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PREDICTION OF TRIBOLOGICAL BEHAVIOR OF ALUMINIUM MATRIX HYBRID COMPOSITES USING ARTIFICIAL NEURAL NETWORKS

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Abstract: *Prediction of tribological characteristics of hybrid composites with A356 matrix using artificial neural networks (ANN) was performed in this paper. During experiment next parameters were varied: sliding speed, load, sliding distance and wt.% of reinforcement. The obtained experimental results were used to form the artificial neural network in which were varied number of neurons in the hidden layer, number of layers, the activation function and the function of training. Training of the neural network was performed for the wear rate, and optimal regression coefficient was equal to 0.994, for the network 4-15-10-1. Using neural networks to predict the wear rate greatly reduces the time and cost of experiment.*

Keywords: *prediction, wear rate, artificial neural network, coefficient of friction.*

1. INTRODUCTION

The increasing demands of today's industry that seeks to reduce the price and weight of the construction, as well as, to increase their working life, have contributed to the development of new materials. Under the concept of new materials, in this case, it refers to the composite materials obtained by combining two or more materials. One constituent of the composite represents its basis, while other constituent or more of them make reinforcements. The application of composite materials has increased in relation to the materials that constitute its basis for the purpose of improved characteristics [1-4].

In the engineering industry, the most attention is given to composites with a metal base. Aluminium, magnesium, iron, cobalt and others are mainly used as the basis for these composites, while the ceramics are most commonly used as the reinforcements, such as, for example, silicon carbide.

Many researchers have studied the production of the composites in terms of variations in parameters during the process of obtaining and the combination of contents, types and size of the reinforcing particles. For the processing of the experimental data often are used Taguchi method, factor design, Taguchi Grey relation analysis, and in recent years the use of artificial neural networks is increased [5-10].

The artificial neural network is a non-linear statistical technique that is used for data processing when it is very difficult or impossible to apply a statistical method [11-16].

Babić and Mitrović studied the effect of adding the reinforcement Al_2O_3 in the base alloy ZA-27. The tests were performed on the tribometer with block on disc contact geometry in conditions without lubrication. The study plan was implemented with the variation of the wt.% of reinforcement, as follows: 3%, 5% and 10%; normal load of 10 mN, 50 mN, 100 mN and 120 mN; and the sliding speed: 10 mm/s, 20 mm/s and 30 mm/s. They concluded that that the composites with the addition of Al_2O_3 have a much lower coefficient of friction than the base alloy ZA-27 in all test conditions. The composite with the highest wt.% of Al_2O_3 particles (10%) has the best friction characteristics [17].

Basavarajappa et al. studied the tribological wear behaviour of Al2219/SiCp-Gr composites in conditions without lubrication. The tests were performed on the tribometer with pin on disc contact geometry, for sliding speeds up to 6 m/s and for the normal forces up to 60 N. According to the obtained results, it was concluded that the wear resistance of composites was increased with addition Gr and SiCp [18].

Stojanović performed the investigation of wear of the composite with A356 base and silicon carbide and graphite reinforcements, sliding speed, sliding distance, normal load and the percentage of reinforcement's content varied during the testing. The tested materials were: A356 base material, as well as composite materials with 10 wt.% SiC and 1, 3 and 5 wt.% Gr. The composite material with 10 wt.% SiC, and 1 wt.% Gr had the lowest wear rate at all test conditions [2].

Saravanan et al. performed the prediction of the wear rate and the friction coefficient of composites with aluminium base and Rice Husk Ash (RHA) reinforcement by applying artificial neural network [19]. To form the network, they used the following parameters: the normal load, sliding speed, particle size of RHA reinforcement and the wt.% of RHA reinforcement. After training, they obtained the value of the regression coefficient of 0.99. Based on the conducted analysis, they concluded that the trained neural network can be used for predicting the wear rate and the friction coefficient with up to 95% accuracy [19].

Rashed et al. used a neural network to predict the of wear rate of A356/SiC composites. They used normal load, test temperature, SiC particle size and their wt.% in the composite as the input. The neural network has proven to be a very effective tool for predicting the tribological behaviour of composites [20].

Maheswaran et al. studied the wear of hybrid composite Al6061-Al_2O_3-Gr, where the sliding speed, sliding distance, normal load and the percentage of the reinforcement varied. By comparing the experimental results and the one obtained by training the neural network, they showed that the neural network was a useful tool for predicting the wear of a hybrid composite in comparison to other experimental research [21]. Likewise, Varol et al. concluded that the neural network was a very powerful tool for predicting the physical and mechanical properties of composites based on the comparison of experimental results and the results obtained by training the neural network. They studied the characteristics of the composite Al2024–B_4C, for different size and wt.% of the reinforcement which formed the input of the neural networks, while density, hardness and tensile strength were used as the output. After training the network, the regression coefficient was 0.99 [22].

Altinkok et al. predicted the mechanical characteristics of Al_2O_3/SiC composites by using artificial network. They used the neural network with back propagation for predicting density and tensile strength, and the results of the regression coefficient had a satisfactory accuracy [23]. Hayajneh et al. studied the addition of copper as an alloying element and as the reinforcement on tribological behaviour of Al–4Mg composite with the help of neural networks [24]. Different alloys Al-Cu were subjected to examination in the temperature conditions without lubrication for the normal load of 40 N. They came to the conclusion that the addition of SiC has a good effect on increase of the wear resistance of composites. The neural network was formed with the help of obtained results, and its total error value was 2.40 %, which was satisfactory and this neural network can be effectively used to predict tribological behaviour of the composite Al-4Mg [24].

Durmus et al. used a neural network to predict the wear loss and surface roughness with the aluminium alloy AA 6351. They compared the results obtained by experimental tests with the results obtained by using neural networks, and they noticed there was a coincidence to a large extent [25]. Vettivel et al. concluded that, for prediction of the tribological behaviour of sintered Cu-W composites, the neural network was better for prediction than polynomial regression based on the percentage error [26]. As the parameters of the neural network, they used wt.% of tungsten, sintering temperature, load and sliding distance in order to predict the characteristics such as the hardness, specific wear rate and coefficient of friction. They obtained very good coincidence of the experimental results and the results obtained with the help of neural networks [26].

Based on the paper overviews, it can be concluded that the artificial neural network is used to predict the behaviour of tribological, frictional and mechanical characteristics of composites. In this paper, there is the prediction of the tribological characteristics of hybrid composites by using the artificial neural network based on the obtained experimental results.

2. EXPERIMENTAL TESTING

The material obtained from compo-casting method was tested in this paper. This procedure has often been used in obtaining composites and hybrid composites with aluminium base [2, 3, 27].

Tribological characteristics of hybrid composites with aluminium base in conditions without lubrication were performed in the Tribology Center of the Faculty of Engineering in Kragujevac. The test was performed on the computer supported tribometer TR-95 with a block-on-disc contact geometry for the following parameter values: a normal load of 10 N, 20 N and 30 N; sliding speed of 0.25 m/s, 0.5 m/s and 1 m/s; and sliding distance of 30 m, 60 m, 90 m, 150 m, 300 m, 600 m and 900 m.

2.1 Test results

Tribological behaviour of hybrid composite with A356 matrix was followed through several phases. The tests were performed in conditions without lubrication on samples with the best structural, mechanical and anti-corrosion characteristics. The wear rate was measured during the testing.

The wear rate, as one of the major parameters for wear monitoring, was obtained based on the volume of the worn material, and as a function of sliding distance. Values of wear rate depending on the sliding speed, normal load and sliding distance for tested materials are given in Table 1. Due to the extensiveness of the obtained results, a partial number of experimental values of wear rate is shown in the Table 1.

First, the testing of base material - aluminium alloy A356, was performed, and then 10 wt.% SiC was added in the base. The wear rate decreased by adding silicon carbide to the base material of the composite. A graphite was added to the previous composite in order to obtain a hybrid composite. The wear rate of the composite significantly reduced by adding only 1 wt.% Gr. With the increase of graphite to 3 wt.%, the wear rate increased in certain intervals, while in others it decreased. When the percentage of graphite increased to 5 wt.%, the wear rate increased.

2.2 Artificial neural networks

A neural network is a form of implementation of artificial intelligence system, which represents a system consisting of a number of interconnected nodes, which are called artificial neurons. The body of neurons is called node or unit, and each neuron has a local memory which memorizes the information that are processed. The data that are exchanged in this way are usually numerical [28].

Table 1. Experimental results of wear rate

Material	Sliding speed, m/s	Normal load, N	Sliding distance, m	Wear rate, mm^3x10^{-3}/ m
A356	0.25	10	30	0.389
			60	0.358
			90	0.324
			150	0.306
			300	0.361
			600	0.577
			900	0.901
A356/10SiC	0.25	10	30	0.037
			60	0.095
			90	0.13
			150	0.115
			300	0.12
			600	0.367
			900	0.776
...	...	...	...	...
A356/10SiC/1Gr	0.5	20	30	1.243
			60	1.434
			90	1.422
			150	1.307
			300	1.07
			600	0.909
			900	1.509
...	...	...	...	...
A356/10SiC/3Gr	1	30	30	3.735
			60	4.447
			90	4.274
			150	3.662
			300	2.96
			600	2.952
			900	3.477
A356/10SiC/5Gr	1	30	30	4.622
			60	5.134
			90	4.757
			150	4.299
			300	3.702
			600	3.57
			900	3.877

Artificial neural networks are simplified mathematical models of human brain function and they represent a new generation of information processing systems [29]. These mathematical models simulate some of the properties of biological nervous systems in order to solve different problems, where classical methods do not give satisfactory results. In biological systems, the learning is done through regulation of synaptic connections that connect the axons and dendrites of neurons. The learning of typical events through examples is achieved through training or discoveries to the accurate sets of data inputs - outputs which train the algorithm by repeating and adjusting the weight coefficients of connections (synapses) [25]. It is necessary to collect as many data as possible for network to behave precisely in later use.

Neural networks are not programmed, they are trained, which means that it takes a long time for their training before they start to be used. The training of neural networks is done in a way that the weight coefficients are updated in order to get the output closer to the given value next time. During the training, the user assign the input and desired output values, and the programme attempts to obtain the corresponding output value [11, 28].

Matlab software [30] (Matlab R2016) was used for the neural network prediction of wear rate of tested materials.

The parameters of tribological tests are used as the input data: material, sliding speed, load and sliding distance (Table 1), while the obtained wear rate is used as the output. When training the network, there was a variation of the following: number of neurons in the hidden layer (for two hidden layers 15-10, 10-15, 8-10, 7-8, and for one hidden layer 20, 15, 10, 8, 6, 5, 4) and the activation function (log sigmoid transfer function - LOGSIG, hyperbolic tangent sigmoid transfer function - TANSIG). The output network function is linear transfer function (PURELIN), while the training function is Levenberg-Marquardt (TRAINLM). Table 2 presents the total regression coefficients (ALL) for different numbers of neurons and activation function.

It is necessary for the total regression coefficient to be greater than or equal to 0.95 in order for neural network to be acceptable. All obtained regression coefficient are acceptable, except for the coefficient obtained for LOGSIG activation function and 4 neurons in the hidden layer. The neural network with two hidden layers, 15 and 10 neurons in the hidden layers and the LOGSIG activation function has proven to be the best for predicting the wear rate.

Table 2. Variated network parameters

No. of hidden layers	No. of neurons in hidden layers	Wear rate for activation fuction:	
		LOGSIG	TANSIG
1	4	0.93647	0.9795
1	6	0.98282	0.98514
1	8	0.98236	0.98334
1	10	0.98552	0.98533
1	15	0.98959	0.99376
1	20	0.99283	0.99312
2	7-8	0.99185	0.99381
2	8-10	0.99389	0.98917
2	10-15	0.99114	0.99004
2	15-10	0.99401	0.98794

The regression coefficient obtained by training this network is shown in Figure 1.

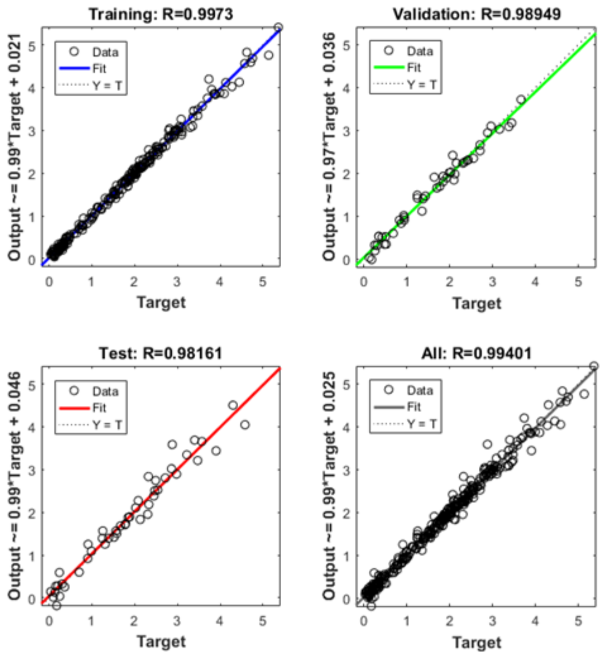

Figure 1. Regression coefficient for predicting wear rate

By training the artificial neural network, the obtained regression coefficient is 0.994, which indicates a very good coincidence with the experimental results.

In addition to the regression coefficient, a diagram of validation performance is obtained, which is shown in Figure 2.

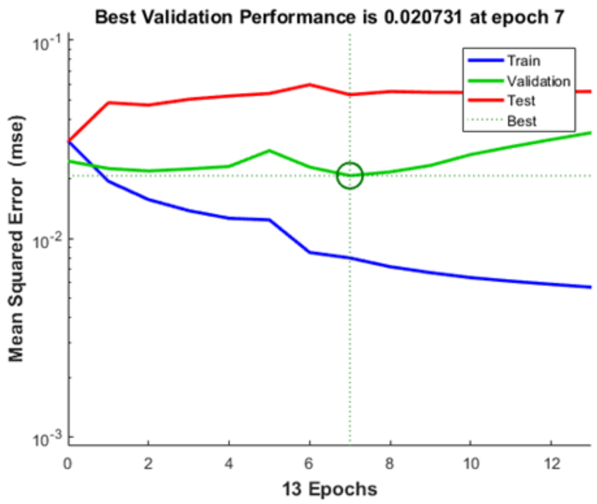

Figure 2. Validation performance

Figure 2 shows that the best validation performance is for iteration 7 and it is 0.020731; the training continued for 6 more iterations before the training stopped.

The errors representing the difference between targets and outputs are obtained after training the neural network, and they are given in Figure 3.

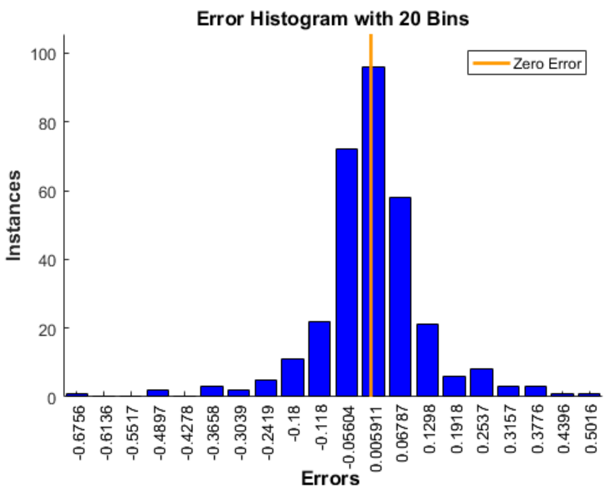

Figure 3. Error histogram

Figure 3 shows that there is a slightest deviation between the predicted and experimental values and it is 0.006911.

3. CONCLUSION

Based on the performed experimental tribological tests, it can be concluded that the wear rate decreases by adding reinforcement such as silicon-carbide to the aluminium alloy. However, poor mechanical properties can cause excessive content of SiC in the aluminium alloy. In order to improve these characteristics, the graphite, which considerably affects the decrease of wear rate, is added to a previous composite.

Based on the performed tribological tests, it can be concluded that a hybrid composite material with 10 wt.% SiC and 1 wt.% of graphite, i.e. A356/10SiC/1Gr, has the best tribological characteristics, or the least wear rate, in all test conditions compared to other tested composites.

An artificial neural network was used in order to reduce the number of experiments, and the predictions of the tribological behaviour of hybrid composites. The neural network was modelled in the Matlab software in the paper.

According to the obtained results for the regression coefficient, the neural network with two hidden layers, TRAINLM training function and LOGSIG activation function was adopted. The regression coefficient for this network was 0.994.

Satisfactory values of wear rate were obtained in comparison to the experimentally obtained values. The regression coefficient obtained by training the neural network is quite high, so therefore the neural network can be used for predicting tribological parameters of hybrid composites.

The obtained regression coefficient for predicting the tribological characteristics is similar to those that can be found in the available literature [17-24].

The results obtained by training the neural network for the wear rate show good coincidence with experimental results.

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