2.1213*10^{14}$	7.7695
Si$_{15}$		$2.87*10^{14}$	$2.6805*10^{14}$	6.6027
Si$_{20}$		$3.41*10^{14}$	$3.185*10^{14}$	6.4956
Si$_{25}$		$3.37*10^{14}$	$3.2704*10^{14}$	2.9554
P	Wet	$3.16*10^{14}$	$3.1599*10^{14}$	0.0031
Si$_5$		$1.92*10^{14}$	$1.9874*10^{14}$	3.5104
Si$_{10}$		$2.00*10^{14}$	$2.1213*10^{14}$	6.0650
Si$_{15}$		$2.52*10^{14}$	$2.5805*10^{14}$	2.4007
Si$_{20}$		$3.20*10^{14}$	$3.1285*10^{14}$	2.2343
Si$_{25}$		$3.17*10^{14}$	$3.2704*10^{14}$	3.1671
P	Salty wet	$2.58*10^{14}$	$3.0729*10^{14}$	7.4181
Si$_5$		$1.56*10^{14}$	$1.5923*10^{14}$	2.0705
Si$_{10}$		$1.73*10^{14}$	$1.6830*10^{14}$	2.7167
Si$_{15}$		$2.05*10^{14}$	$2.0568*10^{14}$	0.3317
Si$_{20}$		$2.99*10^{14}$	$2.7866*10^{14}$	6.8026
Si$_{25}$		$2.88*10^{14}$	$2.9202*10^{14}$	1.3958

Fig-8: ANN results for the electrical resistivity of SiO$_2$ /epoxy composite samples under different contaminated conditions

It can be noted from Table-3 and Fig-8 that ANN model has been trained which can evaluate the electrical resistivity (ohm.cm) of different concentrations of SiO$_2$ in epoxy composites. The average percentage of errors was evaluated for ANN model and ranging from 0.0031% for sample P to 7.7695% for sample Si$_5$ as shown in Table-3.

CONCLUSION

The following conclusions can be drawn from this study
The electrical resistivity (ohm.cm) has been improved by adding filler to epoxy resin.
1. The electrical resistivity (ohm.cm) of different fillers decreased in wet and salty wet conditions as compared with those in dry condition.
2. Electrical properties of epoxy composite filled with Ba(IO$_3$)$_2$ are reliable at 25 wt% and have better electrical resistivity than SiO$_2$ composites.
3. Artificial neural network model reduces the high cost of multiple measurements.
4. The optimum percentage of Barium iodate that could be adopted in the epoxy samples is 25 wt%.

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