DEMI 2021

15th International Conference on Accomplishments in Mechanical and Industrial Engineering

Banja Luka
28–29 May 2021.

www.demi.mf.unibl.org

Optimization of hybrid ZA-27 nanocomposites using ANOVA and ANN analysis

S. Gajević[a], S. Miladinović[a], O. Güler[b], H. Çuvalcı[b], N. Miloradović[a], B. Stojanović[a]

[a]*Faculty of Engineering University of Kragujevac, Department of Mechanical Constructions and Mechanization, Sestre Janjic 6, 34000 Kragujevac, Serbia,*
[b]*Karadeniz Technical University, Department of Metallurgical and Materials Engineering, 61080, Trabzon, Turkey*

Abstract *Nanocomposites based on graphite and aluminium oxide were synthesized via hot pressing process with pre-processing mechanical milling. Optimization of wear loss and coefficient of friction of the nanocomposites with ZA-27 alloy matrix, was performed through the analysis of the following influences: sliding speed (100, 150, 200, 250 rpm), reinforcement of Gr (1, 2, 3, 4 vol.%) and reinforcement Al_2O_3 (1, 2, 3, 4 vol.%). Percentual influence of factors on wear loss and coefficient of friction was determined by ANOVA analysis and is as follows: sliding speed 10.05% and 0.61%, reinforcement of Gr 30.30% and 19.37%, reinforcement of Al_2O_3 52.99% and 69.01%, respectively. Validation of results using Artificial Neural Network (ANN) gave good correlation with experimental results. Based on this research, it can be observed that nanocomposites with reinforcement of Gr and Al_2O_3 can be potentially employed in many industries as a good substitute for the base alloy.*

Keywords *Hybrid nanocomposite, ZA27 alloy, wear loss, coefficient of friction, ANOVA, ANN*

1. INTRODUCTION

Composites have a great influence in the development of today's industry, due to their different tremendous properties. Nano-composites are combination of nanoreinforce-ment and base material. Nanoreinforcements can be nanopraticles, nanotubes, nanowhiskers, nanofibers and nanoplates. Mostly used nanoreinforcements are nanoparticles which have a very small size. As base materials in metal matrix nanocomposites (MMNC) widely used are aluminum, zinc, magnesium, titanium and their alloys.).

Corresponding author

MSc, Sandra Gajević
e-mail: sandrav@kg.ac.rs

Faculty of Engineering University of Kragujevac
Sestre Janjic 6
Kragujevac, Serbia

Zinc aluminium alloy (ZA) are characterized by good combination of physical, mechanical and technological properties and low manufacturing costs. Alloy ZA27 has the highest tensile strength and wear properties compared to other ZA alloys, which makes this alloy a good material for a replacement of bronze bearings [1, 2, 3].

Experimental research of many authors is based on improvement of tribological and mechanical properties of ZA alloys by adding nanoreinforcements like SiC, Gr, Al_2O_3, ZrO_2 and others. In addition to the above these nanocomposites are characterised by easy machinability and low manufacturing costs.

Vencl et al. have conducted research of structural, mechanical and tribological properties of nanocomposites using Zn25Al3Si and Zn25Al3Si0.03Sr alloys as the matrices and nanoparticles of 1 wt.% Al_2O_3 as the reinforce-ment. Nanocomposites were fabricated by compocasting process [4]. After the extensive testing they concluded that there was improvement in mechanical and tribological properties of nanocomposites compared to the matrix alloy. Improvement in mechanical properties of nanocomposites with the base of ZA27 fabricated by compocasting process have observed Bobic et al. They used different ceramic reinforcements more precisely Al_2O_3 (20–30 nm and 100 nm), and SiC (50 nm) nanoparticles [5]. Hybrid nanocomposites with ZA27 base and B_4C and Gr reinforcements were researched by Güler et al [6]. In process of fabrication the time of mechanicall milling was varied and then it was followed by hot-pressing technique. Improvement in properties of these nanocomposites was observed. Application of optimization methods in all stages of research is constantly increasing. One of the optimization methods is Taguchi analysis which was applied by Shivakumar et al. in order to reduce wear volume loss of ZA27/Al_2O_3 nanocomposite [7]. They used different weight percentage of Al_2O_3 (1, 3 and 5%) in stir casting followed by squeeze casting technique for fabrication of composites. Tribological test were done in dry conditions and the load, sliding speed and sliding distance were varied. With ANOVA analysis it was determined that the highest influence on wear loss has reinforcement content with 77.3% and determined optimal reinforcement content was 5 wt.% of Al_2O_3.

In this paper tribological properties of ZA27 based MMNC reinforced with ceramic and soft nanoparticles were investigated. Taguchi design of experiment was used to investigate dry sliding wear behaviour of the ZA27/Al_2O_3/Gr nanocomposite.

2. EXPERIMENTAL INVESTIGATION

For obtaining the optimum combination of factors, in this study, Taguchi experimental design was used. Taguchi method uses the orthogonal array and signal to noise ratio (S/N) for investigation of performance characteristics with the least number of experiments.

2.1 Materials and methods

For fabrication of nanocomposite ZA27 alloy was used as a base in which reinforcements of Al_2O_3 and Gr, with average particle size of 50 nm and 100 nm, were dispersed. These nanocomposites were produced by mechanical milling process followed by hot pressing process, more details about this process can be found in previous studies [8, 9].

2.2 Design of experiments

In order to obtain the optimum combination for the nanocomposite with the lowest coefficient of friction (CoF) and wear loss (WL), three four-level factors were considered. These factors are: sliding speed (100, 150, 200 and 250 rpm), content of Gr (1, 2, 3 and 4 vol.%) and content of Al_2O_3 (1, 2, 3 and 4 vol.%). In table 1 are presented experimental results and S/N ratio obtained by using statistical software MINITAB19. With A is marked sliding speed, B is content of Gr, and C is content of Al_2O_3. All experiments were done for constant load of 10 N.

Table 1. Experimental results and results of S/N analysis

No. exp.	A	B	C	WL (mg)	CoF	S/N for WL	S/N for CoF
1	100	1	1	9.8	0.343	-19.825	9.288
2	100	2	2	9.0	0.311	-19.085	10.143
3	100	3	3	10.0	0.336	-20.000	9.487
4	100	4	4	6.2	0.236	-15.848	12.561
5	150	1	2	9.1	0.323	-19.181	9.823
6	150	2	1	17.1	0.392	-24.660	8.138
7	150	3	4	9.3	0.306	-19.370	10.301
8	150	4	3	9.2	0.257	-19.276	11.807
9	200	1	3	6.0	0.23	-15.563	12.754
10	200	2	4	9.2	0.257	-19.276	11.806
11	200	3	1	21.4	0.388	-26.608	8.226
12	200	4	2	25.6	0.372	-28.165	8.600
13	250	1	4	4.5	0.202	-13.064	13.897
14	250	2	3	10.0	0.296	-20.000	10.567
15	250	3	2	16.9	0.359	-24.558	8.909
16	250	4	1	31.7	0.411	-30.021	7.725

Statistical analysis of wear loss and CoF of ZA27 nanocomposites are performed by S/N ratio analysis, ANOVA and Artificial Neural Network (ANN). In this paper S/N ratio analyses of wear loss and CoF by using smaller-the-better quality characteristic as responses have to be minimized [10]. Experimental results are converted with S/N ratio in order to perform a characteristic analysis.

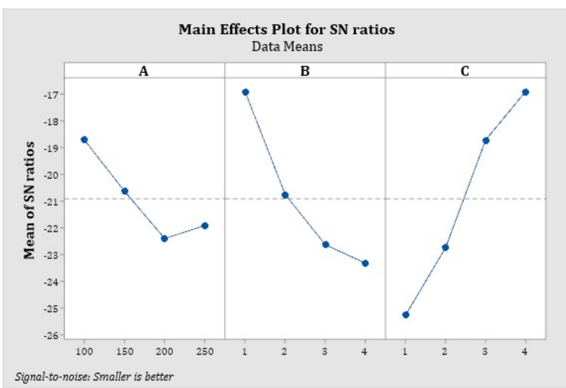
3. RESULTS AND DISCUSSION

Analysis of the effect of each control factor on the tribological characteristics was performed with S/N analysis. Responses of S/N ratios for WL and CoF in table 2. Analysis of S/N ratios of the experimental results determined order of factor importance (Rank).

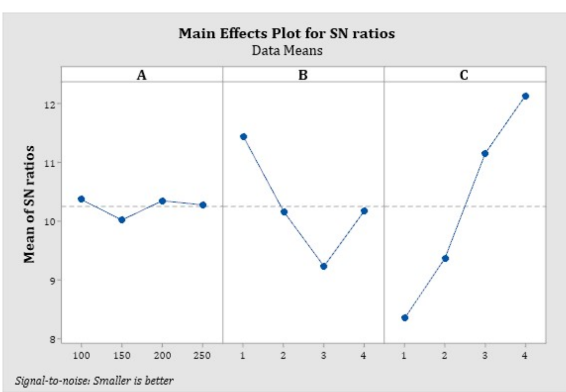
Table 2. Responses Table for S/N Ratios

	WL			CoF		
Level	**A**	**B**	**C**	**A**	**B**	**C**
1	-18.69	-16.91	-25.28	10.370	11.440	8.344
2	-20.62	-20.76	-22.75	10.017	10.163	9.369
3	-22.40	-22.63	-18.71	10.346	9.231	11.154
4	-21.91	-23.33	-16.89	10.274	10.173	12.141
Delta	3.71	6.42	8.39	0.352	2.210	3.797
Rank	3	2	1	3	2	1

Based on the table 2 it can be observed that the highest influence on wear loss and CoF has the content of Al_2O_3 followed by content of Gr and sliding speed. Optimal combination of factors can be seen on the figure 1 or determined from table 2 according to the highest S/N.



a)



b)

Fig. 1. Main effects plot for a) WL and b) CoF of nanocomposite

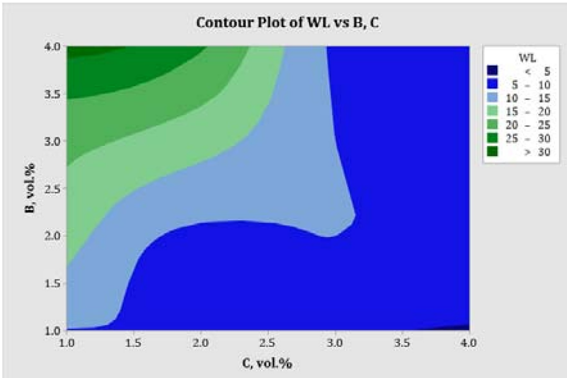
According to table 2 and figure 1 optimal factor combination for WL and CoF is A1B1C4, more precisely: sliding speed of 100 rpm, reinforcement content of 1 vol.% Gr and reinforcement content of 4 vol.% Al_2O_3.

Analysis of variance (ANOVA) is a statistical method for determining the impact of various input factors and for interpreting experimental data. Degrees of freedom (DF), mean square (MS), sum of squares (SS), F and P values and percent of contribution are all included in ANOVA analysis. The effect of sliding speed and reinforcement content of Gr and Al_2O_3 on tribological behaviour of nanocomposite was performed with a 95% confidence level and it is shown in the table 3.

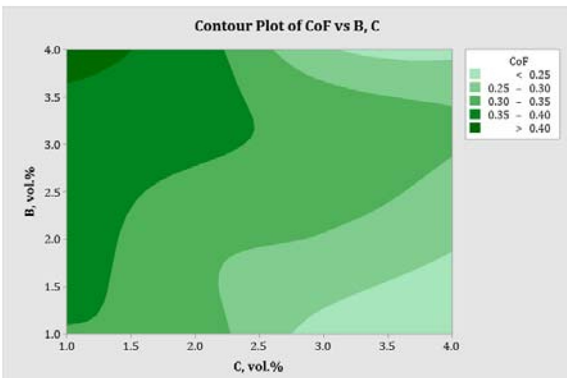
Table 3. ANOVA for SN ratios WL and CoF

WL							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**%**
A	3	32.98	32.98	10.994	3.02	0.116	10.05
B	3	99.42	99.42	33.139	9.09	0.012	30.30
C	3	173.86	173.86	57.953	15.90	0.003	52.99
Residual Error	6	21.87	21.87	3.644			6.67
Total	15	328.13					100
CoF							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**%**
A	3	0.313	0.313	0.105	0.11	0.950	0.61
B	3	9.879	9.879	3.293	3.52	0.089	19.37
C	3	35.201	35.201	11.734	12.53	0.005	69.01
Residual Error	6	5.618	5.618	0.936			11.01
Total	15	51.01					100

The results of ANOVA for wear loss (table 3) show that the wear behaviour of nanocomposite is highly affected by Al_2O_3 reinforcement content with 52.99%, followed by reinforcement content of Gr with 30.30% while the sliding speed has the least influence with 10.05% on the wear loss of nanocomposites. CoF of nanocomposite is, also, highly affected by Al_2O_3 reinforcement content (69.01%), followed by reinforcement content of Gr (19.37%) while sliding speed (0.61%) has almost no influence on the CoF of nanocomposites. Figure 2 shows a 2D diagram of the dependence of the influencing factors on wear loss and coefficient of friction.



a)



b)

Fig. 2. Diagram of dependence of reinforcements Gr and Al_2O_3 on a) WL and b) CoF

The influence of factors A: reinforcement Gr and B: reinforcement Al_2O_3 was chosen because of their highest influence on wear loss (figure 2a). Minimal wear loss based on the diagram is indicated by blue colour. By following a light green colour (figure 2b) minimal CoF was obtained. It is possible to achieve the target value of wear loss and CoF by adjusting the factors to certain values.

In order to verify the results obtained by the Taguchi method prediction is performed by training experimental data using the ANN method. In this purpose neural network with 3 input factors, 15 neurons in hidden layer and 2 output values was created. The network trained with the help of the software Matlab R2016a is feed forward neural network.

On figure 3 is represented regression plot of trained network. Observing the values for the regression coefficients, it can be found that the coincidence of the results obtained by ANN training and experimental is very good, as indicated by the total regression coefficient of 0.99.

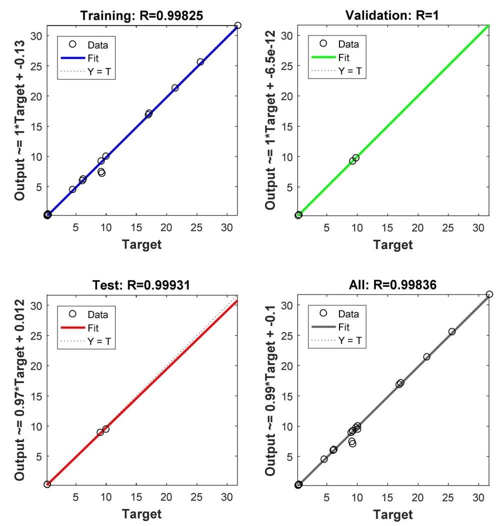


Fig. 3. ANN regression plot for WL and CoF

By observing regression coefficients for testing, validation, training and overall it can be concluded that the trained network can be used for prediction of responces with high reliability. Images for the worn surface, obtained for the different sliding speeds, of the ZA27 hybrid nanocomposites with the highest Al_2O_3 and the lowest Gr reinforcement amount are given in figure 3, since the greatest effect on the wear loss and friction coefficient values is caused by Al_2O_3 reinforcement. As can be seen in this figure, the abrasive lines on the eroded surfaces decrease and the surface becomes smoother until the sliding speed increases from 100 rpm (figure 3a) to 150 rpm (figure 3b) and then to 200 rpm. It has been previously noted that the wear losses are reduced until the sliding speed is increased to 200 rpm. With the effect of hard Al_2O_3 particles, the abrasive wear mechanism has become dominant, and the specific contact area decreases with the increase of the sliding speed (up to 200 rpm), so wear loss is decreased in ZA27 hybrid composites with hard Al_2O_3 additive. It is clear that the resulting abrasive lines narrow down to 200 rpm and the grooves have almost disappeared (figure 3c). With the increase of the sliding speed to 250 rpm and the increase in temperature during wear, material rupture zones were found at the edges of the grooves (figure 3d). While the abrasive wear mechanism is still preserved, it has been observed that materials with high sliding speed move away from the surfaces create pits. This situation can be attributed to material detachment from the abrasive groove edges with continued sliding of the soft ZA27 matrix zones adhering to the abrasive disc by increasing the sliding speed to 250 rpm.

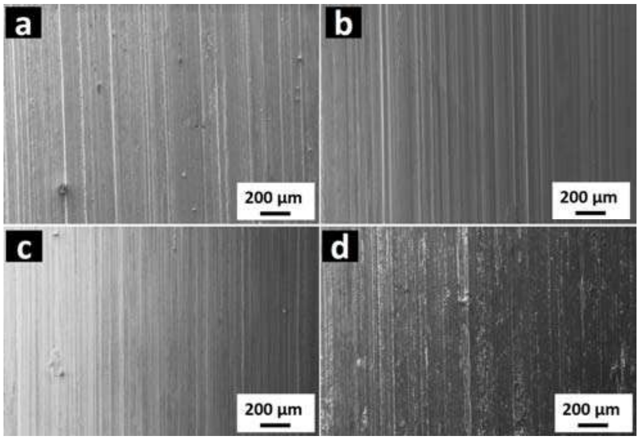


Fig. 3. SEM images of the worn surface of ZA27 composites reinforced 1 vol.% Gr and 4 vol.% Al_2O_3 under the sliding speed of (a) 100, (b) 150, (c) 200 and (d) 250 rpm

Figure 4 presents the mapping analysis of SEM image obtained from the worn surfaces as a result of the wear tests performed under 250 rpm sliding speed of ZA27 hybrid nano composites with 1 vol.% Gr and 4 vol.% Al_2O_3 reinforced. As a result of the increase in the sliding speed, the oxide density is noticeable at the edges of the grooves. In addition, the oxide from Al_2O_3 in the structure, can be attributed to the increase in temperature caused by the increase in shear rate causing the matrix material to oxidize. Also, the presence of C within the groove regions draws attention. In this case, it can be understood that the soft structure of the Gr regions is caused by pitting. This phenomenon supports that the effect of Al_2O_3 additive on wear performance in this study is higher than that of Gr. In addition, it is seen that the regions where iron elements are detected are the edges of the grooves.
Thus, it has been determined that the increase in the sliding speed causes adhesion on the abrasive disc and the transfer of Fe from the disc surface to the material worn surface has been determined.

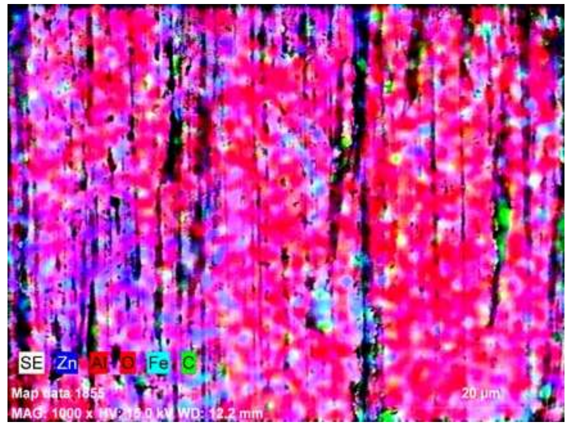


Fig. 4. EDS image of mapping for ZA27 composites 1 vol.% Gr and 4 vol.% Al_2O_3 under the sliding speed of 250 rpm

4. CONCLUSION

This study has presented an experimental investigation of WL and CoF of hybrid metal matrix nanocomposite.
Based on ANOVA and ANN the following conclusions can be made:

- The most influential factor on WL is reinforcement of Al_2O_3, followed by reinforcement of Gr and sliding speed with the least percent of influence.
- In analysis of CoF the most influential factor is reinforcement of Al_2O_3, followed by reinforcement of Gr and with the least influence is sliding speed.
- By observing the achieved results, it can be concluded that ANN can be successfully used to predict the tribological characteristics of hybrid nanocomposites with ZA27 base.
- Based on worn surfaces of hybrid ZA27 nanocomposite it can be seen that dominant mechanism is abrasion.

Acknowledgement

This paper presents the results obtained during research within the framework of the project TR 35021, supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia. In addition, the authors would like to thank TÜBİTAK (The Scientific and Technological Research Council of Turkey) for the support in the carrying out of this study with project number 213M276.

REFERENCES

[1] Bobić, B., Bajat, J., Bobić, I., & Jegdić, B. (2016). Corrosion influence on surface appearance and microstructure of compo cast ZA27/SiCp composites in sodium chloride solution. *Transactions of Nonferrous Metals Society of China*, vol. 26, no. 6, p. 1512-1521.

[2] Shivakumar, N., Vasu, V., & Narasaiah, N. (2017). Processing and dry sliding wear behavior of Al_2O_3 nanoparticles reinforced ZA-27 composites. Materials Today: Proceedings, vol. 4, no. 2, p.4006-4012.

[3] Miloradović, N., Vujanac, R., Stojanović, B., & Pavlović, A. (2021). Dry sliding wear behaviour of ZA27/SiC/Gr hybrid composites with Taguchi optimization. *Composite Structures*, vol. 264, no. -, p.113658.

[4] Vencl, A., Bobić, B., Vučetić, F., Svoboda, P., Popović, V., & Bobić, I. (2018). Effect of Al_2O_3 nanoparticles and strontium addition on structural, mechanical and tribological properties of Zn25Al3Si alloy. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 40, no. 11, p. 1-13.

[5] Bobić, B., Vencl, A., Ružić, J., Bobić, I., & Damnjanović, Z. (2019). Microstructural and basic mechanical characteristics of ZA27 alloy-based nanocomposites synthesized by mechanical milling and compocasting. Journal of Composite Materials, vol. 53, no. 15, p. 2033-2046.

[6] Güler, O., Çelebı, M., Dalmış, R., Çanakçi, A., &Çuvalci, H. (2020). Novel ZA27/B_4C/Graphite Hybrid Nanocomposite-Bearing Materials with Enhanced Wear and Corrosion Resistance. *Metallurgical and Materials Transactions A*, vol. 51, no. 9, p. 4632-4646.

[7] Shivakumar, N., Vasu, V., & Narasaiah, N. (2015). Synthesis and characterization of nano-sized Al_2O_3 particle reinforced ZA-27 metal matrix composites. *Procedia Materials Science*, vol. 10, no. -, p. 159-167.

[8] Güler, O., Çuvalcı, H., Gökdağ, M., Çanakçi, A., & Çelebi, M. (2018). Tribological behavior of ZA27/Al2O3/graphite hybrid nanocomposites. *Particulate Science and Technology*, vol. 36, no. 7, p. 899-907.

[9] Güler, O., Cuvalci, H., Canakci, A., & Celebi, M. Ü. S. L. İ. M. (2017). The effect of nano graphite particle content on the wear behaviour of ZA27 based hybrid composites. *Advanced Composites Letters*, vol. 26, no. 2, p. 30-36.

[10] Stojanovic, B., Blagojevic, J., Babic, M., Velickovic, S., & Miladinovic, S. (2017). Optimization of hybrid aluminum composites wear using Taguchi method and artificial neural network. *Industrial lubrication and tribology*, vol. 69, no. 6, p. 1005-1015.