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Comparison of Mechanical Properties and Artificial Neural Networks Modeling of PP/PET Blends

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The aim of this study is to show the applicability of artificial neural networks, which are getting more applications with the advancement of technology, to determine the mechanical properties of polymeric materials. Mechanical properties of pure polypropylene, polyethylene terephthalate and their blends are determined in this study and the effect of temperature (room temperature, 40 °C and 60 °C) on mechanical properties is investigated. The method of artificial neural networks is used to make a prediction for mechanical properties. Mechanical properties of samples are measured using Lloyd 250N capacity tension and compression apparatus at crosshead speed of 10 mm/min, 25 mm/min, and 50 mm/min. For artificial neural networks modelling, the tensile experiment results, temperature, percent ratio, and crosshead speed are used as the input and output parameters. Three-layered multilayer perceptron, feed-forward neural network architecture is used and trained with the error back propagation. The results obtained from the output of the network are compared with the experiment results. The suitability of the method is found to be satisfactory.

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1. Introduction

Polypropylene (PP), polymers are used very broadly in the plastics industry, mainly due to their high availability and such features as flexibility [1]. Because they have inferior mechanical properties, such polymers have often been preferred in applications that do not require high loading. They can be used at high temperatures. As an alternative to those polymers, high-strength engineering plastics may be used. However, high strength engineering plastics are costly and are difficult to process when they are used alone.

Unlike PP, polyethylene terephthalate (PET) has superior mechanical properties, but is more difficult to process [2]. Therefore, in this study PP with PET polymer blending is intended to obtain a new polymer blend.

Experimental measurements can be used to determine the mechanical properties of a blend. However, they are usually very expensive and time-consuming. Mechanical properties of polymer materials show nonlinear behavior caused by viscoelastic processes and there is no mathematical formula available which could express such behaviour [3]. Hence, in this paper, we explore the potential use of artificial neural networks (ANNs) in the field of polymer characterization. Neural networks can easily learn the behaviour of extremely complex and non-linear systems. Once learning process has been completed, the results become available in real time.

Therefore, in this study, we use ANNs as an alternative approach to the prediction of mechanical properties of PP/PET blends and the temperature effect on the mechanical properties of PP/PET blends is investigated. First, the mechanical properties of PP/PET blends have been measured, and then experimental results have been used for ANN modeling. The capability of ANN to predict the mechanical properties of PP/PET blends has been tested.

1.1. *Artificial neural networks model*

ANNs are mathematical systems that mimic the way in which the human brain works [4]. A neural network is a collection of interconnecting computational elements simulated like neurons in biological systems. The development of ANN is based on basic computational elements [5]. The first work on neural networks was done by Frank Rosenblatt in the late 1950s and early 1960s. At the same time, Bernard Widrow and Ted Hoff have studied first adaptive systems by using the simple neural models and improved the learning mechanism [6].

Scientists have improved ANNs, based on the ability of apprehending difficult and complex samples of the brain [7]. ANNs learn from the data, which are related to the problem under study. In other words, system is trained by experience using appropriate learning examples and without programming. Neural networks gather their knowledge by detecting the patterns and relationships in data [8].

In this work, three-layered multilayer perceptron (MLP) architecture was used and trained with the error back propagation algorithm. MLP consists of one hidden layer of nodes with nonlinear activation functions. In this neural network architecture, each layer is fully connected to the previous layer, and has no other connections.

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2. Experiment

PP and PET polymers were used in this study and 3% maleic anhydride functionalized polypropylene (PP-MA) was used as the compatibilizer. Samples with average film thickness of 300–700 μm were provided by Mir Research and Development Inc. Five different blends of PP/PET were obtained (100/0, 90/10, 80/20, 70/30, 60/40 wt.%). The tensile tests were carried out using Lloyd Instruments LF Plus Single Column Universal Materials Testing machine, according to ASTM D638 standard, at three constant crosshead speeds of 10 mm/min, 25 mm/min and 50 mm/min. All tests were carried out at room temperature (23 ± 5 °C), 40 °C and 60 °C. The morphology of blends was investigated using scanning electron microscopy (SEM, JEOL Ltd., JSM-5910LV) after Au/Pd coating.

3. Results and discussion

3.1. Mechanical experiments

The mechanical tests of samples were carried out to determine Young modulus and yield strength as functions of PET content. Figures 1 and 2 show the dependencies of Young modulus and yield strength, respectively, on the PET content, at different temperatures and crosshead speeds.

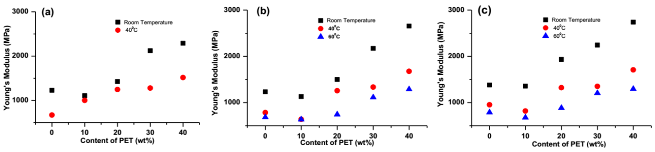

Fig. 1. Dependence of Young modulus on content of PET at crosshead speed of 10 mm/min (a), 25 mm/min (b) and 50 mm/min (c).

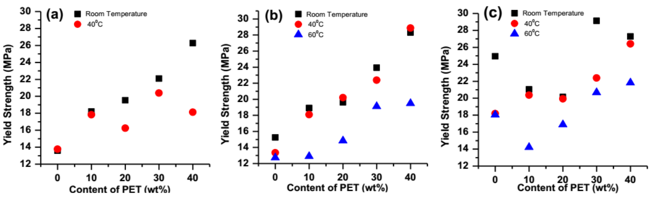

Fig. 2. Dependence of yield strenght on content of PET at crosshead speed of 10 mm/min (a), 25 mm/min (b) and 50 mm/min (c).

As the Young modulus of PET is higher than that of PP, it was expected that Young modulus of blends will increase when the percent of PET is increased. Such behaviour is observed in Fig. 1. However, in some of the result it was observed that Young modulus was not increasing. This is related to the fact that PET and PP are highly immiscible, so that blends might not be mixed equally or compatibilizer may have caused a decrease in Young modulus value [9].

When the mechanical properties of all of the blends were evaluated, it became clear that increasing of the temperature has decreased the Young modulus. The functionalized blends have a considerable improvement in mechanical properties over the blends with PET itself.

3.2. Morphology of PP/PET blends

The morphologies of PP/PET blends with the different content ratios are presented in Fig. 3. It is seen that different PP/PET content ratios result in entirely different morphologies. In the first example it is seen that PET particles have circular shapes and different diameters and are dispersed in the matrix heterogeneously. It is clearly observed that the number PET particles is increased in the structure of PP/20%PET sample. It was observed that an increase in the PET proportion leads to a tendency for the drops to connect with each other and fibrous structures are formed. Fibrous structures appear to become more regular in the 40% sample.

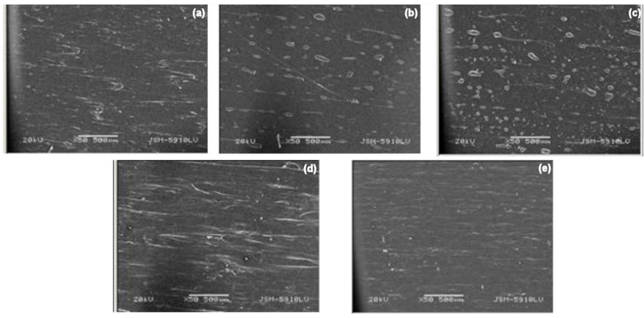

Fig. 3. SEM micrographs of the PP/PET blends: (a) pure PP, (b) PP/10%PET, (c) PP/20%PET, (d) PP/30%PET and (e) PP/40%PET.

3.3. ANN results

During ANN modelling, the results of the tensile experiment was used for training. For the training process, input sets were composed of eighty percent of the experimental results. Percent ratio, crosshead speed and temperature were used as input values and the Young modulus, yield strength were used as the output values. Sigmoid activation function was used and the training sets were normalized by scaling the real numbers into the range between 0 and 1. Number of hidden layers

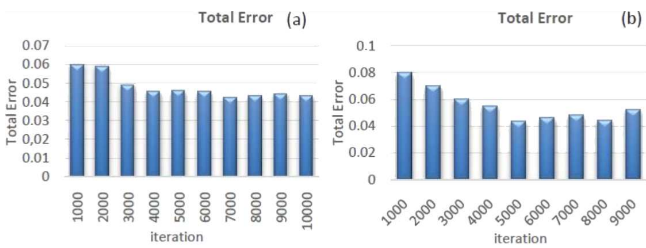

Fig. 4. Relations between the total error and the iteration number for (a) for Young modulus and (b) yield strenght.

was chosen to be one and the number of its neurons was chosen to be two. Number of iterations was changed between 1000 and 10000 to get the smallest error. Learning rate of 0.5 and momentum rate of 0.5 were reached after 7000 iterations for Young modulus and 5000 iterations for yield strength. For best values, the 0.042 percent error for Young modulus and 0.043 percent error for yield strength were obtained. The relations between the total error and the iteration number are given in Fig. 4.

For testing, a test data set was created from experimental results unused in the training stage. The system was tested maintaining the parameters corresponding to the smallest error value in the first stage. Test results can be seen in Table I.

TABLE I

ANN test results.

Content of PET [%]	Speed [mm/min]	Temperature [°C]	Young modulus exp. [MPa]	Young modulus ANN [MPa]	Yield strength exp. [Mpa]	Yield strength ANN [Mpa]
40	25	23	2653.79	2525.58	28.301	27.11
10	25	40	639.53	670.17	18.10	17.49
30	25	40	1336.21	1418.01	22.38	21.17
0	25	60	684.88	698.23	12.73	11.69
10	10	23	1106.91	1251.27	18.21	18.86
40	10	40	1515.12	1589.27	18.13	18.27
30	50	40	1352.36	1393.22	22.38	20.96
10	50	60	680.17	696.24	14.23	13.35

4. Conclusions

In this research, we have experimentally investigated the temperature-related mechanical properties of PP/PET mixtures and modeled our findings using artificial intelligence methods. The material studied in the present research is intended to be used for wrapping. Therefore, the samples were expected to be elastic, flexible and non-fragile. These samples should also have a high tensile strength. Results of tensile tests, performed at room temperature, ($23 \pm 5\,^{\circ}$C), 40 °C and 60 °C, indicate that at 10–20% of PET, the mechanical properties have been within the acceptance interval. Finally, it was found that ANN results have been consistent with our experimental results.

Acknowledgments

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