# EFFICIENT VISCOSITY EVALUATION USING ARTIFICIAL NEURAL NETWORK FOR EPOXY AFTER ADDITION WASTE NATURAL MATERIAL

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## ABSTRACT

Artificial neural networks (ANN) were used to predict the viscosity of epoxy resin modified by natural waste material (pomegranate peel) powder. This waste material, which has a high pollution capacity for the environment, could be used as an improvement to the properties of a weaken material such as epoxy resin In reservoir engineering computations the viscosity parameter is a very important fluid property. The data is not either reliable or unavailable most of the time; It should be specified in the lab. Levenberg-Marquardt backpropagation of artificial neural network based model (ANNs) was evolved to predict the viscosity of modified pomegranate peel powder of epoxy resin. Three parameters affecting the viscosity of mixtures based on epoxy resin containing pomegranate peel powder and pure epoxy resin were studied. These are temperature, concentration of pomegranate peel, and shear rate. The viscosity as output was predicted by training the network. A network was built up and trained using experimental information. The effects of temperature (30-50 °C), concentration of pomegranate peel powder (0-3)wt% and shear rate (4.35-15.95 1/sec) on the epoxy resin were modeled by ANNs as well. The expected values were in excellent agreement with the measured ones, showing that the developed model is really accurate and has the great ability for predicting the viscosity. The linear regressions $R^2$ 0.9994 and 0. 9998 are the values of the ANN viscosity model for training and testing data set, respectively, $2.7175*10^{-4}$ and $1.2441*10^{-4}$ are the values of mean square error respectively.

**Keywords:** Artificial neural network . Viscosity. Waste natural material. Pomegranate peel. Epoxy resin

# تقييم كفاءة اللزوجة باستخدام الشبكات العصبية للايبوكسي بعد اضافة مخلفات مادة طبيعية

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**الخلاصة**

تم استخدام الشبكة العصبية الاصطناعية للتنبؤ بلزوجة راتنج الايبوكسي عن طريق اضافة مسحوق احد مخلفات المواد وهي قشور الرمان. تعتبر هذه المخلفات من الملوثات البيئية ذات السعة الكبيرة في تلويث البيئة ولكن يعد استخدامها هنا لتحسين بعض الخواص الضعيفة لراتنج الايبوكسي ويعتبر معيار اللزوجة هو عامل انسياب مهم في الحسابات الهندسية.

تحسب اللزوجة في المختبرات ولكن معظم البيانات تكون غير مناسبة اومتوفرة. لذا تم تطوير شبكة عصبية اصطناعية لاجل التنبؤ باللزوجة لراتنجات الايبوكسي حيث توجد ثلاث عوامل تؤثر على لزوجة المزيج المكون من راتنج الايبوكسي المحتوي على مسحوق قشور الرمان وهي درجة الحرارة , تركيز القشور و معدل اجهاد القص.

تعتبر هذه العوامل الثلاثة هي المتغير الداخل (input) وتم تدريب الشبكة ليتم التنبؤ باللزوجة كناتج خارج (output).

تم تدريب الشبكة بالاعتماد على النتائج العملية وحيث ان حدود المتغيرات كدرجة الحرارة هي(30−50 °C) , تركيز قشور الرمان wt% (0−3) واجهاد القص (4.35−15.95 1/sec) على راتنج الايبوكسي.

تم بناء موديل للشبكة العصبية ووجدت ان القيم المتنبأ بها على تطابق ممتاز مع القيم العملية والذي يشير الى ان الموديل المطور دقيق جدا" وله قابلية كبيرة للتنبؤ باللزوجة.

ان قيمة التقريب الخطي $R^2$ بنظام التدريب والاختبار بقيمة 0.9994 و 0.9998 على التوالي.

وان مقدار قيمة التقريب الخطي مربع الخطأ بقيمة $2.7175*10^{-4}$ و $1.2441*10^{-4}$ لنظامي التدريب والاختبار على التوالي.

**الكلمات المرشدة:** الشبكة العصبية الاصطناعية . اللزوجة . مخلفات المواد الطبيعية . قشور الرمان . راتنج الايبوكسي .

## 1. INTRODUCTION

One of the most important computational tools is the artificial neural network (ANN) that allows overcoming the difficulty of calculating the difficult and highly nonlinear relationships among model parameters through self-organization, pattern recognition and functional approximation. The structure and internal functions of the biological brain is simulated by ANN. Unlike conventional models, the model structure between input and output variables does not assumed by ANN. The database was provided by training the network to generate the model. The problems were solved by ANN using creating parallel networks and the training/learning of those networks, rather than by a specific programming scheme based on well-defined rules or assumptions [1].

ANN has the ability to learn from the pattern acquainted before. The network is trained with adequate number of sample data sets and then it can make guesses when new input data sets of the similar pattern are given. Hence, ANN is successfully used in many industrial areas in addition to research areas for the prediction of different complex parameters from simple input parameters[2].

One of the most popular of polymers materials is the epoxy resin which has been widely used as protection system of heterogeneous composites in many structures because of its prominent process ability, good electrical insulating properties, distinguished thermal resistance, strong adhesion, and affinity to heterogeneous material with a higher mechanical properties under heavier loading [3].

It is very important reducing the cost in the modern industries also declining the pollution which represents a big harmfulness to the environment. Nowadays, the waste materials are used increasingly in reinforcement and formation new materials. The necessity for materials that are non-toxic to the human body and have appropriate characteristics for specific purposes is ever increasing because of the lack of resources and increasing levels of environmental contamination. Due to the inexpensive and ability to reduce the environmental contamination caused by the characteristic biodegradability, the natural substances as reinforcing fillers are used for the production of composites, these composites are important in resolving the future environmental problems [4]. In polymer composites the filler type is very important [5].Because strong astringency and making them a popular remedy throughout the world, the waste natural materials (pomegranate peels) are exploited in traditional uses [6].

New composites are being developed in the continual quest to improve material performances [7]. The rheological properties of epoxy resin must be understood in order to improve the pumping and transports in the design [8].

The viscosity is defined as resistance to flow therefore it is one of the most important theological characteristics of a fluid [9] and it is the most important thermophysical properties of fluids, especially in thermal applications where heat transfer and fluid flow take place. In industrial applications the changes in viscosity attributes effect the convective heat transfer coefficients in addition to the pumping power required. Therefore, accurate information on the viscosity attributes of fluids is necessary [10].

The Behavior of epoxy can be expected by different conditions such as the well-known dependence of viscosity on the shear rate, temperature, concentration of additive and other parameters.

Therefore, the values of viscosity epoxy are not fine predicted and it is hard to define a concise relationship between the factors (variables), or the problem is too intricate to be described mathematically [11]. Increasingly, ANN is starting considered to develop models from data in their ability to improve the modeling accuracy and to improve the process modeling eventually [12].

The works experimentally and theoretically have been devoted to the viscosity of fluids by using ANNs that studied by several researchers [1, 9-11, 13-16,19].

The purpose of this paper is to study the variation of viscosity of epoxy resin by the addition of waste natural material (pomegranate peel) powder at different concentrations, temperatures and shear rates. Also compare the viscosity of epoxy resin predicting by using Levenberg-Marquardt backpropagation of artificial neural networks with experimental values.

## 2.MATERIALS AND METHODS

### 2.1. Experimental Procedure

In this study, epoxy resin was used as a matrix polymer. The Epoxy resin type Epikote828 were provided by shell Company. Properties of epoxy resin are given in table (1).

The type of reinforcing filler of waste natural material was pomegranate peel powder used in this research.

The pomegranate peel was collected and crashed by using a ball milling process, the specification of it (250 rpm).

The viscosities of the resin systems containing (0, 1, 2 and 3) wt % of powder of pomegranate peel were determined by using a rotational Brookfield Viscometer model DV-II-Pro at different temperatures (30, 40 and 50 °C) and six different shear rates (4.35, 6.67, 8.99, 11.31, 13.63 and 15.95 $s^{-1}$).

## 2.2. Artificial Neural Networks (ANN)

In this study, ANN is used to predict viscosities of epoxy systems. A computer program was performed under Matlab 7.10 software. The categories divided into two parts for the results of experimental data the first was used for NN training while the other part was employed for network testing, and finally train the ANN that is built according to the specified data and calculate the performance of training results by using mean square error (MSE)and the linear regressions ($R^2$). The MSE and $R^2$ were computed using the following equations (1,2) [17,18]:

$$\mathrm{MSE} = 1/\mathrm{N} \sum_{t=1}^{N} \left(t_j - o_j\right)^2 \tag{1}$$

$$R^2 = 1 - \left[\frac{\sum_j \left(t_j - o_j\right)^2}{\sum_j \left(o_j\right)^2}\right] \tag{2}$$

Where *t* is a target value, *o* is an output value, and *N* is a pattern.

The network having minimum MSE and maximum $R^2$ is chosen as the best ANN models. For the epoxy system, 60 of 72 data are used for training the ANN and 12 data are used for testing purposes With sigmoid hidden neurons and linear output neurons, three layers feed forward network is used as the network. Levenberg-Marquardt backpropagation training algorithm is used to train the network. The layers were used one input layer, one hidden layer, and one output layer. The hidden layer performs the computations in the network. Table (2) clears the range of the input parameters in ANN. Three parameters affecting the viscosity were considered as inputs, including concentration of pomegranate peel, the temperature, and shear rate. The network was then trained so that to predict the viscosity as outputs.

The present study of neural network architecture is given in **Fig.(1)**.In the feed forward networks, neurons are arranged from input towards output in order layers and transmission from one layer to another is only available for the next layer. The data which are acquired moved first to the input layer then to the hidden layer and lastly to the output layer where they are processed and the results are joined to the outer world. It has been verified that a three layers feed forward ANN can approximate any continuous function at the wanted accuracy level provided that an adequate number of neurons are included in the hidden layer.

Eventually, and in order to support the neural network to deal effectively with the data, all the input data were normalized to the range of (0-1).

## 3. RESULTS AND DISCUSSION

The particle size of pomegranate peel in this research was less than (2 µm), as verified by Scanning Electron Microscope (SEM), model Tescan VEGA 3 SB which was employed to determine the morphology of the samples at 20Kv. The SEM micrograph is shown in **Fig.(2)**.

### 3.1. Effect of Parameters on Viscosity

### 3.1.1. Effect of Additive Pomegranate Peel Powder on Viscosity

The viscosity variation with increasing concentration of pomegranate peel powder in the epoxy resin was studied for different concentration (0-3) wt% at different temperatures. This will help us in determining the optimum fluid viscosity for fluid pump ability necessary for efficient flow at different conditions of concentrations and temperature.

**Fig.(3)** shows viscosity change with shear rate for different wt% of pomegranate peel powder at fixed temperature ($30^oC$).

It is clearly seen that at this temperature the addition of pomegranate peel powder in different wt% has no remarkable effect on reduction of viscosity of epoxy resin. In fact the best reduction in viscosity occurs without any addition of pomegranate peel powder.

**Fig.(4 and 5)** illustrate the variation of viscosity with shear rate at various wt% of pomegranate peel powder at $40^oC$ and $50^oC$ respectively.

**Fig.(4)** demonstrates that when the addition of pomegranate peel powder is 2wt% gives the better reduction in viscosity of epoxy resin at $40^oC$ while, **Fig.(5)** shows that better reduction in viscosity occurs after the addition 3wt% of pomegranate peel powder at $50^oC$ which indicate that addition of pomegranate peel powder to epoxy resin could be the a good option for the viscosity reduction with temperature increase.

This behavior is in good agreement with results obtained by Stabik [19].

### 3.1.2. Effect of Temperature on Viscosity

**Fig.(6,7,8 and 9)** show the relation between viscosities of epoxy resin unmodified – modified with different temperatures (30, 40 and 50) $^oC$ versus shear rate at different amounts of Pomegranate Peel (0-3) wt%. As can be seen in the figures the viscosity decreased with increasing temperature for all concentrations. It is the result of generally observed polymers viscosity decrease with temperature increase. Actually known is Arrhenius law for temperature dependence of viscosity [19]:

$$\mu(T) = \mu_r \left[\frac{E}{R}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

Where: $\mu_r$ Viscosity in reference temperature, E – activation temperature, R – gaseous constant, $T_r$– reference temperature.

These results are in good agreement with the results get from Stabik [19].

### 3.1.3. Effect of Shear Rate on Viscosity

In general of all **Fig.(3,4,5,6,7,8 and 9)** illustrated the viscosity of epoxy resin modified by pomegranate peel powder used in this work increased as the shear rate is increased. This behavior occurs because as in some substances when the relationship between viscosity and shear rate is proportional that is called shear-thickening [20].

### 3.2. Artificial Neural Network Model

A three layers ANN with a tangent sigmoid transfer function (tansig) at hidden layer and a linear transfer function (purelin) at output layer were used. Feed forward Levenberg-Marquardt backpropagation network was used. The input layer has 3 neurons (temperature, concentration of pomegranate peel, and shear rate) , one hidden layer has 9 neurons and output layer has one neuron (viscosity).

As shown in **Fig.10 (a, b)**, the $R^2$ values of the NN viscosity model are 0.9994 and 0.9998 for training and testing data sets respectively. Their mean square error (MSE) values are $2.7175*10^{-4}$ and $1.2441*10^{-4}$. **Fig.(10)** shows that the ANN displays an accurate prediction based on a high $R^2$ value and a low MSE value. As a result, the developed NN viscosity model successfully improves the prediction possibility of viscosity value of epoxy modified pomegranate peel powder at various conditions.

## 4. CONCLUSIONS

1. Viscosity variation with shear rate for different composition of pomegranate peel powder at different temperatures, the addition of pomegranate peel powder to the epoxy resin could be a good option for the viscosity reduction with an increase in temperature.
2. Viscosity decreased with increasing temperature for all concentrations.
3. Viscosity of epoxy resin modified by pomegranate peel powder increased as the shear rate is increased.
4. ANNs were used to predict the viscosity of epoxy resin modified by natural waste material (pomegranate peel) powder. The expected values are in excellent agreement with the measured ones, showing that the developed model is very accurate and has a greater aptitude for expecting the viscosity.

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**Table (1):** Epikote828 properties.

| Typical properties | Value |
|---|---|
| Epoxide equivalent weight | 194 -182 |
| Viscosity, at 25 °C, poise | 150 -110 |
| Color, Gardner | 1 max |
| Physical form | Clear liquid |
| Density, g/ml at 25 °C (77 °F) | 1.16 |
| Flash point | No flash at 249°C (480 °F) |
| Vapor pressure, mm Hg at 77 °C (170°F) | 0.03 |
| Refractive index at 25 °C (77 °F) | 1.573 |

**Table (2):** The range of the input parameters in ANN.

| Inputs | Range |
|---|---|
| Concentration of pomegranate peels wt% | 0-3 |
| Temperature ($^{o}$C) | 30-50 |
| Shear rate (1/s) | 4.35-15.95 |

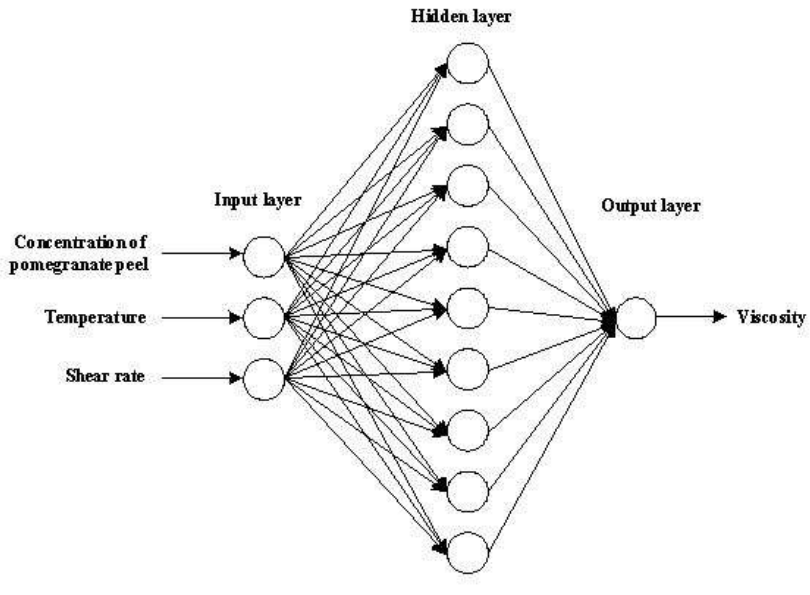


**Figure (1):** The system architecture used in the ANNs models.

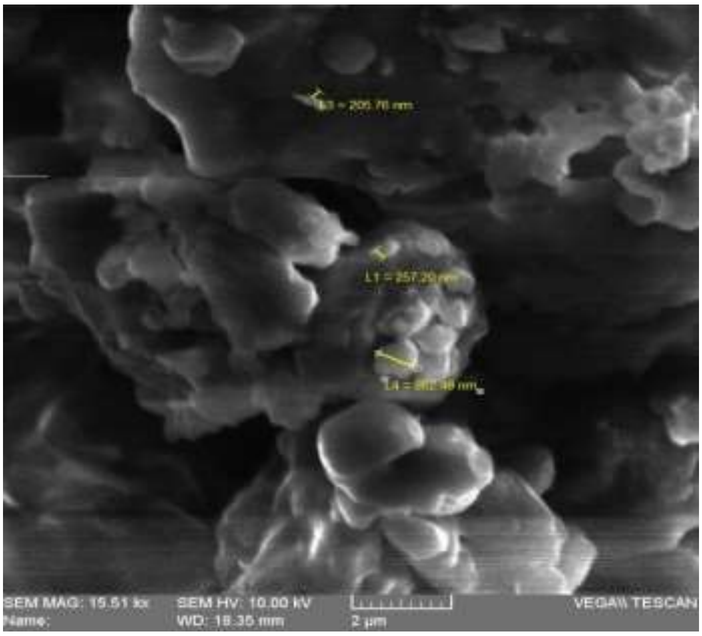


**Figure (2):** SEM micrograph of pomegranate peel.

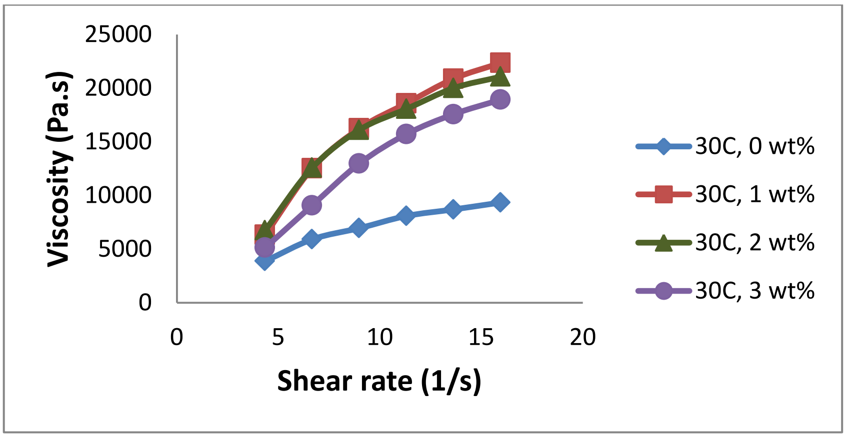


**Figure (3):** Viscosity of epoxy resin modified by pomegranate peel for different concentration vs. shear rate at 30 $^{o}$C.

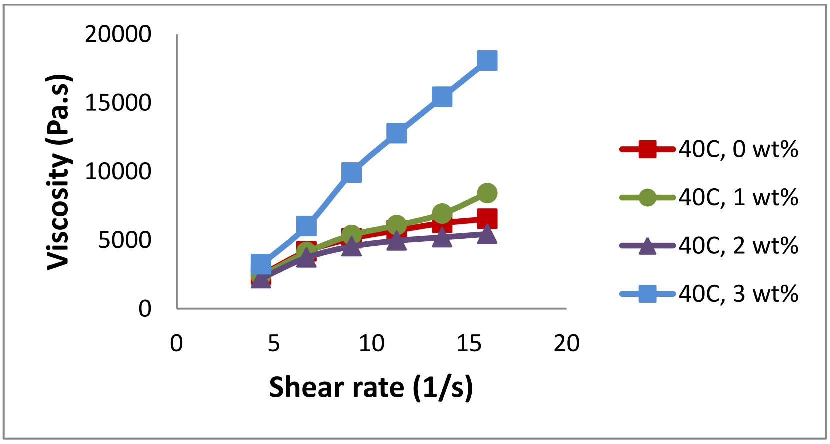


**Figure (4):** Viscosity of epoxy resin modified by pomegranate peel for different concentration vs. shear rate at 40 $^{o}$C.

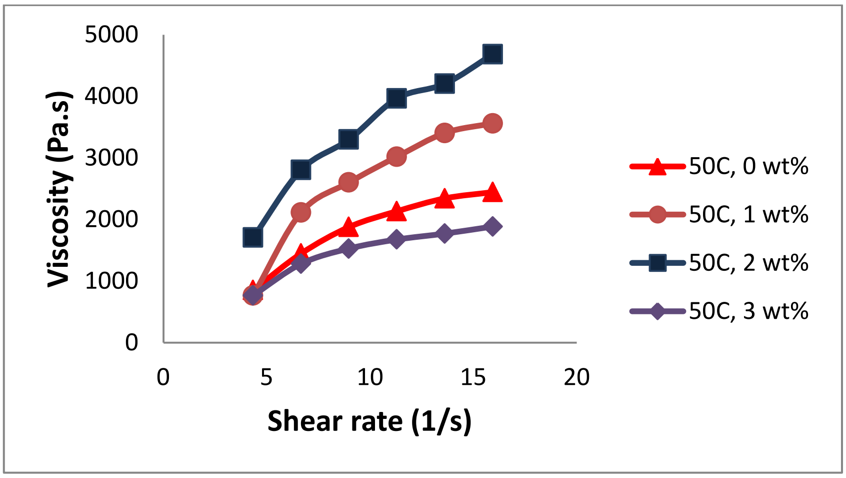


**Figure (5):** Viscosity of epoxy resin modified by pomegranate peel for different concentration vs. shear rate at 50 $^{o}$C.

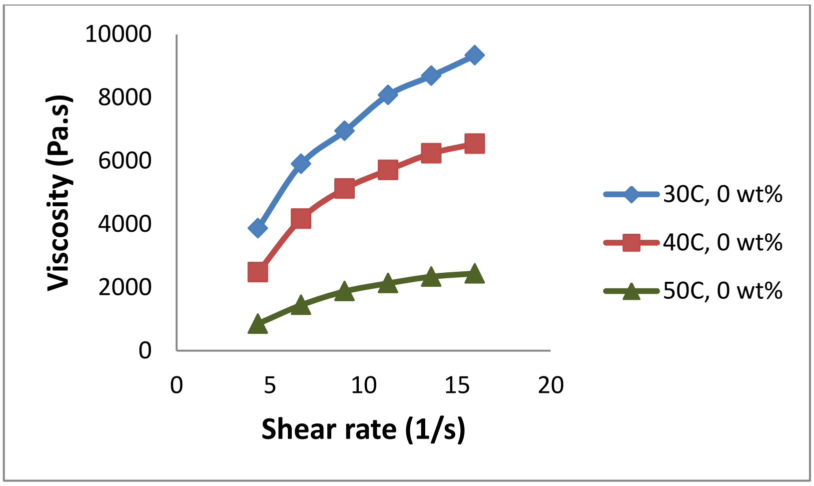


**Figure (6):** Viscosity of epoxy resin modified by pomegranate peel (0 wt%) versus shear rate at different temperatures.

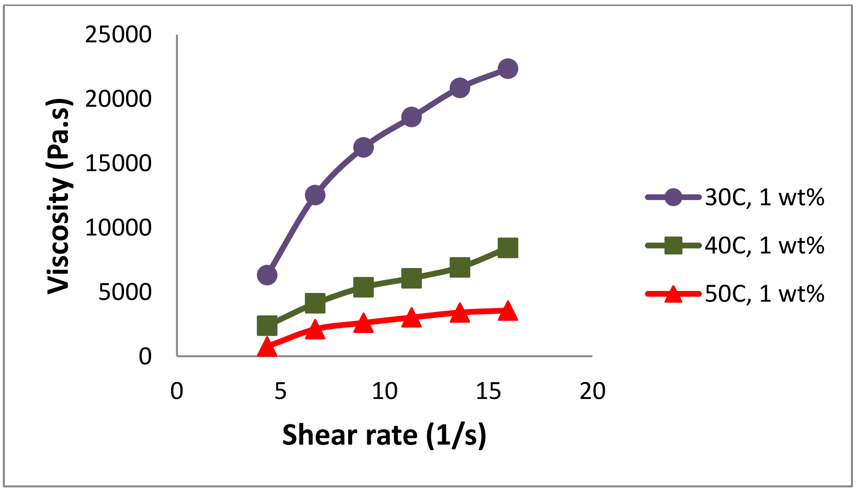


**Figure (7):** Viscosity of epoxy resin modified by pomegranate peel (1 wt%) versus shear rate at different temperatures.

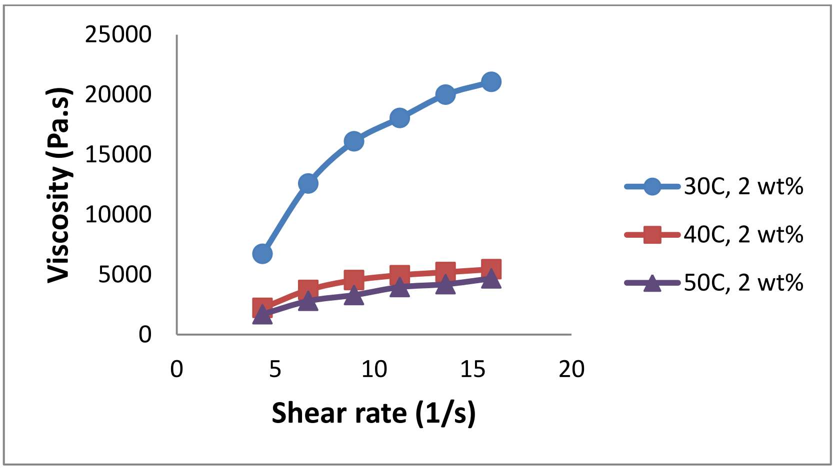


**Figure (8):** Viscosity of epoxy resin modified by pomegranate peel (2 wt%) versus shear rate at different temperatures.

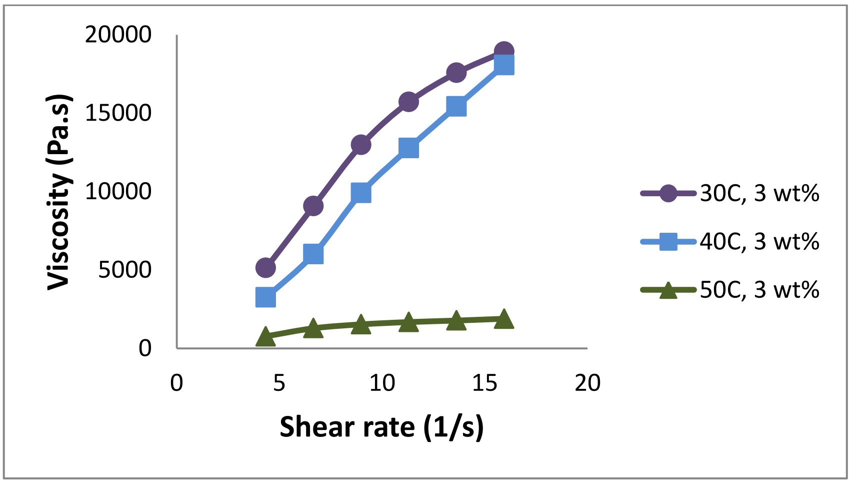


**Figure (9):** Viscosity of epoxy resin modified by pomegranate peel (3 wt%) versus shear rate at different temperatures.

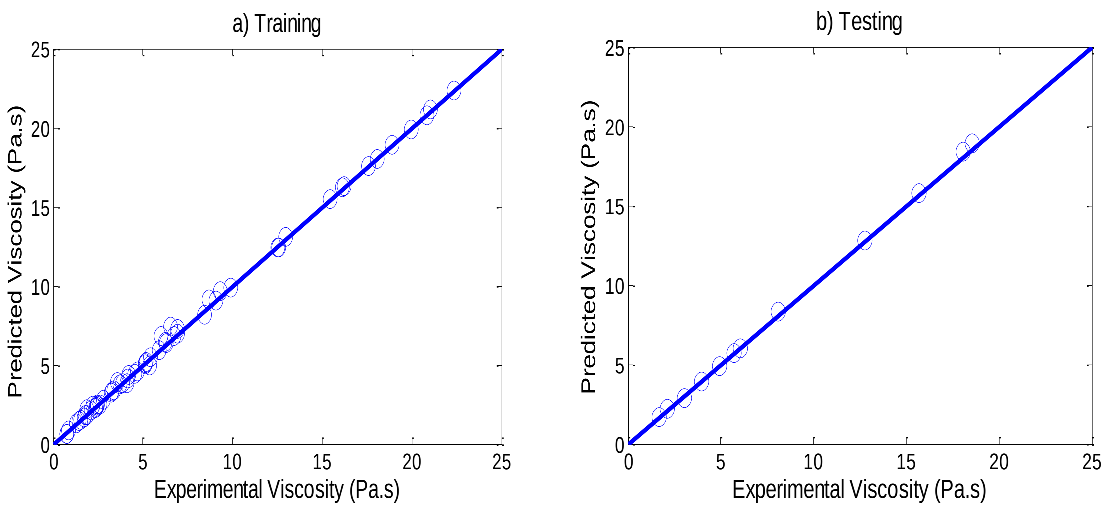


**Figure (10):** The graphical output of the experimental viscosity plotted versus neural network predicted viscosity.