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THERMAL STRESS EFFECT ON DIELECTRIC STRENGTH OF RUBBER BLENDS USING FEED-FORWARD NEURAL NETWORK

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ABSTRACT

Because of the Variety in characteristics, strength, economy, and ease of manufacturing, the rubber blends are very suitable for use in the field of insulating materials. The blending technology has effects on the chemical, physical, mechanical, and electrical properties of polymers; this effect is predominately convenient for electrical insulation purposes. Electrical systems are often subject to faults resulting from short circuits or any other cause, which naturally leads to an increase in temperature for Insulating materials; And from here required considering good electrical properties and additional to have desired mechanical properties for insulation and bear it for different temperatures. The effect of thermal stress on the blending ratio of ethylene propylene diene monomer (EPDM) and silicone rubber (SiR) at various temperatures is studied using the Feed-Forward Neural Network (FFNN) after laboratory testing in this paper. The five different samples of EPDM-SiR blends (100/0; 75/25; -50/50; 25/75; 0/100) were prepared. The Breakdown Voltage (BDV) was measured under various temperatures (25, 60,100 and 130°C) according to ASTM standards. The experimental data was used to train the FFNN model. The blends ratio and temperatures represent the input of the FFNN system while the breakdown voltage kV is the output. The outputs obtained from FFNN were compared and checked against the data obtained in the laboratory. This study indicates that FFNN can be trusted to simulate the effect of thermal stress of various blending ratio on breakdown voltage with a satisfactory rate. It also demonstrates that the FFNN approach is an active tool that can be adopted as a reference to reduce the time and cost required in preparing and testing samples in the experimenter.

KEYWORDS: “Ethylene Propylene Diene Monomer (EPDM)”, “artificial Neural Network (ANN) ”, “Silicone Rubber (SiR)”, “Breakdown Voltage (BDV) ”.

تأثير الإجهاد الحراري على القوة العازلة لخلائط المطاط باستخدام شبكة التغذية الأمامية العصبية

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الملخص

يهدف هذه البحث إلى دراسة تأثير الاجهاد الحراري علي قوة العزل الكهربي للعازلات البوليمرية المولفة من المطاط ومنها السليكون المطاطي والايثيلين بروبلين دايين مونمر ومحاكاة النتائج المعملية عن طريق شبكة التغذية الامامية العصبية. نظرًا للتنوع في الخصائص الكهربائية والميكانيكية والفيزيائية للمواد البوليمرية بالإضافة الي سهولة التصنيع والتكلفة المنخفضة، فإن خلطات المطاط مناسبة جدًا للاستخدام في مجال المواد العازلة. غالبًا ما تتعرض العازلات الكهربائية للظروف المحيطة من ملوثات بيئية او ارتفاع في درجات الحرارة ناتجة عن قصر الدائرة وبناء علي ذلك تم دراسة أداء العينات المختلفة من حيث مقدار شدة العزل الكهربي عند درجات حرارة مختلفة. تم تحضير خمس عينات مختلفة من خلطات EPDM-SiR (٠/١٠٠ ؛ ٢٥/٧٥ ؛ ٥٠/٥٠ ؛ ٧٥/٢٥ ؛ ١٠٠/٠). تم قياس جهد الانهيار (BDV) تحت درجات حرارة مختلفة (٢٥ و٦٠ و١٠٠ و ١٣٠ درجة مئوية) وفقًا لمعايير ASTM. تم استخدام البيانات التجريبية لتدريب نموذج FFNN. تمثل نسبة المزج ودرجات الحرارة الدخل لـ FFNN بينما يمثل جهد الانهيار kV الخرج. تمت مقارنة المخرجات التي تم الحصول عليها من FFNN وفحصها مقابل البيانات التي تم الحصول عليها في المختبر. تشير هذه الدراسة إلى أنه يمكن الوثوق بـ FFNN لمحاكاة تأثير الإجهاد الحراري على جهد الانهيار للعينات العازلة بمعدل مرضٍ. كما يوضح أيضًا أن محاكاة FFNN هو أداة فعالة يمكن اعتمادها كمرجع لتقليل الوقت والتكلفة اللازمين لإعداد العينات واختبارها في المعمل.

الكلمات المفتاحية : إيثيلين بروبيلينديين مونومر (EPDM) "،" الشبكة العصبية الاصطناعية (ANN) "،" مطاط السيليكون (SiR) "،" جهد الانهيار (BDV)

1. INTRODUCTION

Polymers, such as ethylene propylene diene (EPDM) rubber and silicone rubber (SiR) are widely used in wire and cable manufacturing due to their high performance under wet and polluting conditions with their varied electrical and mechanical properties. Silicone rubber is perhaps the most preferred material among the polymeric materials that are used as a base material in non-ceramic insulators as it has good water repellency properties, so the insulators made of silicone rubber can suppress the leakage current [1]. In the beginning, the total reliance was on laboratory experiments only to study the electrical and mechanical properties of insulating materials under variable conditions of humidity and different temperatures, etc., which leads to an increase in cost and time and testing a limited number of samples. To overcome this problem, many researchers have used artificial intelligence methods to train in previously obtained laboratory results and to predict material behaviors, characteristics, and attributes under changing circumstances (e.g., aging over time, heat treatment due to temperature changes, etc.). These methods, such as artificial neural networks (ANN) and fuzzy logic, provide simulation designers who can adapt to environmental changes that may lead to changes in behaviors and physical characteristics. [2-4]. Due to the good thermal properties of polymers and various electrical and mechanical properties, blending two elements of these materials in different percentage leads to obtaining a new material that combines electrical and mechanical endurance. For instance, pure Ethylene Propylene Diene Monomer (EPDM) and Silicone Rubber (SiR) and their blends EPDM / SiR have attracted considerable industrial attention. Experimental testing is usually used to evaluate the enhanced electrical behavior of polymer blends and to check its approval of a structural component. Since the processes of blending and testing are costly and time consuming, this paper explores the potential of using ANNs in predicting the electrical performance over a wide range of blend ratio. In this paper, the experimental results of laboratory will be utilized to examine the capability of ANNs in predicting the electrical breakdown voltage with change in different temperature curves and properties of pure EPDM and SiR and their blends (EPDM /SiR).The experimentally gained data are used to train and test the neural network's performance. The key system inputs for the modeler are blend ratio and temperature, and the system output is the breakdown voltage. The ANN predicted outputs were compared and confirmed against the obtained experimental data.

2. Artificial neural networks

Artificial Neural Networks (ANNs) define a specific class of machine learning algorithms designed to gain their own knowledge by training with the amount of available data. In this work, the feed-forward back propagation neural network model has been used. The used FFNN model was built by writing m-file code using MATLAB neural network toolbox (built-in function). Experimental information obtained from the blending process of EPDM/SiR, are used as input–output data to form a model of the system. The strength of neural computing structures lies in their ability to learn and adapt to changing process and environmental conditions [5]. The main component of a neural network is the neuron (Fig. 1) that performs a nonlinear weighted summation of the applied inputs.

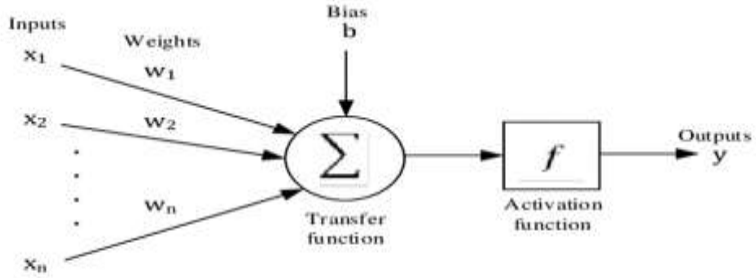


Fig. 1 The basic structure of the neuron

The input signals xi (i=1, 2,…, p inputs) are applied to the network. Once received by the neuron, they are modified by wji, which is the interconnection weight between input xi and neuron j. All weighted inputs to a particular neuron are summed along with a bias weight wjo to produce a single result uj. This result is then passed through nonlinearity called an activation function, or a transfer function, which can be a sigmoid, hyperbolic tangent or sinh. Mathematically, the output of neuron j can be expressed as

$$y_j=f(w(n)Tx(n))$$

where y_j is the output of neuron j, W(n) is the interconnection weight vector, T is the transpose, X(n) is the input signal vector for iteration n, and f (•) is the activation function.

3. Experimental tests

Experimental tests were conducted to determine the breakdown voltage with change in temperature curves of EPDM, SiR, and their blends for all EPDM/SiR (wt%). At the beginning of the study different mixing procedures have been followed in order to identify the best conditions to get good homogeneity [6-7]. Dielectric strength is defined as the maximum voltage that an insulating material can withstand before the breakdown voltage happens. It commonly depends on the thickness of the material and the method and conditions of the test. The results are expressed in kV/mm. Sets of composite samples have been prepared and tested using AC voltage. The specimens should be dry and clean before starting the high voltage test to remove dust and other contaminated particles on the surface before testing Dielectric strength is measured through the thickness of the sample, which is equal to 2 mm. The samples has been tested using AC voltage under different temperatures conditions. The voltage was gradually increased at a constant rate of 2 kV/s until the voltage breakdown occurs as shown in Fig. 2. The test assessed by ASTM-D149 [8] at room temperature (25°C) and relative humidity of 51%. At least five valid results are to be achieved in order to calculate the breakdown voltage properties; otherwise, the test is repeated and any wrong test result was ignored. The average value of the results is then used.

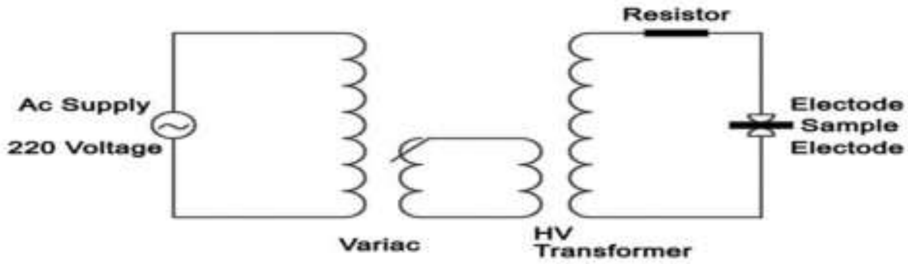


Fig. 2 Schematic diagram used for dielectric strength test

Five different mixtures/strips of EPDM/SiR (wt%) were obtained (0/100, 25/75, 50/50, 75/25, and 100/0). Experimental tests were conducted to determine the breakdown voltage at different temperatures (25, 60,100 and 130°C) as electrical test as shown in Fig. 3

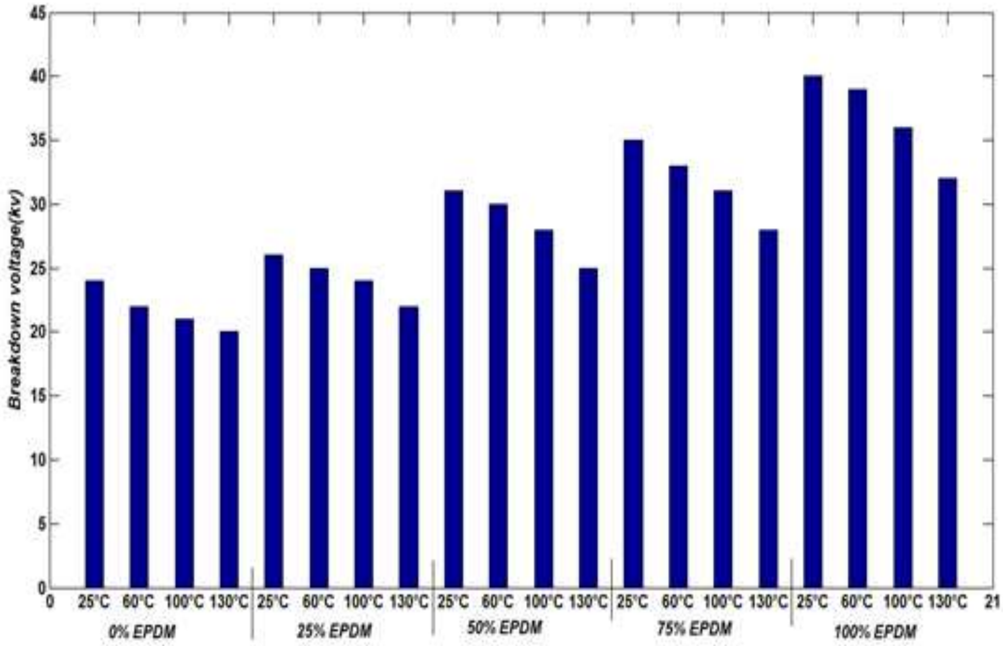


Fig3 Experimental tests of breakdown voltage(KV) under different temperatures of EPDM/SiR blends

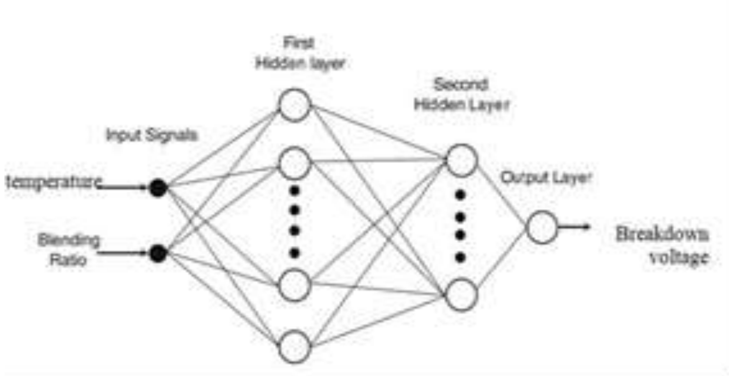
4.ANN simulation and properties

The feed forward neural network (FFNN) technique is used to predict the dielectric strength for the intermediate values of untested samples [9].From previous laboratory experiments, we have a clear picture of the breakdown voltage with the change in the different temperatures of the EPDM/SiR mixture and provide the experimental data used to feed the neural network, during the learning phase, with the necessary information about the behavior of the input and output of the process. This stored behavior is used by the neural network as a reference that is retrieved during the operation phase as the network models the actual operation of specific test conditions. The simulation part has been done in three steps:

- In the first set, the ANN was used to predict an existing experimental data for a specific blend ratio and calculate the error percentage.
- The second set tested the capability of the ANN to predict anon existent experimental data curve for a different blend ratio at same temperatures, and its location with respect to the existing ones.
- The third set tested the capability of the ANN to predict anon existent experimental data curve for a different blend ratio at different temperatures.

4.1 Step-1 Predict an existing experimental data.

In the first step of experiments, an ANN modeler was prepared to simulate the relationship between breakdown voltage and change in different temperatures of an EPDM/SiR for blends of different ratios (0:100, 25:75, 50:50, 75:25, and 100:0 %) under different temperatures (25,60,100 and 130°C) based on the available experimental data. In order to check this, 80 % of the data of each of the blends are used to train the network on the actual experimental data, then the rest 20 % of the data were to support the performance of the network. The temperature and the blend ratio were used as the inputs while the breakdown voltage was the output as shown in fig (4)



. Fig. 4 Typical multilayer perceptron

After the network has converged to the preset error value, the trained network was requested to simulate the existing data and the output of the network is compared with the available experimental data to check the validity of the network as shown in Table 1.

Table 1 FFNN results and experimental results for the Breakdown voltage (KV) of EPDM/SiR blends at different temperatures.

Percentage of EPDM blend %	Temperature °C	Breakdown voltage KV		Error percent, %
		Experimental result	FFNN estimation	
0	25	24	24.01	0.042
	60	22	22.18	0.818
	100	21	21.002	0.0095
	130	20	19.877	0.615
25	25	26	25.93	0.269
	60	25	25.198	0.792
	100	24	24.02	0.083
	130	22	21.97	0.136
50	25	31	30.95	0.161
	60	30	29.996	0.013
	100	28	28.01	0.0357
	130	25	24.94	0.24
75	25	35	34.96	0.114
	60	33	33.53	1.606
	100	31	30.91	0.29
	130	28	27.84	0.571
100	25	40	39.88	0.3
	60	39	38.62	0.974
	100	36	35.79	0.583
	130	32	32.15	0.468

Predicted curves obtained by this procedure are shown in Figs. 5, 6, 7, 8, and 9 it is clear from the trend of the curves that the network has the ability to simulate the experimental results. The network could simulate the modulus of the breakdown voltage of the blends under different temperatures to a high degree of accuracy as the predicted from calculation percentage of error.

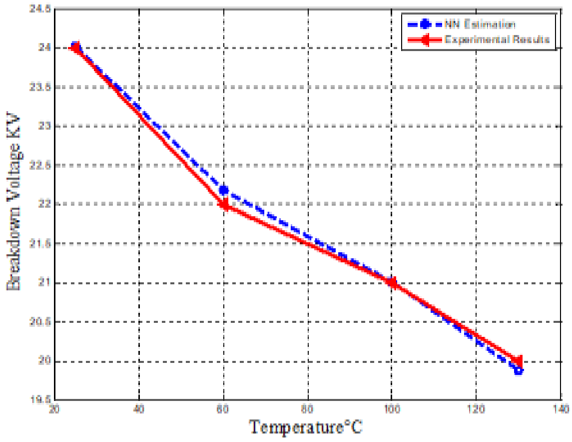


Fig 5 EPDM/SiR Blend ratio (0:100) of Experimental result and NN Estimation

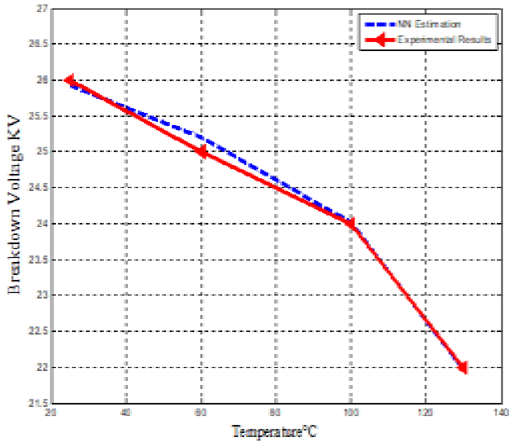


Fig 6 EPDM/SiR Blend ratio (25:75) of Experimental result and NN Estimation

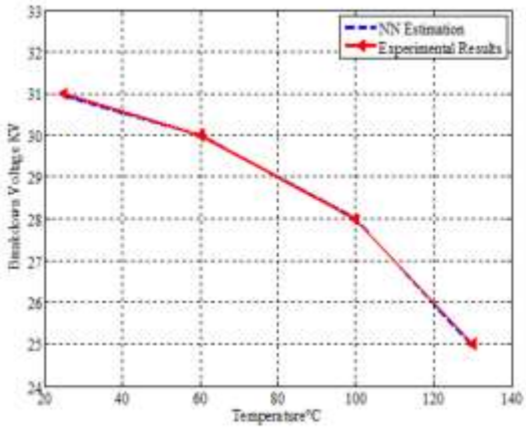


Fig7 EPDM/SiR Blend ratio (50:50) of Experimental result and NN Estimation

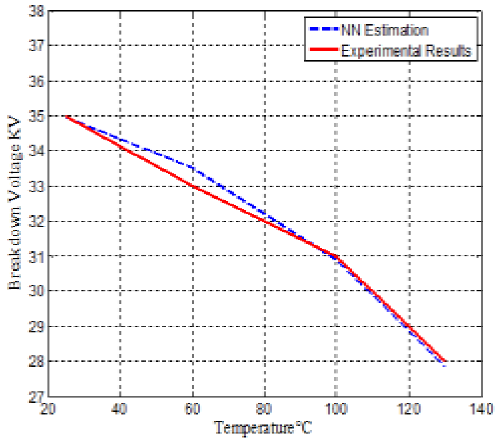


Fig8 EPDM/SiR Blend ratio (75:25) of Experimental result and NN Estimation

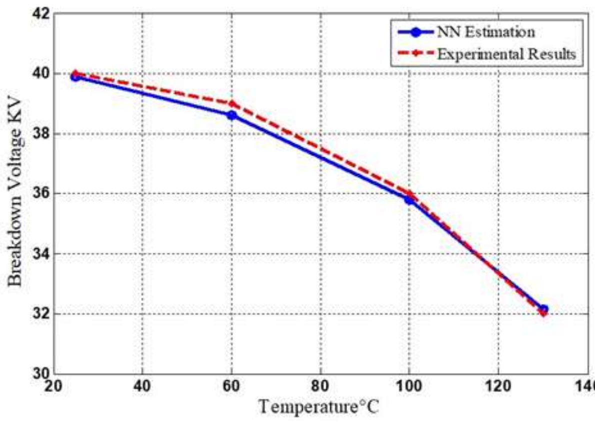


Fig9 EPDM/SiR Blend ratio (100: 0) of Experimental result and NN Estimation

4.2 Step-2 Prediction of nonexistent experimental data at new blends under the same temperatures.

In this step of experiments show simulating the breakdown voltage curves under temperatures (25,60,100 and 130°C) for new blending ratios(15:85,65:35,35:65 and 85:15) that fall between the available experimental data as shown in table 2.

After simulating the network for the experimental results and showing its efficiency, we can obtain new results for blending from the network, and to ensure the validity of these results, we can compare them with the experimental results as shown in the figure10, 11, 12, and 13.

Table 2 FFNN results for the Breakdown voltage(KV) of nonexistent EPDM/SiR blends at the same temperature

Percentage of EPDM blend %	Temperature °C	Breakdown voltage KV FFNN estimation
85	25	36.98
	60	35.47
	100	32.54
	130	29.24
65	25	33.25
	60	32.02
	100	29.71
	130	26.67
35	25	27.63
	60	27.02
	100	25.69
	130	23.12
15	25	24.28
	60	23.83
	100	22.57
	130	20.98

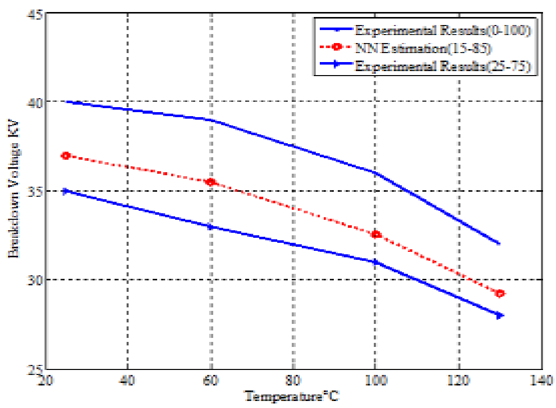


Fig 10 Prediction of 85% EPDM curve using100 and 75 % EPDM experimental curves

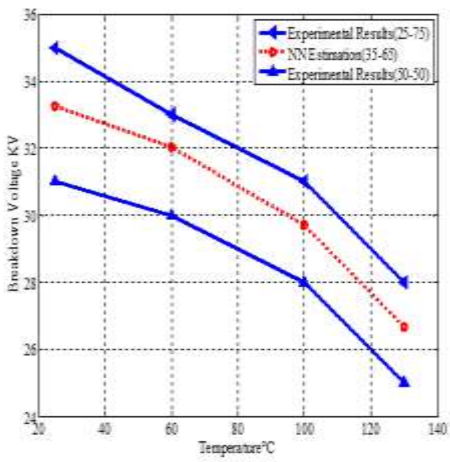


Fig 11 Prediction of 65% EPDM curve using 75 and 50 % EPDM experimental curves

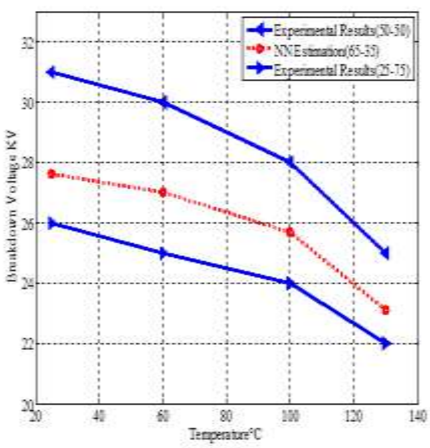


Fig 12 Prediction of 35% EPDM curve using 50 and 25 % EPDM experimental curves

4.3 Step-3 Prediction of nonexistent experimental data at new blends under the new temperatures.

In the last step, the network is ready to get any data required as breakdown voltage, temperatures and blends for example at temperatures (45,80 and 115°C) and new blending ratios (15:85,65:35,35:65 and 85:15) as shown in table 3 and Figure13.

Table 3 FFNN results for the Breakdown voltage (KV) of new EPDM/SiR blends at the new temperatures

Percentage of EPDM blend %	Temperature °C	Breakdown voltage KV FFNN estimation
85	45	36.21
	80	34.20
	115	31.02
65	45	32.61
	80	31.04
	115	28.39
35	45	27.29
	80	26.57
	115	24.58
15	45	24.38
	80	23.16
	115	21.89

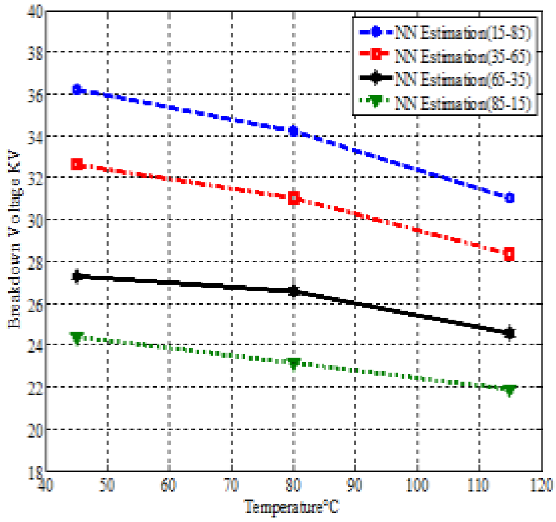


Fig 14 Prediction of breakdown voltage at new blends under new condition from different temperatures.

The network can provide a useful resource, database and information for the materials used in the blending by which the results can be expanded without the need for additional experimental tests. This could save cost and time, provide tools and an easy means of testing the performance of polymer.

CONCLUSIONS

The following conclusions can be drawn from this work:

1) Blending (EPDM) with (SiR) is an effective way to improve the dielectric strength.

2) The dielectric strength of the EPDM/SiR blend decreased in high-temperatures conditions as compared with those in low-temperatures conditions.
3) An artificial neural network procedure was used to model and analyze the electrical properties of EPDM, SiR, and their blends.
4) An artificial neural network that has been used to analyze the electrical properties of EPDM and SiR and their blends at different temperatures.
5) From a comparison of the laboratory results with the results obtained from the neural network it is clear that An artificial neural network provides accurate and reliable results..
6) The artificial neural network technology reduces the cost and time in the field of dielectric properties.

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