Iranian Journal of Chemical Engineering, 17(4), 21-32, (2020) pISSN: 1735-5397
DOI: 10.22034/ijche.2020.130358 eISSN: 2008-2355

Full Paper

Studying the Influence of the Mixing Speed of the Polymer Blend of General-Purpose Polystyrene and Acrylonitrile-Butadiene Styrene with the Applications of Artificial Neural Networks

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ARTICLE INFO

Article history:
Received: 2020-12-10
Accepted: 2021-04-25
Available online: 2021-05-25

Keywords:
General Purpose Polystyrene (GPPS), Artificial Neural Networks (ANN), Acrylonitrile-Butadiene Styrene (ABS)

ABSTRACT

General Purpose Polystyrene (GPPS) has weak properties and this weakness made the applications of this polymer be limited. Therefore, the use of the mixtures of polymers can improve these properties. Different parameters like the mixing speed can affect the quality of the properties of preparing polymer from the mixture of several polymers. In this research, the polymer blend of GPPS and Acrylonitrile-Butadiene Styrene (ABS) has been investigated. In order to prepare this polymer mixture, GPPS has been considered as the main phase (base polymer) and ABS has been considered as the scattered phase (additive). Firstly, the blended polymers with different weight percentages (0, 0.04, 0.08 and 0.12) of ABS/GPPS in different mixing speeds (30, 40, 50 and 60 rpm) have been prepared and for each mixture, the Melt Flow Index (C), Vicat Softening Temperature, Tensile at Break and impact test have been measured. The laboratory data collected from different tests, has been simulated by the Multi-Layer Perceptron (MLP) method of Artificial Neural Networks (ANN) and the results of the simulated data covered the laboratory data perfectly. The results declare that the presence of ABS in the mixed polymer improved the Tensile strength and thermal properties. In order to reach the highest quality in carried out tests, it is considered to use ABS in a high percentage (0.12) and the maximum possible mixing speed (60 rpm).

1. Introduction

Polystyrene is one of the most important thermoplastics and due to the good properties of this polymer, it has many applications in different fields. However, weak properties of this polymer limit these applications [1-5]. In a research, in order to optimize the synthesis of Expandable Polystyrene (EPS), a new method (Multi-Stage Initiator Dosing, MID), in which the initiator is dosed into the reactor, is proposed. Results showed better control of the process, shorter reaction times and better

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quality of the product and time of the process and a reduced amount of consuming the initiator . Also, in this process because of varied doses of the initiator in several stages the suspension control would be easier [6, 7]. With an increase in using the polymeric blends in today's modern society, they have become more important due to their characteristics. Polymer blends have a long history and it has been correlated with polymer history. Blending polymers can develop new polymeric systems having new properties, also blending neutralizes the uneconomical and long synthesis process [8-10]. In a research, the expanded polystyrene (EPS) waste was modified and investigated by polyvinylpyrrolidone (PVP) using the simultaneous gas release in various solvents. The results of this research have showed an increased compatibility between the components and the compacted structure [11]. In a study, the solubility and diffusivity of n-pentane in the blends of a low-molecular weight polystyrene (PS) and a high-molecular weight poly (methyl methacrylate) (PMMA) were investigated. For evaluating the swelling behavior of npentane-impregnated blends an equation of state has been used. The results showed a good agreement between the experimental and numerical analyses [12]. In a paper, paraffin prepared with a polystyrene shell. The results declared that with the incorporation of a flame retardant on microcapsules for energy storing concrete samples, improved flame retardancy and thermal energy storage properties were achieved [13]. In a research, the Natural Rubber (NR)/(EPS) blends were prepared by melt mixing using a Brabender Plasticorder. The grafted blend had more of NR during the mill compounding. Results showed that EPS had better dispersion in the compatibilized blend compared to in the noncompatibilized blend. [14]. In a study, for buried concrete pipes, the performance of imperfect trench installations has been evaluated combining a soft material zone. The results declared that in order to reduce the surrounding pressures, soft zones could be a highly effective way [15]. In a research, the impact of having two compatibilizers added to 80/20 (wt/wt) polypropylene (PP)/(ABS) blends in the presence of carbon black (CB) has been investigated. the formation of the matrix-droplet morphology has been shown by the composition. Adding both polymers to 80/20 (wt/wt) PP/ABS blends refined the morphology significantly compared to that of 80/20 (wt/wt) PP/ABS blend in presence and absence of these polymers individually. Adding CB up to 5 wt % to both PP-g-MA and SEBS-g-MA in 80/20 (wt/wt) PP/ABS blends refined the morphology significantly compared to in 80/20 (wt/wt) PP/ABS blend in presence and absence of PP-g-MA and SEBS-g-MA individually [16]. In a research, the effect of the compatibilizers and blending sequences on the morphology and properties of the immiscible poly (L-lactide) (PLLA/ABS) blend have been investigated. The results showed better compatibilizers for improving the properties of the PLLA/ABS blend, compared to linear polymers (RL) [17]. In a research, the influence of the ABS polymer and compatibilizer on different properties of the polycarbonate (PC)/ABS blend has been studied. The results declare that the compatibilizer had useful effects on the general properties of the (PC/ABS) blend [18]. In a study, the composites from polymer (trimethylene terephthalate) (PTT)/(ABS) are blended with maleic anhydride grafted PTT (PTT-g-MA) as a compatibilizer. Results showed that the phase stability in the presence of the compatibilizer PTT-gMA and the toughness of the composites have been improved [19]. In a research, in order to investigate the influence of compatibilizers and carbon nanotubes on the mechanical, electrical, and barrier properties of trimethylene terephthalate (PTT)/ABS blends, the two materials, ABS and thermoplastic polyurethane (TPU), were prepared. It was shown that the blends containing 10-20 wt % of TPU had more enhancement, and the one with 30 wt % of TPU had a good adhesion [20]. In a research, the goal was to investigate the morphology and properties of the blends of PA6 with core-shell and grafted ABS by in-situ reactive extrusion. The morphology results illustrated that submicron-sized ABS droplets were evenly dispersed in core-shell ABS/PA6 blends, having improved the impact strength [21]. In a research, organo-sepiolite (O-Sep) filled 80/20 (w/w) polypropylene (PP)/ABS nanocomposites were fabricated for improving the poor impact toughness of polypropylene (PP). The obtained results show that O-Sep filled polymer had more enhancement of the dispersion and increased the crystallinity of blends [22]. In a study, the parameters of the injection molding (IM) process of the (PC/ABS) blends were optimized in order to investigate the application of the Taguchi method. The results showed no injection defects on the injected (PC/ABS) parts and the optimal combination of parameters provided injected (PC/ABS) parts with a better shear stress [23]. In a research, PET wastes in different weight percentages have been combined with ABS under different conditions of temperature, and the time and speed of extruder in order to reuse PET and reduce the environmental pollution. The results declared that for condition with the constant temperature and time and speed of mixing with increasing PET waste in ABS, properties of this polymer have been improved. Also, the results of the simulation covered the laboratory data perfectly [24]. In our previous research, the effect of the general performances of the radial basis function (RBF) method of artificial neural networks (ANN) with laboratory data on different nanoparticles under different conditions of crude oil were studied. The results declared that RBF neural networks had an acceptable performance. This method includes all the experimental data perfectly, and provides the possibility of using different conditions for getting the information about the viscosity [25].

In this research, by using ABS, the tensile and thermal properties of GPPS have been corrected. The experiments in different percentages of ABS in GPPS (0, 0.04, 0.08 and 0.12) have been executed. Also, the investigations of authors of this research declares that the influence of the mixing speed of the mixed polymer is used for the first time in this research. The different percentages of ABS/GPPS in different mixing speeds (30, 40, 50 and 60 rpm) lead to developing a copolymer. Different tests (MFI, Vicat Softening Temperature, Tensile at Break and impact test) are done on the polymer. The results declared that changing the mixing speed was very effective. All of the results are simulated by ANN with the MLP method, other than our research, there has been no simulation for the similar researches yet and it has been accomplished for the first time in this research. Because of good overlap of experimental data and simulated data, the results of simulation can be used for areas which have no tests performed on.

2. Materials and equipment

2.1. Materials

GPPS 1540 from Tabriz petrochemical company is used as the base of this researche which has been done for preparing ABS/GPPS polymer with improved properties and easier application,. Acrylonitrile-Butadiene Styrene (ABS SD0150) from Tabriz petrochemical company has been used as scattered phase. For this purpose, several samples with different percentages of compositions in the extruder have been prepared.

2.1.1. General purpose poly styrene (GPPS 1540)

This grade is with introduction oil and has lower Vicat temperature and higher MFI number. This grade is useful in injecting applications. GPPS 1540 is an artificial aromatic polymer which has been prepared by the combination and polymerization of styrene monomers as chain. The specification of this polymer is shown in Table 1.

Table 1

Specification of the general purpose poly styrene (GPPS 1540) polymer.

Property	Unit	Value
MFI (5 kg)	Gr/10 min	11.1
IZOD	Kj/m^2	1.11
Vicat	^oC	94.6
Tensile	MPA	25.4
Elongation	%	-

2.1.2. Acrylonitrile-butadiene styrene (ABS SD0150)

ABS is a thermoplastic polymer which has been prepared by the polymerization of styrene and acrylonitrile in the presence of poly butadiene and has amorphous structure. It has balanced mechanical, thermal and chemical properties. The specification of this polymer is shown in Table 2.

Table 2

Specification of the acrylonitrile-butadiene styrene (ABS SD0150) polymer.

Property	Unit	Value
MFI (5 kg)	Gr/10 min	1.9
IZOD	Kj/m^2	24.7
Vicat	^oC	97
Tensile	MPA	-
Elongation	%	15

2.2. Methods

GPPS and ABS with different percentages, 0.4, 0.8, 0.10 and 0.12, of ABS inside GPPS have been blended. After setting the temperature (220 ^oC) and configuring the device, in the first step, in order to clean the injection path, a certain amount of GPPS has been added in to the hopper of the extruder device. After GPPS leaving the die head part of the device and making sure of the cleanliness of the path, the granules of the blended polymer are poured into the hopper part of the extruder device. After melting in the extruder route, the materials are mixed perfectly in different mixing speeds (30, 40, 50 and 60 rpm) and melted materials exit the device from the die head part. These strings are cooled by moving inside the cold-water pools and then in order to be cut in the shape of plates, they enter the grading section. From these plates, the MFI is measured, but for measuring the Vicat Softening Temperature, the impact test number and stretching properties, the plates must be in an exclusive injection device as flat and dumbbell parts.

2.3. Equipment

A twin screw extruder from SM Platek with the screw diameter of 20 mm and the length to diameter ratio of 32 was used for mixing polymeric materials. The injection device with the extruder temperature of 190 ^oC, injection pressure of 160 bar, injection volume of 3116 cm^2 and template volume of 253 cm^2 from Billion, was used in order to prepare molds needed for the elongation at break and impact tests. SHIMADZU Autograph AG-X with ASTM D-638 was used in order to investigate the elongation at the break of the samples. For the impact test, coded 6967.00 from Ceast, Italy with ASTM D-256 was used. For MFI, coded 7026.00 from Ceast, Italy with ASTM D-1238 was used in order to investigate the processability of the prepared mixture and index the flow of mixtures. For Vicat Softening Temperature test, HD-PC from Yasuda, Japan with ASTM D-1525 was used in order to declare the softening Temperature of materials without the specified melting point. A oxygen device has been used in order to fully mix the two polymers, and a molding device has been used for the preparation of the samples for having different tests.

2.4. Artificial neural network (ANN)

2.4.1. Multi-layer perceptron (MLP) network

The basic element of a Multi-Layer Perceptron (MLP) neural network is the artificial neuron performing a simple mathematical operation on its inputs. The inputs are the variables x_1, x_2,…,x_p and a threshold (or bias) term. Every input value is multiplied by weight, w_i, after which the results are added with the bias term to produce z. Finally, φ, a known activation function, performs a pre-specified (non-linear) mathematical operation on the projected inputs. MLP networks can conclude many neurons ordered in layers. The job of the neurons in the hidden layer is the actual processing. Although, many hidden layers can be used, because of their simple structure, using one hidden layer network is more popular for practical applications. Using multilayer hidden neurons usually results in increasing the degrees of freedom that is not necessary. The MLP network has been trained using adapting the synaptic weights using a back-propagation technique or any other optimization procedures. During training phase, the network output has been compared with a desired output. The error between these two signals has been used to adapt the weight. This rate of adaptation can be controlled by a learning rate. A high learning rate will make the network adapt its weights quickly but will make it potentially unstable. In order to make the network keep its weights constant, learning rate should be set to zero. The steepest-decent optimization technique with constant step length parameters (η) was employed in this article.

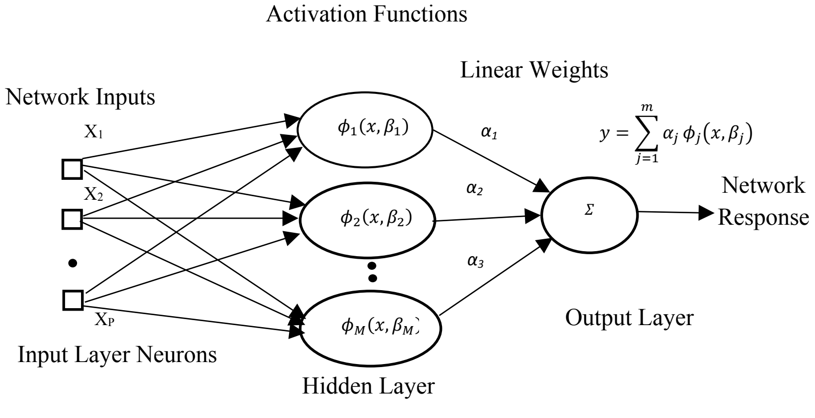

Figure 1. The regularization network.

As in our previous work, additional linear weights (α's, as shown in Figure 1) were used to accelerate the network convergence [26]. The optimal values of these linear parameters are updated after each back-propagation iteration using the following set of linear equations:

$$(\phi^T \phi)\underline{\alpha} = \phi^T \underline{y} \quad (1)$$

where $\phi_{I,j} = \varphi(z_{i,j})$, i= 1,…, N & j= 1, …, M and y is the N*1 vector of measured values. The parameters N and M represent the number of training data and number of neurons respectively. The training flow chart of such MLP network is given in our previous articles.

Also, other quadratic methods (e.g. Newton like techniques) can be used to compute the optimal performances of the MLP networks. The "line search" technique is usually used to predict the optimum learning rate compared to the Newtown step length 4 ($\Delta x = -G^{-1}g$). Evidently, the quadratic methods converge faster near the optimal point and not necessarily far from it. This is one of the reasons why quasi-Newton techniques such as Levenberg-Marquadt or Guass-Newton are used [30]. Finally, the steepest-descent methods (such as back-propagation) are more robust than the quadratic techniques when a proper step length control is used. In practice, almost never Newton like optimization methods are used for the efficient neural network training because they can be easily trapped into sub-optimal solutions. The algorithm of the MLP network is shown in Figure 2.

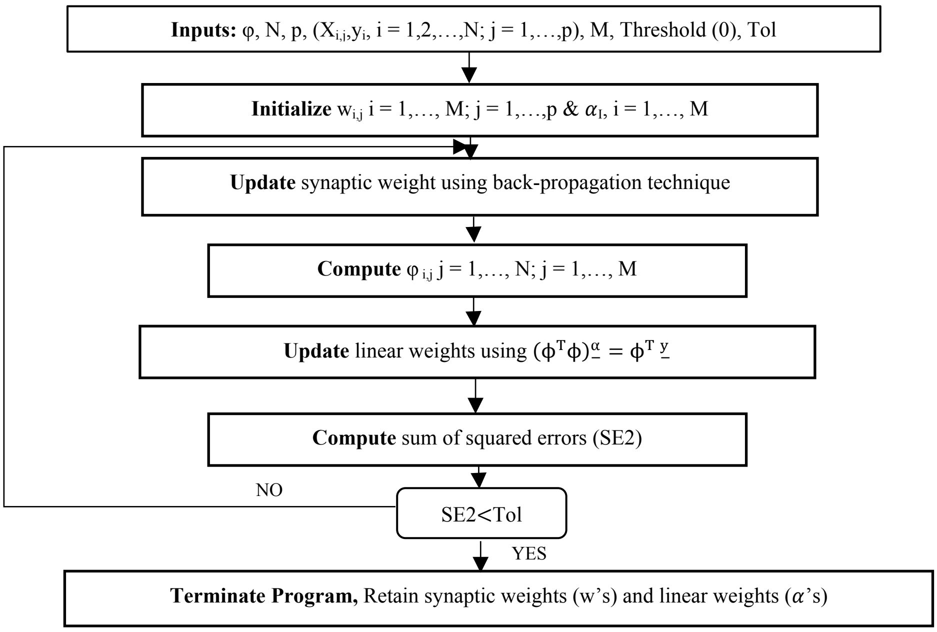

Figure 2. Learning algorithm for MLP networks.

One of the properties of this algorithm is being responsive even for the low data count and the amount of error reaches the minimum and the number of hidden neurons is 16. The calculated error equals to 5.11 * 10-5. Weight coefficients and the bias are the [2 (the number of inputs) * 16 (the number of hidden neurons)] matric in which the numbers are selected randomly from 1 to 100.

3. Results and discussion

3.1. Laboratory results

ABS with different percentages (0, 0.04, 0.08 and 0.12) blends with GPPS with different speeds (30, 40, 50 and 60 rpm). Different tests (MFI, Vicat Softening Temperature, Tensile at Break and impact test) have been carried out on the synthesized polymer; the results have been shown in Figure 3-6.

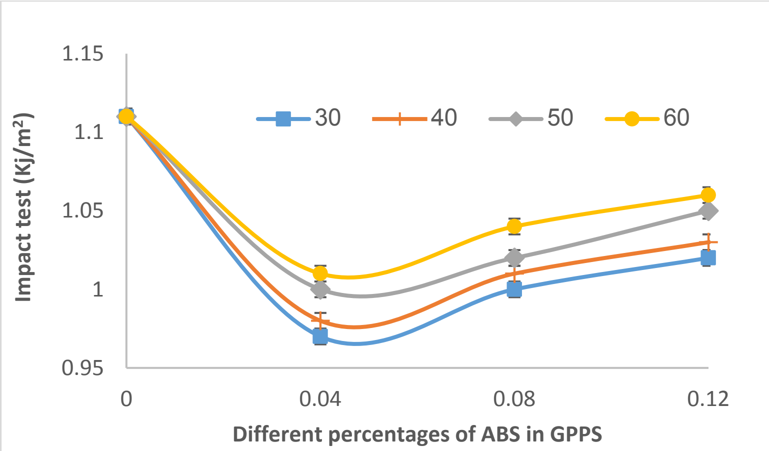

Figure 3. The amount of the impact test for different percentages of ABS in GPPS in different mixing speeds.

The impact test results on different mixing speeds and different ABS percentages in GPPS are shown in Figure 3. The numerical value of pure GPPS equals to 1.11 kg/m^2. As it has been shown by the figures, by increasing the amount of ABS, in compare to the pure state, the strength of the polymer decreases by adding polymer. But by increasing the percentage from 0.04 to 0.12, the strength increases due to the presence of the ABS polymer which has a higher strength compared to the GPPS polymer.

With an increase in the mixing speed from 30 to 50 rpm, because of the fact that these two polymers blend perfectly and have higher pressure and suitable tension on the developed polymer, the amount of the impact test increases.

Therefore, in order to reach the highest impact test value, the mixing speed should be 60 rpm and the ABS percentage in GPPS should be 0.12.

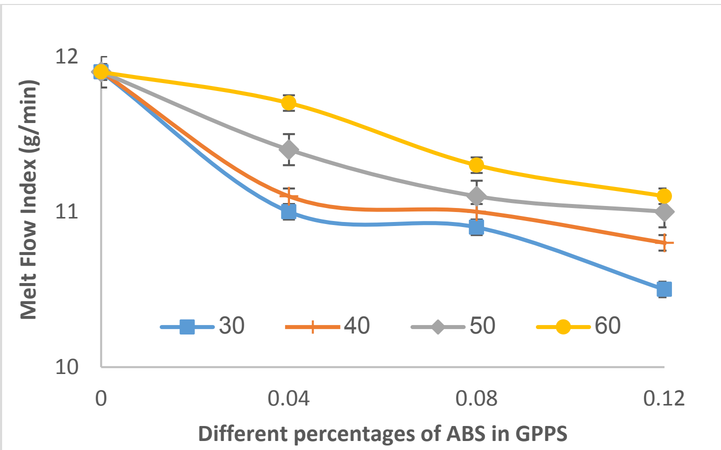

Figure 4. The Melt Flow Index test for the different percentages of ABS in GPPS in different mixing speeds.

The results of the Melt Flow Index test in different mixing speeds and percentages of ABS in GPPS are shown in Figure 4. The results declare that by increasing the amount of ABS in the polymer mixture, the MFI number decreases by the same amount and the strength increases subsequently. Thus, as much as the amount of the MFI gets lower, the melt viscosity is higher. By increasing the mixing speed, the melt viscosity decreases and as a result, the amount of the MFI will increase. For 0.08 percent of ABS in GPPS, the amount of the MFI does not change much. based on the target polymer, the amount of the mixing speed and the percentage of ABS in GPPS can be chosen.

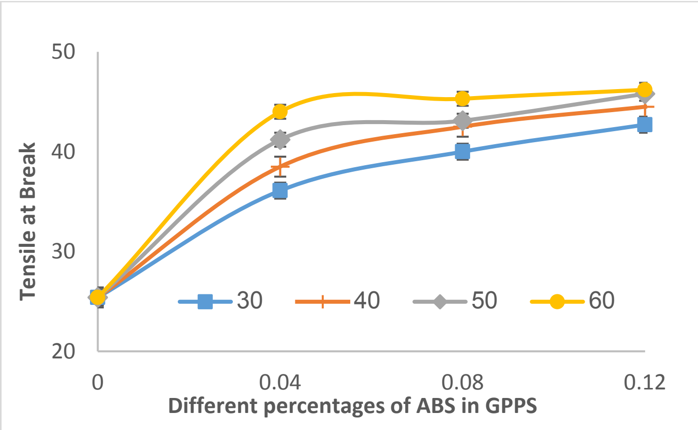

Figure 5. Tensile at the Break test for the different percentages of ABS in GPPS in different mixing speeds.

Investigation for the Elongation at Break in the break point in the different percentages of ABS in GPPS in different mixing speeds is shown in Figure 5. According to the figure, the amount of the Elongation at Break of the mixture polymer in the break point increases by increasing the percentage of ABS in GPPS and the mixing speed. The Elongation at Break of the GPPS equals to 25.4. By adding ABS up to 0.12 in the mixing speed of 60, this value increases to 50 rpm, and that's because of the Elongation at Break being high for the ABS polymer and by increasing the mixing speed, the value of the Elongation at Break reaches the maximum amount. Although, it is noteworthy that this increase in the distances between 0.08 to 0.12 happens with a slower slope.

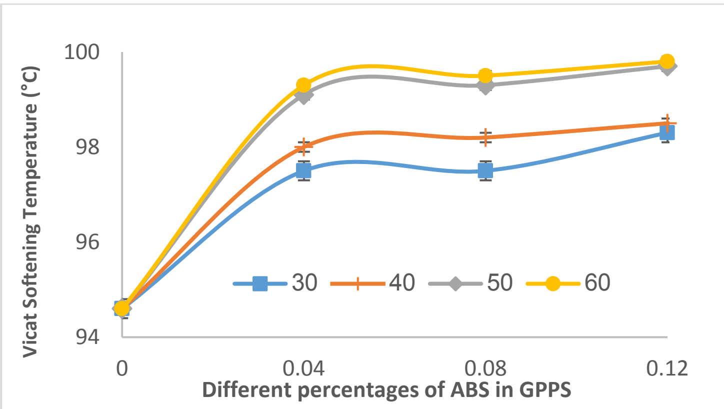

Figure 6. Vicat Softening Temperature test for the different percentages of ABS in GPPS in different mixing speeds.

The results of the Vicat Softening Temperature test in the different percentages of ABS in GPPS and mixing speeds are shown in Figure 6. As it has been shown in figures, by adding ABS to the GPPS, the resistance of the polymer against heat and softness increases. And this increase is more in higher mixing speeds. But with an increase in the percentages of polymer, because of the very low increment in the percentages of the polymer, the amount of the Vicat test is almost the same.

3.2. Simulated results

Data gained from Different tests (MFI, Vicat Softening Temperature, Tensile at Break and impact test) in different percentages of ABS in GPPS (0, 0.04, 0.08, 0.12), in different mixing speeds (30, 40, 50, 60 rpm) has been simulated by the MLP method of ANNs. As the results of the simulation have been shown in Figure 7, the simulated data covers the laboratory data perfectly. If there are any other conditions needed than the conditions performed, the simulated results can be obtained for those conditions too.

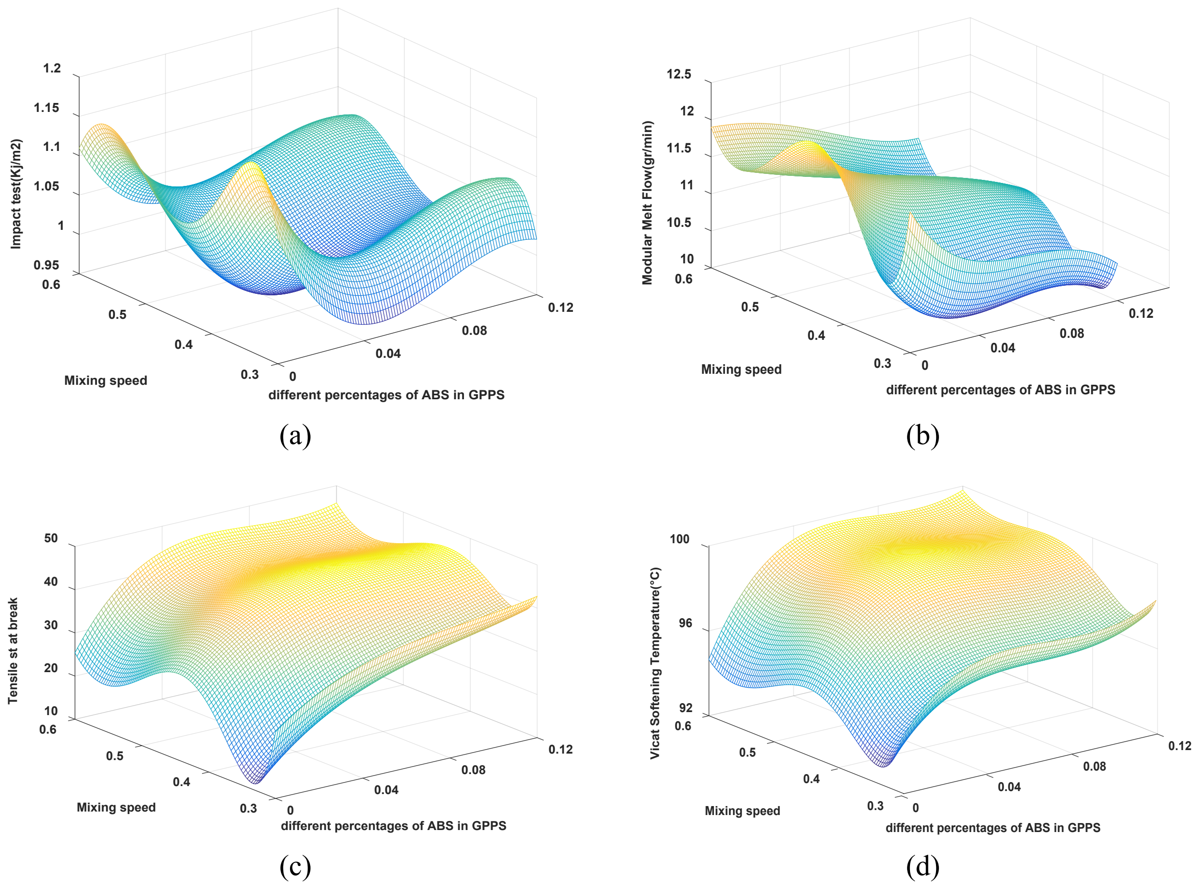

Figure 7. Simulations of the artificial neural networks for different tests: a) Impact test, b) Melt Flow Index, c) Tensile at Break, d) Vicat Softening Temperature.

4. Conclusions

- The mixture of ABS/GPPS in different percentages (0, 0.04, 0.08 and 0.12) in different mixing speeds (30, 40, 50 and 60 rpm) have been prepared.
- Different tests (MFI, Vicat Softening Temperature, Tensile at Break and impact test) have been done on the prepared polymers.
- The simulated MLP and the results have

covered the laboratory data perfectly.

- With increase in ABS in GPPS, the value of the impact test, Tensile at Break, Vicat Softening Temperature increases and the value of the MFI decreases.
- The increase in the impact test, Vicat Softening Temperature and Tensile at Break and the decrease in the MFI cause the quality of the polymer to be increased. Therefore, the addition of ABS causes the quality of GPPS to be increased.
- In each test, in the constant percentages of ABS in GPPS, with an increase in the mixing speed, the numerical value of the related test increases.
- In every Item, in order to increase the quality of the prepared polymer, it is considered to have a high amount of the ABS percentages and the maximum possible mixing speed.

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