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Filtrated Artificial Neural Network (ANN) Approach to Predict the Mechanical behavior of Polystyrene Reinforced with Bakelite

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ABSTRACT

The aim of this paper is to investigate the effect of the addition of different percentages of Bakelite to Polystyrene on its mechanical behavior and the capability of the artificial neural network (ANN) to predict this behavior. Unlike other approaches, the filtration of data took place by using ANN before coming to the final model. The results showed that the higher the Bakelite content of polystyrene, the higher the strength is. The filtrated ANN is a good tool to predict the deformation behavior of Polystyrene reinforced with Bakelite.

Keywords: Modeling, Artificial Neural Network, Polystyrene, Bakelite, Filtration.

1- INTRODUCTION

As a common practical definition, composite and blends of materials may be restricted to emphasize those materials that binds together and provides form to a structure of a stronger, tougher constituent. The resulting composite material has a balance of structural properties that is superior to either constituent material alone. The essential difference between thermoplastics and thermosets is that thermoplastics remain permanently fusible so that they will soften and eventually melt when heat is applied, whereas cured thermoset polymers do not soften, and will only char and break down at high temperatures. This allows thermoplastic materials to be reclaimed and recycled. The reason for this is that thermoplastics have relatively weak forces of attraction between the chains, which are overcome when the material is heated, unlike thermosets, where the cross-linking of the molecules is by strong chemical bonds. Effectively the thermoset is one large molecule, with no crystalline structure [Brent, 2000].

Moreover, polymer blends and composites become a central part of polymer science and engineering because people could make composites that had properties substantially unattainable with homo-polymers, such properties include greater toughness, higher strength, better ductility, and more homogeneous microstructure. Blending thermoplastics (polystyrene) with thermosets (Bakelite) with the aim of improving the mechanical behavior of thermoplastics in addition to get an ANN model for the prediction of this behavior in order to achieve a particular balance of properties for a given range of applications is our main concern in this project.

2- Literature Review

The presence of a reinforcement material can have major effects on the properties and processing of plastic resins. For example, polymer-matrix composite materials may have mechanical properties that equal or exceed those of metals but with superior ease of forming characteristics [Brent, 2000]. So, characteristics of composite materials depend mainly on their manufacturing process [Daniel et al**.**, 1996 and Jalham, 1999], and the reinforcement type, percent, size and shape [Jalham, 1999, Lee, 1999, and Bond et al**.**, 2002]. The effect of processing on certain composite properties such as stiffness, compression strength, etc were studied and lead to the formulation of mathematical models to predict compression stress using different techniques [Sun, 1994, Akbar et al**.**, 1996, Abbu-Farsakh et al**.,** 2000, Jalham, 2004**].**

Studies have been conducted on polystyrene matrix composites which are reinforced with Jordanian silica sand physically separated to achieve a high purity SiO_2 [Jalham et al**.**, 2001], also the potential of this silica sand for industry as a reinforcement for polystyrene [Al-

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Momany and Jalham, 1999], and the use of Jordanian silica sand with cement to reinforce the polystyrene base matrix composites [Jalham, 1993]. It was concluded that an improvement of the mechanical properties was achieved and a reduction of the mechanical properties started after 70 weight percent of silica reinforcement of the polystyrene matrix. On the other hand, studies on shear and elongational flow measurements on polystyrene melts reinforced with small particles of calcium carbonate, titanium dioxide, and carbon black were carried out by Tanaka et al [Tanaka and White, 1980]. They concluded that the experimental values for the ratio of the tensile to the shear yield stress give satisfactory agreement with the predictions of the von Mises yield criterion and the yield value appears to increase with decreasing particle size of particles of calcium carbonate, titanium dioxide, and carbon black and may be varied with surface treatment.

An electron-microscope technique is presented to permit detailed examination of the fine structure of the rubber particles in reinforced polystyrenes [Keskkula and Traylor, 1967]. Several rubber-modified polystyrenes, prepared by different methods, have been examined by the electron-microscope technique [Keskkula and Traylor, 1967], and the resulting photomicrographs were compared with those of the previously used phase contrast method. Polymers produced by the agitated-solution process are examined in more detail [Keskkula and Traylor, 1967]. It is shown that the rubber particle fine structure is basically unaltered as the amount or type of rubber is changed or if the polystyrene is diluted by mechanically blending with polystyrene. It is characterized by the presence of numberous polystyrene occlusions within the particle.

The tensile properties of polystyrene reinforced with short sisal fiber and benzoylated sisal fiber were studied by [Nair et al., 1996]. The influence of fiber length, fiber content, fiber orientation, and ben-zoylation of the fiber on the tensile properties of the composite were evaluated. The ben-zoylation of the fiber improves the adhesion of the fiber to the polystyrene matrix. the benzoylated fiber was analyzed by IR spectroscopy. Experimental results indicate a better compatibility between benzoylated fiber and polystyrene. the benzoylation of the sisal fiber was found to enhance the tensile properties of the resulting composite. The tensile properties of unidirectionally aligned composites show a gradual increase with fiber content and a leveling off beyond 20% fiber loading (percent). The properties were found to be almost independent of fiber length although the ultimate tensile strength shows marginal improvement at 10 mm fiber length. The thermal properties of the composites were analyzed by differential scanning calorimetry. Scanning electron microscopy was used to investigate the fiber surface, fiber pullout, and fiber–matrix interface. Theoretical models have been used to fit the experimental mechanical data. In this study, it was decided to study the effect of the addition of different weight percentages of Bakelite to polystyrene in order to study the effect of Bakelite addition on the mechanical behavior of polystyrene and the capability of the artificial neural network (ANN) to predict these behaviors.

3- Artificial Neural Network

A neural network is an adaptable system that can learn relationships through repeated presentation of data and is capable of generalizing to new, previously unseen data. It is so powerful because it can learn any desired input-output mapping if they have sufficient numbers of processing elements in the hidden layers. The artificial neural network used in this current work is a supervised multi-layer feedforward network trained with a standard back propagation algorithm [Kong et al., 1998]. It Computes changes to the weights in the final layer first, reuses much of the same computation to compute changes to the weight in the pre-ultimate layer, and ultimately goes back to the initial layer. Its idea is to make a large change to a particular weight if the change leads to a large reduction in the error observed at the output nodes. The three-layer network with one hidden layer that was used in this investigation is shown in figure1. The multiplayer perceptron were trained with backpropagation algorithm. The equation to update the weights in momentum learning is [Kong et al., 1998]:

$$w_{ij}(n+1)=w_{ij}(n)+\eta\delta_i(n)x_j(n)+\alpha(w_{ij}(n)-w_{ij}(n-1)) \qquad (1)$$

Where w_{ij} is the weight between nodes i and j at iteration n, $\delta_i(n)$ is the local error which can be directly computed from the instantaneous error between the desired response and the system response. At the output processing elements or as a weighted sum of errors at the internal processing elements, η is step size, and α is the momentum and is set to a value between 0.1 and 0.9.

The selection of training algorithm, stopping criteria and representative training set is the most important practical aspect related to training an ANN model. The mean square error of the test set was used as the stopping criteria and to evaluate the performance of the training. The work was accomplished by using the MATLAB software facilities. Unlike other ANN approaches [Kong et al., 1998 and Hwwu et al., 1996], this approach used the output of the previous training to be as an input to the next one which was called in this investigation as filtrated ANN approach.

4- Methodology

The methodology that followed in this investigation can be summarized as follows:

1. Manufacturing of the specimens: The manufacturing procedure was conducted according to the explained procedure in [Hammaud and Al Zagleh, 2010]. The composition of manufactured specimens is shown in Table 1. The criteria for the selection of these factors is based on that the strength of the blend is expected to be between the strength of Polystyrene and the strength of bakelite. For that reason an increment of 10% of bakelite was added until the 90% of bakelite was reached. Three sample of each composition were manufactured. Manufacturing of these samples was accomplished by using an automatic mounting press machine under pressure equals to 6 bars at a temperature of 180 ºC for 20 minutes then they were cooled to room temperature. The shape of the specimen were cylindrical of 30 mm diameter and 30 mm height.
2. Deformation of the specimens: The deformation (compression test) of the specimens was conducted using a universal testing machine. Load displacement data were recorded and converted to a true stress - true strain curves. Using the following formula 1 and 2.

   $\sigma = F/A$ ……………………………………(1)

   σ- True stress
   F- Current force
   A- Current area

   $\varepsilon = \ln (l_i/l_0)$ ………………………………(2)

   ε – True strain
   l_i – Current length
   l_0 - Original length
3. Using the experimental data for the specimen numbers from 1-11 except the data for specimen numbers 2, 8, and 10 (Table 1) to train the ANN which is shown on Figure 1.
4. Verification of the model by predicting experimental data for specimens numbered 2, 8, and 10 (Table 1) and comparing them with their actual experimental data.
5. The preparation of the training data set is related to the way the output vary with inputs and availability of experimental data. If the output varies with inputs in different ways as shown in Fig2 (a and b), the training data used to generalize a model should be prepared differently. For the outputs which vary as in Fig (2b), it is necessary to optimize the training data used. To optimize the training process, Kong [1998] proposed a way to select the most representative data while in this investigation the output of the previous training were used to be as an input to the next one which was called in this investigation as filtrated ANN approach.

Table 1. The composition of the manufactured specimen

Specimen No.	Polystyrene %	Bakelite %
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	40	60
8	30	70
9	20	80
10	10	90
11	0	100

5- Results and Discussions

The true stress - true strain curves of the deformed specimens under compression are shown in Figure 3. The deformation was a single mode compression test with constant speed and the size of the specimen was 30 mm diameter and 30 mm height. It is clear from the curve that the addition of Bakelite to the polystyrene improved the strength of the polystyrene. The higher the percentage of Bakelite, the higher the strength of the specimen is. It is also obvious that the specimen of 100% polystyrene is the weakest and the one with 100% Bakelite is the strongest. On the other hand, the addition of the Bakelite gives an opportunity for longer strains which indicates an increase in ductility and also in toughness.

For the training purposes of the ANN, all the data were used except those for the deformation of the specimens of the following compositions: 90% (P) and 10% (B), 30%(P), and 70% (B), and 10%(P) and 90% (B), where P indicates polystyrene and B indicates bakelite. These specimens were used for verification. The ANN approach was used due to its ability to deal with the complex non linearity problems. The relative error of the predicted results after the primary training is shown in Figure (4). These results of the primary training were used as inputs to the second training process. The errors of the predicted results after the second training process is shown in Figure (5). It seems that the results are better but the errors still outside the 10% range. The results of this second training were used as inputs to the third training process. The errors of the predicted results after the third training process is shown in Figure (6). It seems that the results are better and the errors are within the 5% range. This means that the results after the third filtration of the results gave an acceptable results. The filtration process was used to let the ANN choose the most suitable data for training which is better than using a suggested criteria by the researcher [Jalham et al, 2001] which may lead to the omission of a necessary input data for prediction. Figure (7) shows the agreement of the predictions of the ANN approach after the third filtration. A good agreement was found which shows the powerfulness of the predicted constitutive equation by ANN to predict the non linear behavior of the material.

It is possible to examine Figure 7 to be able to compare the results. This Figure shows the experimental data and the ANN predictions, which supports the verification of the ANN and to interpolate the deformation behavior of the polystyrene reinforced with different percentages of Bakelite under compression

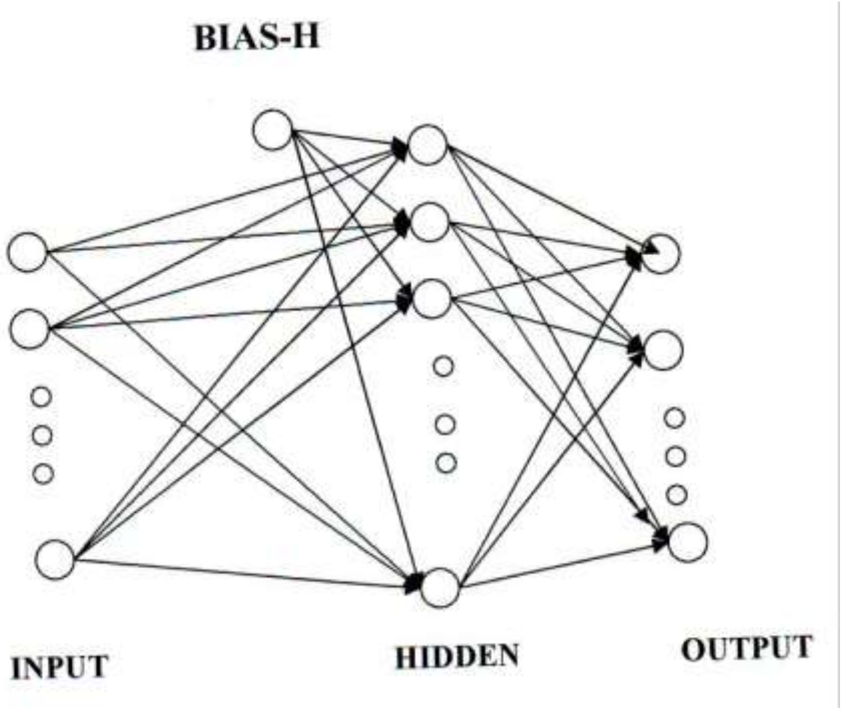

Figure1. The three-layer network with one hidden layer that was used in this investigation

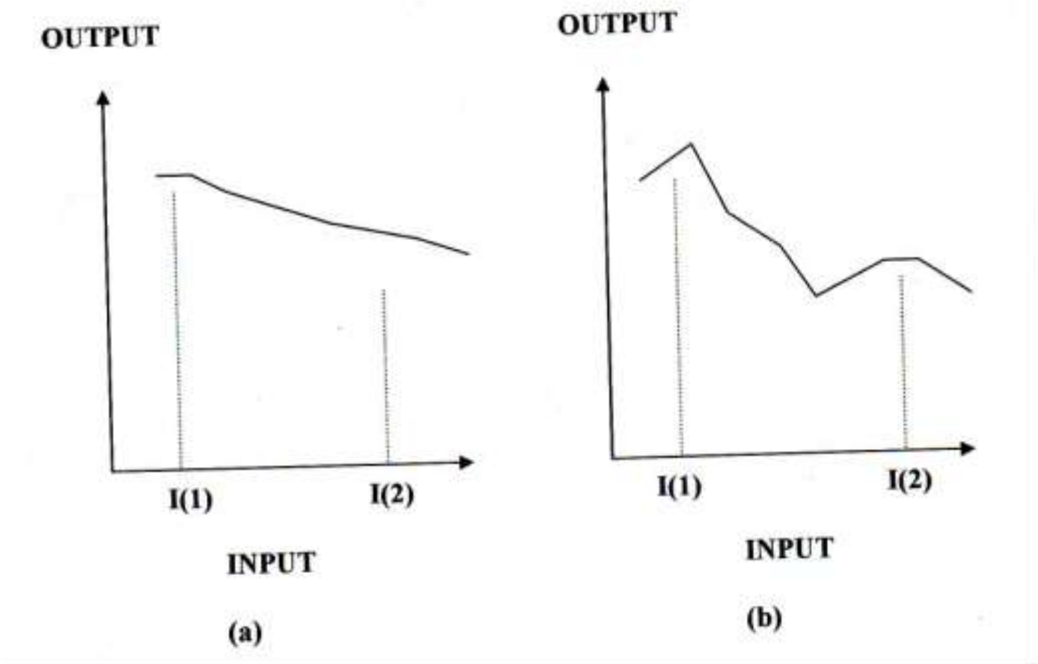

Figure 2. The different ways of output variation with the inputs

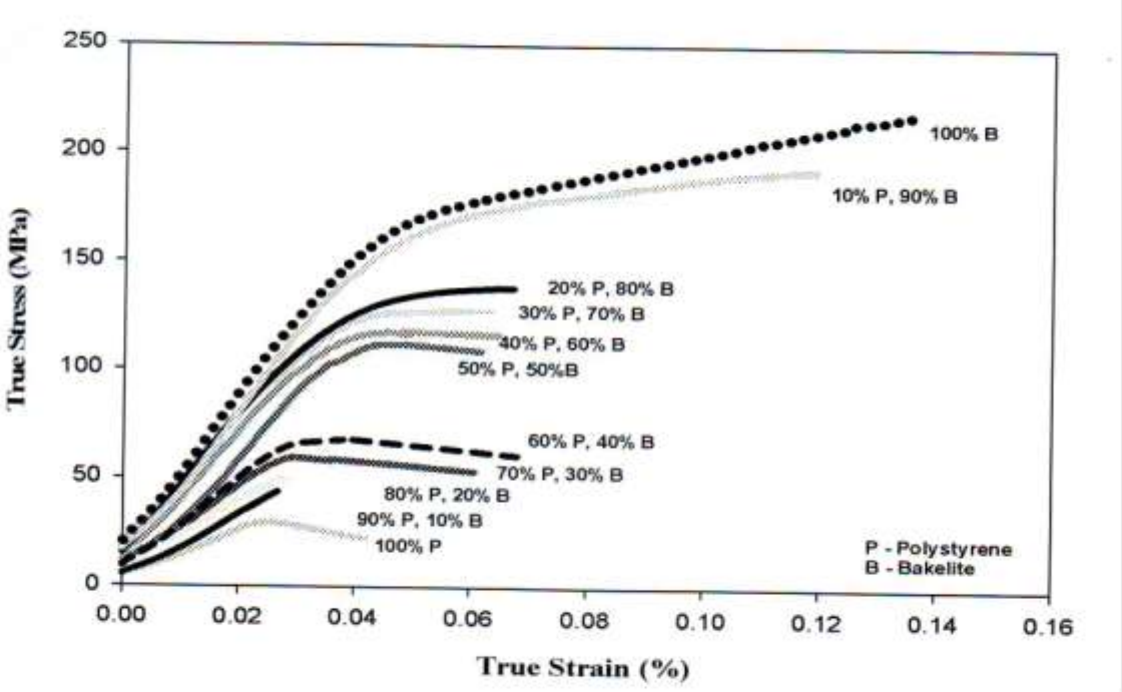

Figure 3. True Stress -True Strain curves for Ploystyrene (P) which is reinforced with different percentages of Bakelite (B)

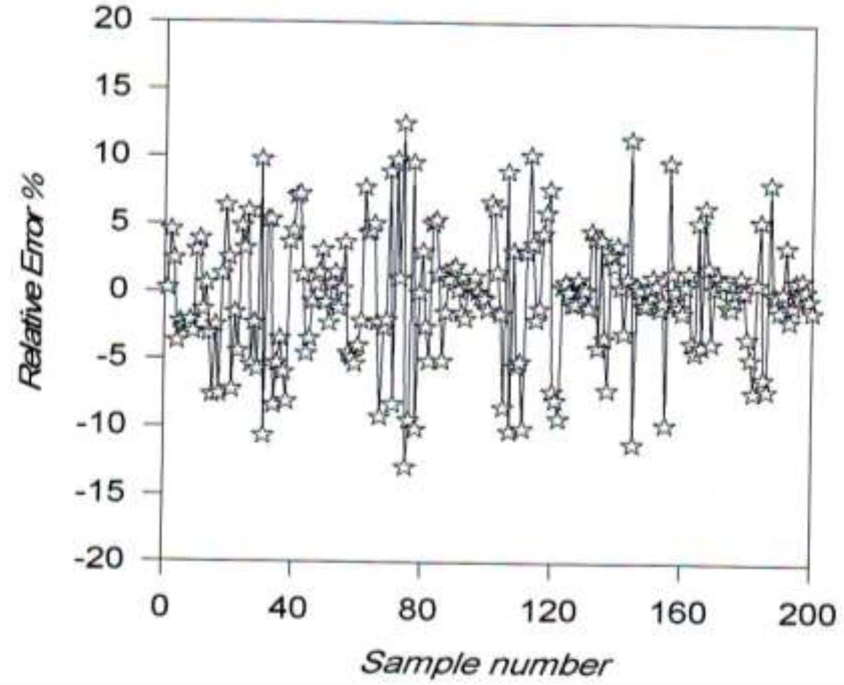

Figure4.The relative error of the predicted results after primary training

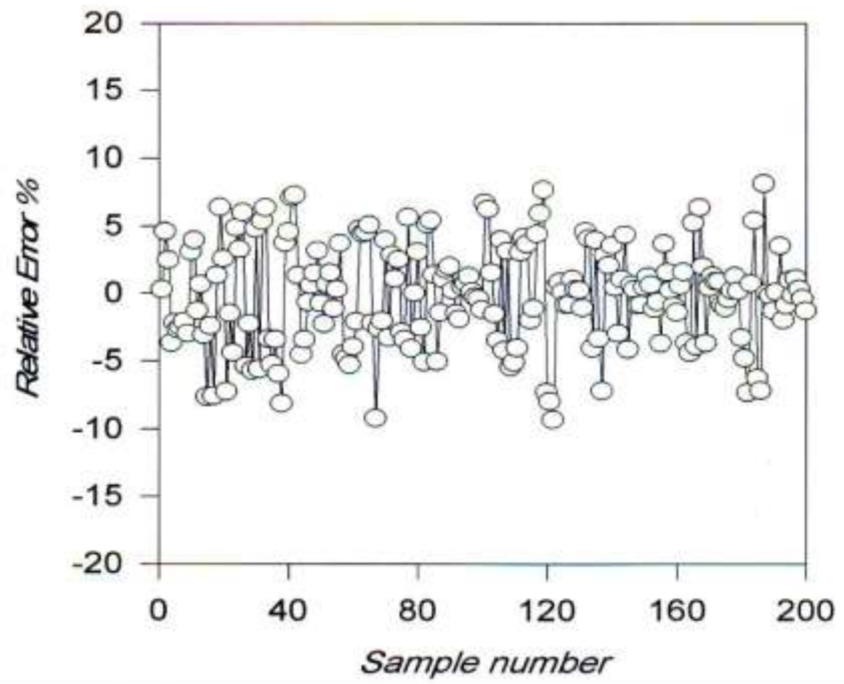

Figure 5.The relative error of the predicted results after secondary training

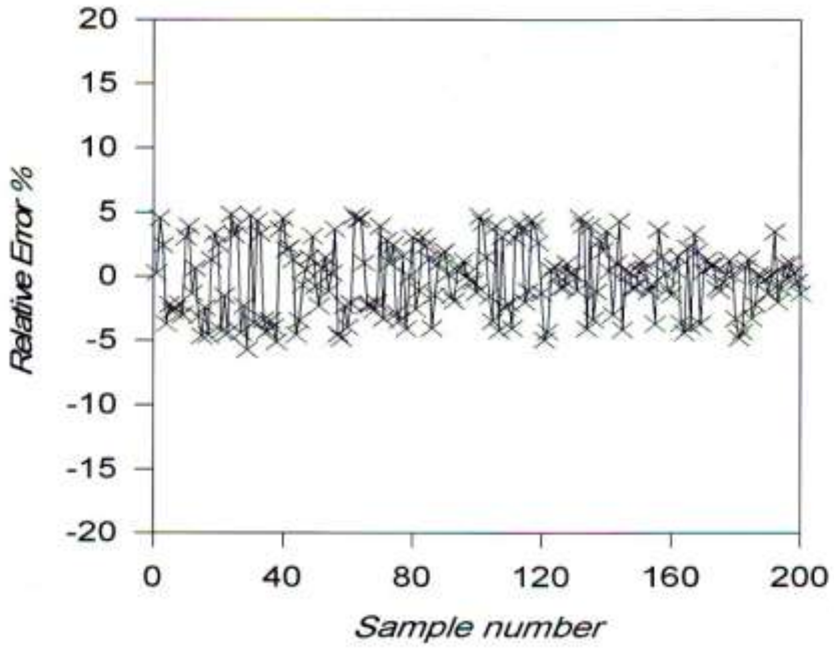

Figure 6.The relative error of the predicted results after the third training

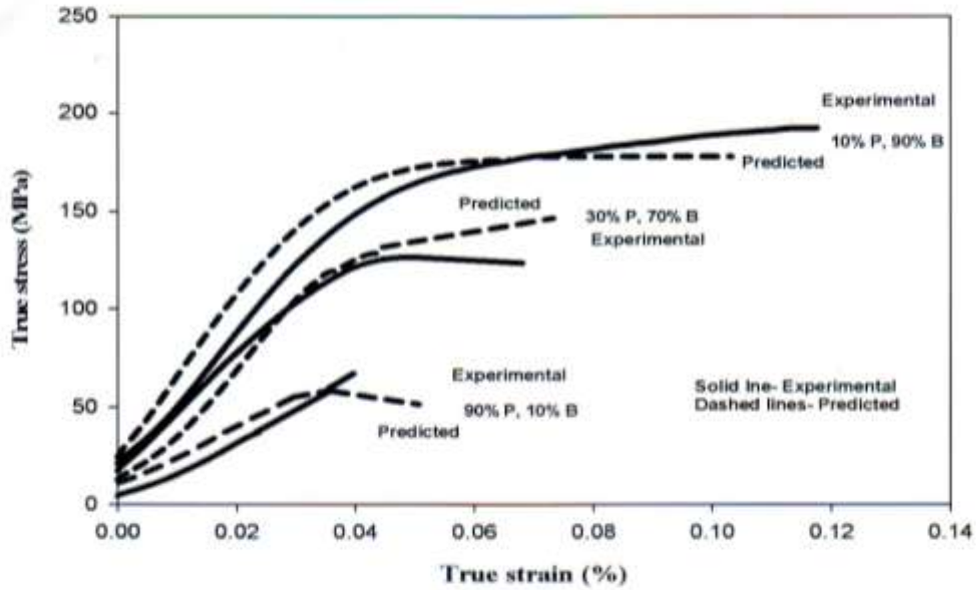

Figure 7. Verification of ANN model and its comparison with the not used experimental data in training and the ANN predictions

CONCLUSIONS

It can be concluded that the addition of bakelite to polystyrene affected its mechanical properties. In other words, the higher the Bakelite content in the polystyrene-bakelite blend, the higher the strength. On the other hand the filtrated Artificial Neural Network (ANN) is rather good tool to predict the deformation behavior of Polystyrene reinforced with Bakelite.

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استخدام الشبكة العصبية المفلترة للتنبؤ عن السلوك الميكانيكي للبولسترين المعزز بالباكلايت

عصام جلهم *

ملخــص

يهدف هذا البحث الى دراسة تاثير اضافة البكلايت بنسب متفاوتة إلى البولسترين على السلوك الميكانيكي للبولسترين، وقدرة الشبكة العصبية المفلترة على التنبؤ بهذا السلوك. وتختلف هذه الطريقة عن الطرق الأخرى بأن الفلترة كانت عن طريق استخدام الشبكة العصبية. وقد أشارت النتائج إلى أنه بزيادة نسبة الباكلايت تزداد قوة البولسترين وإن الشبكة العصبية المفلترة كانت جيدة للتنبؤ عن السلوك الميكانيكي للبولسترين المعزز بالباكلايت.

الكلمـــات الدالـــة: الشبكة العصبية، البولسترين، الباكلايت، الفلترة.

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