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TRIBOLOGICAL BEHAVIOR OF ALUMINUM COMPOSITES USING TAGUCHI DESIGN AND ANN

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Blaža Stojanović[1*], Radoslav Tomović[2], Sandra Gajević[1], Jelena Petrović[1], Slavica Miladinović[1]

[1]University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia
[2]University of Montenegro, Faculty of Mechanical Engineering, Podgorica, Montenegro

Abstract:
In this paper is presented the tribological behavior of A356-based aluminum composites using Taguchi design. Testing of tribological characteristics of aluminum composites was done on a tribometer with block on disc contact geometry. Composite materials were obtained by compocasting. The orthogonal matrix L18 is used to form the experimental design using the Taguchi method. The tribological characteristics of the aluminum composite reinforced with SiC (A356/10 wt.% SiC) were compared to the base material A356 for three sliding speeds (0.25 m/s; 0.5 m/s and 1.0 m/s), three values of normal load (10 N, 20 N and 30 N) and sliding distance of 150 m under lubrication conditions. ANOVA analysis showed that the least wear has a composite material at a load of 10 N and at sliding speed of 0.25 m/s.

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A356, aluminum, composite, wear, Taguchi design, ANOVA

1. INTRODUCTION

With the development of the military, automobile, electronic and other industries, there is a need of mass reduction while increasing the construction requirements. Steel and iron are increasingly being replaced by light metals, such as aluminum, magnesium, copper and others. However, their mechanical and tribological characteristics are much weaker compared to the steel. Improvement of these characteristics is possible by applying composites, i.e. by strengthening soft metals with different reinforcements. In this way, composite materials with improved characteristics are obtained. In this paper, as the base material was used aluminum alloy A356 reinforced with 10 wt.% SiC, thereby strengthening the base material and forming composites with better characteristics [1-4].

Kiran Kumar Ekka and S. R. Chauhan [5] investigated the tribological behavior of aluminum nanocomposites reinforced with SiC and $A_{l2}O_3$ particles. The influence of load, sliding speed and sliding distance on wear of nanocomposite was analyzed. In the analysis Taguchi design was used, and on this analysis the authors determined that the wear of aluminum nanocomposites reinforced with SiC is lower than the wear of nanocoposites reinforced with Al_2O_3. Ghosh et al [6] analyzed the tribological characteristics of aluminum composites reinforced with 7.5% SiC. In the analysis of friction and wear, they used the L27 matrix using Taguchi design and Grey relational analysis. Stojanović and al [7-10] investigated the tribological behavior of aluminum hybrid composites reinforced with SiC and graphite using the Taguchi method and ANOVA analysis. Paramasivam K et al [11] investigated A356/10%SiC metal matrix composite obtained by lost foam casting. For the investigation was used Taguchi design with L9 orthogonal array matrix, for three levels of four process parameters such as sand grain size (AFS no. 50, 80 and 110), coating grain size (75, 150 and 212 μm), pouring temperature (750, 800 and 850°C) and coating method (Dipping, Brushing and Spraying).

CONTACT: B. Stojanović, e-mail: blaza@kg.ac.rs

Considered quality characteristics of the process were considered density and tensile strength. After test it was concluded that the castings obtained with the sand grain size of AFS 50, casting grain size of 212 µm, pouring temperature of 800°C and brushing method had better mechanical properties than other castings. Castings of A356/10%SiC composite had better mechanical properties when compared to A356 base alloy castings. Suneel Donthamsetty and Penugonda Suresh Babu [12] have investigated wear behaviour of nano composites with base of A356 alloy reinforced with nano particles of SiC (wt.% of 0.1, 0.2, 0.3, 0.4 and 0.5) using Artificial Neural Networks (ANN). For tribological tests was used apparatus with pin on disk contact geometry and tests were done for different loads of 30 and 40 N. Developed model has shown that wear can be predicted with minimal error by using ANN.

In this paper, the influence of SiC reinforcement on the tribological characteristics of A356/SiC composites is analyzed using Taguchi design and ANN.

2. MATERIALS

Aluminum alloy A356 reinforced with 10 wt.% SiC with an average size of 39 microns was observed in this research. Composites were obtained by compocasting process, about which there is more information in the papers [7, 13]. Figure 1 shows the metallographic structure of the base material and composite reinforced with SiC.

a) b)

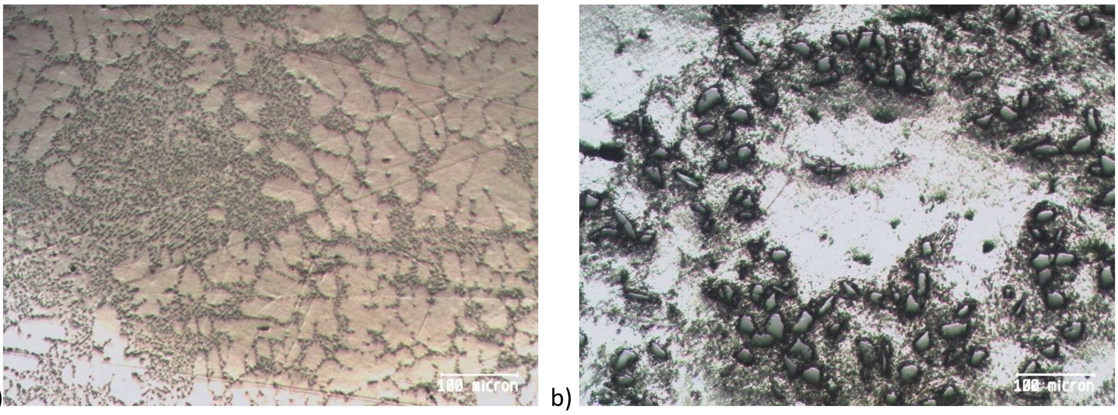

Fig. 1. Metallographic structure of a) base material A356, b) composite A356/10wt.% SiC

3. WEAR TEST AND DESIGN OF EXPERIMENT

The wear tests were performed on a computer-aided tribometer with block on disc contact geometry in accordance with the G77-83 standard. 90MnCrV8 steel with a hardness of 62-64 HRC was used as the disk material. The material of the blocks is the base material or composite material. The experiment analyzed the wear rate of composite A356/10wt.% SiC and base material A356 for different values of normal load (10 N, 20 N and 30 N), sliding speed (0.25 m/s, 0.50 m/s and 1.0 m/) at a constant sliding path of 150 m. Factors affecting wear rate as well as their levels are shown in Table 1.

Table 1. Levels for various control factors

Control factors	Units	Level I	Level II	Level III
(A) Sic	wt.%	0	10	
(B) Sliding speed	m/s	0.25	0.50	1.0
(C) Load	N	10	20	30

The orthogonal matrix L18 (Table 2) obtained by applying Taguchi mixed level design will be used for the design of experiment. The statistical tool Minitab 16 was used to form the orthogonal matrix. The S/N ratio “the smaller the better” characteristic was used to analyze the wear rate. The equation for calculating S/N ratio for Taguchi characteristic “the smaller the better” is as follows [14-15]:

$$S/N = -10\log\frac{1}{n}\left(\sum y^2\right). \qquad (1)$$

Where S/N is the signal-to-noise ratio, n is the repetition number of each trial and y_i is the result of the i-th experiment for each trial. S/N ratio for each level of influencing parameters is calculated on the basis of S/N analysis. Statistical analysis of variable is used to consider parameters statistically worth. Optimal combination of parameters can be predicted.

Experimental values for wear rate are obtained by using orthogonal array for different combinations of factors and they are given in table 2. Table 2 also shows the values of S / N ratios for wear rate.

Table 2. Experimental design using L18 orthogonal array

	SiC (wt%)	Sliding speed (m/s)	Load (N)	Wear Rate (mm3x10-3/m)	S/N ratio wear rate (dB)	ANN prediction
1	1	0.25	10	0.306	10.2856	0.247074
2	1	0.50	10	1.562	-3.8736	1.622216
3	1	1.00	10	1.989	-5.9727	1.971366
4	1	0.25	20	0.769	2.2815	0.752546
5	1	0.50	20	1.926	-5.6931	1.914562
6	1	1.00	20	2.650	-8.4649	2.850211
7	1	0.25	30	1.123	-1.0076	1.230212
8	1	0.50	30	2.576	-8.2189	2.594046
9	1	1.00	30	3.443	-10.7387	3.443748
10	5	0.25	10	0.115	18.7860	0.103767
11	5	0.50	10	1.158	-1.2742	1.139075
12	5	1.00	10	1.756	-4.8905	1.939436
13	5	0.25	20	0.366	8.7304	0.363082
14	5	0.50	20	1.553	-3.8234	1.848337
15	5	1.00	20	2.175	-6.7492	2.181319
16	5	0.25	30	0.827	1.6499	0.996151
17	5	0.50	30	2.127	-6.5553	2.133686
18	5	1.00	30	2.728	-8.7169	2.724431

3. RESULTS AND DISCUSSION

2.1 S/N Ratio Analysis

The dependence of influential parameters, such as SiC mass content (wt.%) in metal matrix composite, sliding speed and normal load was confirmed by S/N ratio analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter. The influence of control parameters on the wear rate is shown in Table 3. Based on the rank, ie the influence, it can be noticed that the load is the dominant parameter that affects the wear rate, and then the sliding speed. The least influence on the wear rate has a mass content of SiC (wt.%).

Table 3. Response Table for Signal to Noise Ratios for Smaller is better

Level	SiC	Sliding Speed	Load
1	-3.4892	2.1768	6.7876
2	-0.3159	-2.2865	-4.9064
3		-5.5979	-7.5888
Delta	3.1733	7.7747	14.3764
Rank	3	2	1

Figure 2 shows a graph of the main effects of the influence of the various testing parameters on the wear rate. In the main effect plot, if the line for a particular parameter is near horizontal, then the parameter has no significant effect. In contrast, a parameter for which the line has the highest inclination has the most significant effect. In this case, the greatest influence on the wear rate has the load, followed by the sliding speed, while the smallest influence has the mass content of SIC (wt.%).

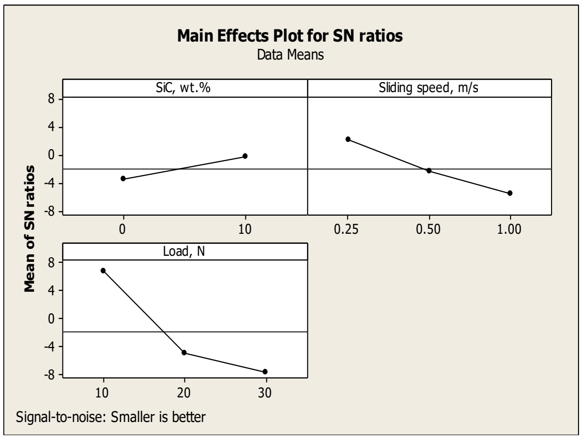

Fig. 2. Main effects plot for S/N ratio for the wear rate

The Figure 3 shows the interactions between some parameters and their mutual influence on wear rate A356/10 wt.% SiC and A356.

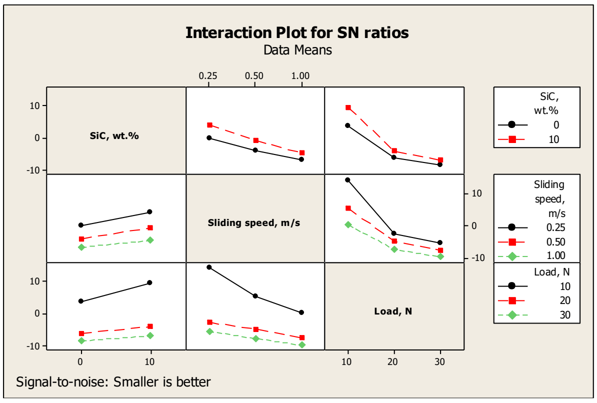

Fig. 3. Interaction plot for S/N ratio for the wear rate

2.2 Analysis of variance results for the wear rate

The experimental results were analyzed using ANOVA analysis used to examine the influence of the considered parameters: SiC mass content, sliding speed and normal load on wear rate. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. Table 4 the ANOVA results for wear rate for three factors and interactions of those factors. This analysis is carried out for a significance level of α=0.05, i.e. for a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures. In Table 4 the last column shows the percentage contribution (Pr) of each parameter on the total variation indicating their degree of influence on the result.

Table 4. Analysis of Variance for SN ratios for wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr
SiC	1	45.31	45.313	45.313	28.54	0.006	4.438
Sliding Speed	2	182.66	182.665	91.332	57.52	0.001	17.890
Load	2	701.26	701.257	350.628	220.82	0.000	68.684
SiC*Sliding Speed	2	2.91	2.908	1.454	0.92	0.471	0.285
SiC*Load	2	16.49	16.494	8.247	5.19	0.077	1.615
Sliding Speed * Load	4	66.01	66.012	16.503	10.39	0.022	6.465
Residual Error	4	6.35	6.351	1.588			0.622
Total	17	1021.0					100

From table 4 it can be observed that the greatest influence on the wear rate has a normal load (68.68%). The sliding speed (17.89%) and the mass content of the reinforcement (4.44%) have a much smaller influence on the wear rate. In terms of interactions, the biggest influence is Sliding speed * Load (6.46%). The influence of other interactions is smaller, almost negligible.

Based on the obtained parameters, Figures 4, 5 and 6 show 2D and 3D diagrams of the dependence of wear rate on the influential parameters: SiC mass content, normal load and sliding speed.

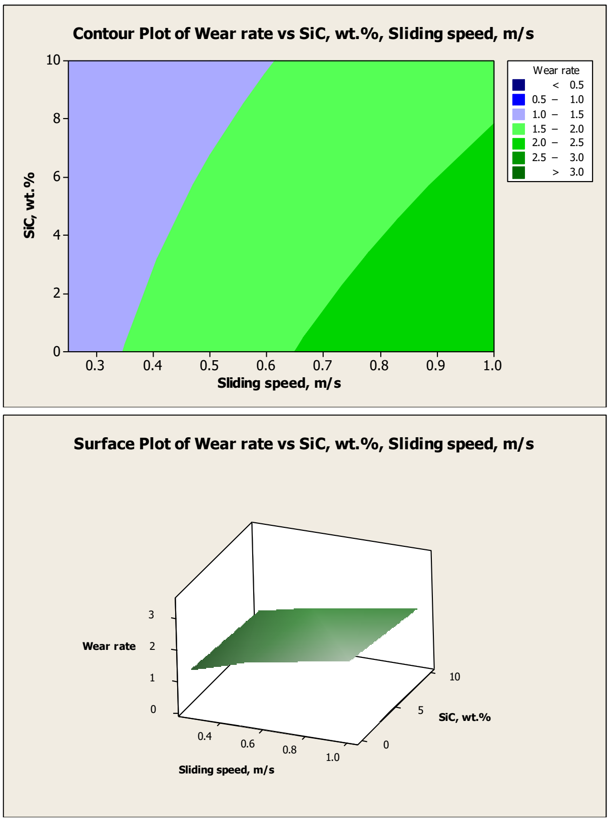

Fig. 4. a) Contour plot and b) Surface plot for dependence between wear rate of the wt.% SiC and sliding speed

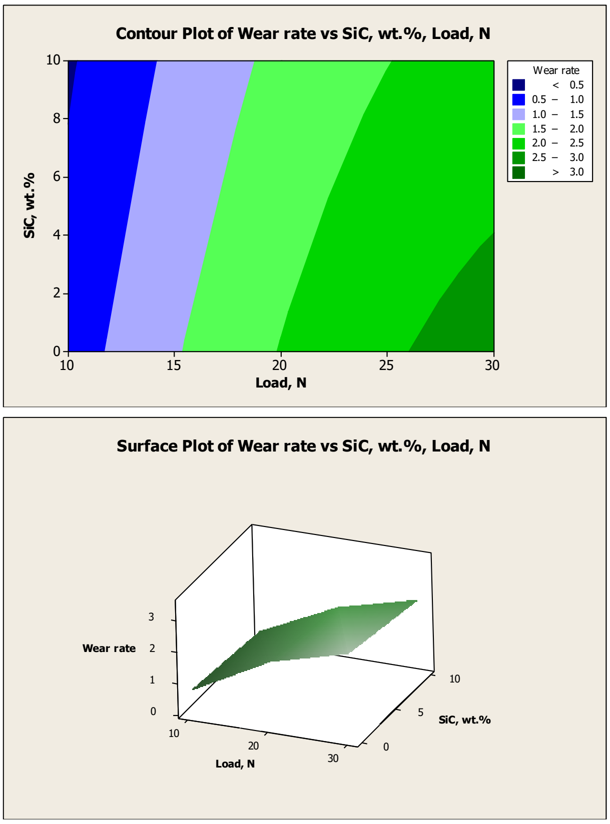

Fig. 5. a) Contour plot and b) Surface plot for dependence between wear rate of the wt.% SiC and load

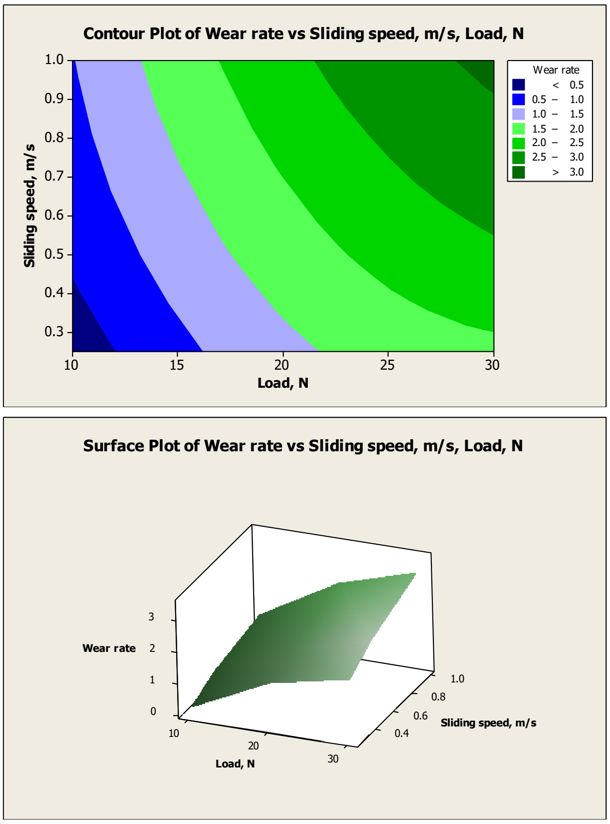

Fig. 6. a) Contour plot and b) Surface plot for dependence between wear rate of the load and sliding speed

2.3 Multiple regression model

Multiple linear regression model has been developed using statistical software "MINITAB 16". This model gives the ratio between parameters and responds by setting linear equation for the observed data. Regression equation generated this way establishes the connection between significant parameters obtained by ANOVA analysis, i.e. mass content of SiC, normal load and sliding speed. Regression equation developed for S/N ratio of wear rate is as follows [16-18]:

Wear rate =-0.810306-0.0393222 SiC, wt.% + 1.29224 Sliding speed, m/s + 0.093625 Load, N (2)

S = 0.204907 R-Sq = 96.01% R-Sq(adj) = 95.15%

The regression curve in Figure 7 shows that the wear rate increases with increasing normal load and sliding speed, and decreases with increasing mass content of SiC.

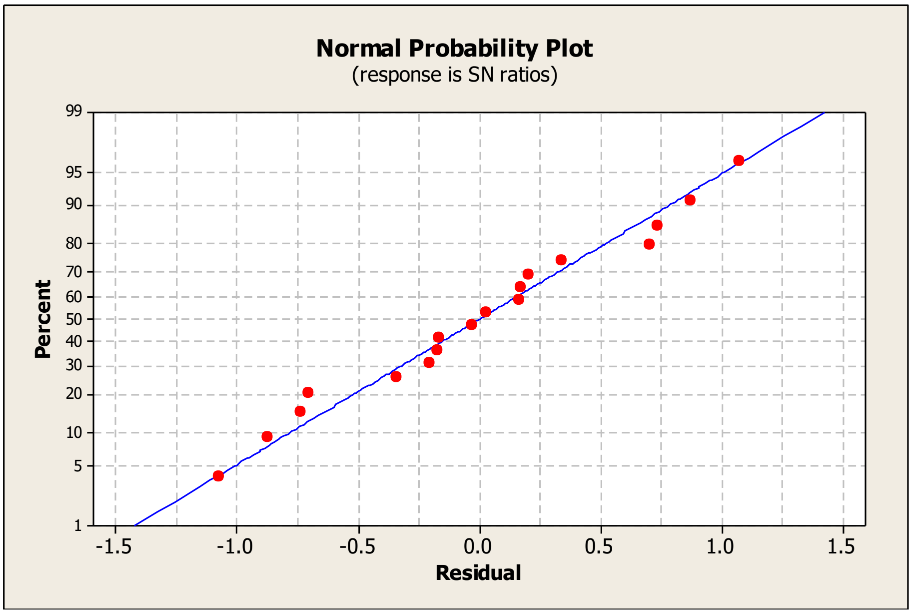

Fig. 7. The regression curve

4. ANN ANALYSIS

Artificial neural networks are used for solving a variety of problems, and they are inspired by the biological nervous system. Ann's are composed of neurons and like the biological nervous system they can learn; therefore they are trained to find solution to a problem [19-21]. The simplest ANN consists of input layer, hidden layer and output layer. Each layer has different number of neurons. In this study the neural network with 3 neurons in the input layer (wt.%SiC, Sliding Speed and Load), 10 neurons in hidden layer and 1 neuron in output layer (wear rate) was used. An ANN configuration is shown in Figure 8. Network weights-connections between neurons are adjusting during the training. The feeedforward back propagation network was used in this study with log-sigmoid transfer function. On Figure 9 is shown regression plot for trained ANN.

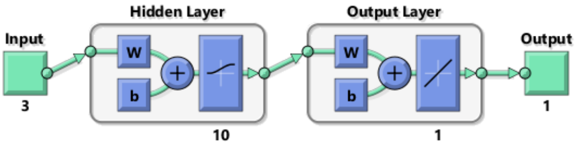

Fig. 8. ANN configuration

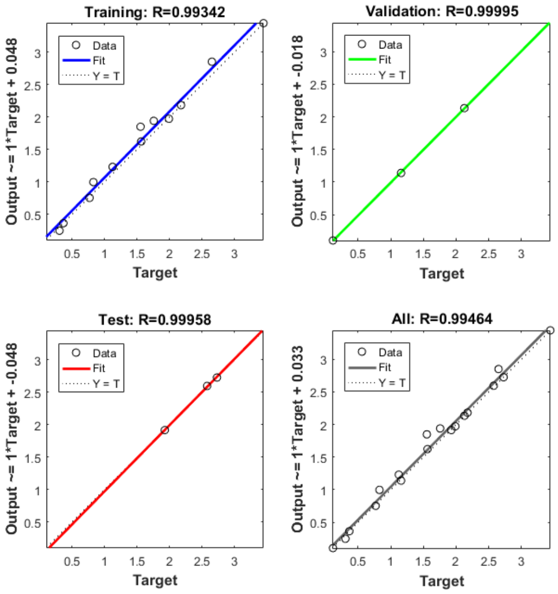

Fig. 9. Regression plot

Figure 9 shows that regression coefficient is close to 1 which means that there is a good correlation between experimental results and ANN predicted values.

5. CONCLUSIONS

The Taguchi design method can be used to analyze the wear problems of composite materials with A356 base alloy as described in the paper. Based on the analysis, the following conclusions can be drawn:

Taguchi design method is suitable to analyze the wear sliding behavior problem as described in this article. It is found that the parameter design of this method provides a simple, systematic, and efficient methodology for the optimization of the wear test parameters.

Normal load has the highest influence on wear rate (68.68%). The sliding speed (17.89%) and the mass content of the reinforcement (4.44%) have a much smaller influence on the wear rate. In terms of interaction, the highest influence has Sliging speed * Load (6.46%). The influence of other interactions is smaller, almost negligible.

The estimated S/N ratio using the optimal testing parameters for wear rate could be calculated, and a good agreement between the predicted and actual wear rates was observed for a confidence level of 99.5%.

ANN can, with great reliability, be used for prediction of wear rate.

REFERENCES

[1] A. Venc, Tribology of the Al–Si alloy based MMCs and their application in automotive industry, in: L. Magagnin (Ed.), Reference Module in Engineered metal matrix composites: forming methods, material properties and industrial applications. *Nova Science,* New York, 127-166.

[2] K.K. Chawla, Metal matrix composites, Composite materials. *Springer*, New York, 2012, 197-248.

[3] B. Stojanovic, L. Ivanovic, Application of aluminium hybrid composites in automotive industry. *Tehnički vjesnik*, 22(1), 2015: 247-251.
https://doi.org/10.17559/TV-20130905094303

[4] B. Stojanovic, M. Bukvic, I. Epler, Application of aluminum and aluminum alloys in engineering. *Applied Engineering Letters*, 3(2) 2018: 52-62.
https://doi.org/10.18485/aeletters.2018.3.2.2

[5] K.K. Ekka, S.R. Chauhan, Varun, Dry sliding wear characteristics of SiC and Al2O3 nanoparticulate aluminium matrix composite using Taguchi technique. *Arabian Journal for Science and Engineering*, 40, 2015: 571-581.
https://doi.org/10.1007/s13369-014-1528-2

[6] S. Ghosh, P. Sahoo, G. Sutradhar, Tribological Performance Optimization of Al-7.5% SiCp Composites Using the Taguchi Method and Grey Relational Analysis. *Journal of Composites*, 2013, 2013: 1-9.
https://doi.org/10.1155/2013/274527

[7] S. Veličković, B. Stojanović, M. Babić, I. Bobić,Optimization of tribological properties of aluminum hybrid composites using Taguchi design. *Journal of composite materials*, 51(17), 2017: 2505-2515.
https://doi.org/10.1177/0021998316672294

[8] B. Stojanovic, J. Blagojevic, M. Babic, S. Velickovic, S. Miladinovic, Optimization of hybrid aluminum composites wear using Taguchi method and artificial neural network. *Industrial Lubrication and Tribology*, 69(6), 2017: 1005-1015.
https://doi.org/10.1108/ILT-02-2017-0043

[9] B. Stojanovic, A. Vencl, I. Bobic, S. Miladinovic, J. Skerlic, Experimental optimisation of the tribological behaviour of Al/SiC/Gr hybrid composites based on Taguchi's method and artificial neural network. *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* 40, 2018: 311.
https://doi.org/10.1007/s40430-018-1237-y

[10] B. Stojanovic, S. Gajevic, N. Kostic, S. Miladinovic, A. Vencl, Optimization of parameters that affect wear of A356/Al2O3 nanocomposites using RSM, ANN, GA and PSO methods. *Industrial Lubrication and Tribology*, 74 (3), 2022: 350-359.
https://doi.org/10.1108/ILT-07-2021-02622022

[11] K. Paramasivam, A. Vijay, M. Sambathkumar, Investigation of optimum process parameter of lost foam casting of A356/SiC metal matrix composite. *Materials Today*, 47(14), 2021: 4801-4806.
https://doi.org/10.1016/j.matpr.2021.06.035

[12] S. Donthamsetty, P. S. Babu: An ANN Approach for Predicting the Wear Behavior of Nano SiC-Reinforced A356 MMNCs Synthesized by Ultrasonic-Assisted Cavitation. In: Reddy, A., Marla, D., Favorskaya, M.N., Satapathy, S.C. (eds) Intelligent Manufacturing and Energy Sustainability. Smart Innovation, Systems and Technologies. *Springer, Singapore*, 2021: 113-124.
https://doi.org/10.1007/978-981-33-4443-3_12

[13] A. Vencl, I. Bobic, S. Arostegui, B. Bobic, A. Marinkovic, M. Babic, Structural, mechanical and tribological properties of A356 aluminium alloy reinforced with Al2O3, SiC and SiC+ graphite particles. *Journal of alloys and compounds*, 506(2), 2010: 631-639.
https://doi.org/10.1016/j.jallcom.2010.07.028

[14] R.K. Ranjit, A primer on the Taguchi method. *Society of Manufacturing Engineers,* 2010.

[15] G. Taguchi, Taguchi on robust technology development: bringing quality engineering upstream. *ASME Press*, New York, 1993.

[16] A. Bagchi, S. Saravanan, G. S. Kumar, G. Murugan, K. Raghukandan, Numerical simulation and optimization in pulsed Nd: YAG laser welding of Hastelloy C-276 through Taguchi method and artificial neural network. *Optik*, 146, 2017: 80-89.
https://doi.org/10.1016/j.ijleo.2017.08.082

[17] M. Senthilkumar, S. Saravanan, S. Shankar, Dry sliding wear and friction behavior of aluminum–rice husk ash composite using Taguchi's technique. *Journal of Composite Materials*, 49(18), 2015: 2241-2250.
https://doi.org/10.1177/0021998314545185

[18] A. Sharma, M. Garg, S. Singh, Taguchi optimization of tribological properties of Al/Gr/B4C composite. *Industrial Lubrication and Tribology*, 67(4), 2015: 380-388.
https://doi.org/10.1108/ILT-10-2014-0099

[19] P.K. Padhi, A. Satapathy, Analysis of sliding wear characteristics of BFS filled composites using an experimental design approach integrated with ANN. *Tribology Transactions*, 56(5) 2013: 789-796.
https://doi.org/10.1080/10402004.2013.798448

[20] B. Stalin, P.R. Kumar, M. Ravichandran, M.S. Kumar, M. Meignanamoorthy, Optimization of wear parameters using Taguchi grey relational analysis and ANN-TLBO algorithm for silicon nitride filled AA6063 matrix composites. *Materials Research Express*, 6(10), 2019: 106590.
https://doi.org/10.1088/2053-1591/ab3d90

[21] Z. Zhang, K. Friedrich, K. Velten, Prediction on tribological properties of short fibre composites using artificial neural networks. *Wear*, 252(7-8), 2002: 668-675.
https://doi.org/10.1016/S0043-1648(02)00023-6