Serbian Tribology
Society

SERBIATRIB '19

16th International Conference on
Tribology

Faculty of Engineering
University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

APPLICATION OF TAGUCHI METHOD IN THE OPTIMIZATION OF ZINC BASED COMPOSITE

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Abstract: *Tribological behaviour of composite with the ZA-27 alloy base reinforced by 5% SiC is considered in this paper. The optimization of tribological behaviour was conducted using the Taguchi method. Composite was prepared by the compocasting procedure. Tribological experiments were carried out using a block on disc tribometer with the variation of three different load values (10, 20 and 30 N), three sliding speed values (0.25, 0.5 and 1 m/s) and sliding distance value of 600 m. All the experiments were conducted under dry sliding test conditions. The analysis of the wear rate was executed using the ANOVA method of analysis. The sliding speed has the greatest impact on the wear rate (81.72%), then the SiC content (11.07%), and the least the contact load (5.07%).*

Keywords: *ZA27 alloy based composites, wear behaviour, Taguchi method*

1. INTRODUCTION

The high aluminium containing zinc alloys, known generally as ZA-27, which are commonly used in a variety of applications, have good physical, mechanical and tribological properties. It is suitable for producing castings of different shapes and sizes.

Over the last few decades, many researchers have used different approaches to improve the properties of ZA-27 alloy and its composite materials. Thus, composite materials have emerged which can be used to make components with great wear resistance such as engine bearings, pistons, piston rings and cylinder liners.

The sliding wear performance of zinc based alloy reinforced with SiC particles in dry and lubricated conditions was studied in [1]. Research has confirmed that dimensional stability and wear resistance of the composites were improved Effects of SiC particles reinforcement were investigated for different loads and sliding distances [2, 3]. The authors have discovered that the composites exhibited a lower wear rate compared to the unreinforced alloy specimens in testing conditions.

The mechanical behaviour of ZA-27 alloy and hybrid composites reinforced with 3 wt.% graphite and 0-9 wt.% silicon carbide particles was described by Kiran et al. [4]. It has been concluded that these hybrid composites are suitable for making the journal bearings.

The positive effects of SiC reinforcement were pointed out in [5, 6]. The experiments were performed on a block-on-disc tribometer under dry sliding conditions.

Tribological properties of a hybrid composite based on zinc-aluminium ZA27/SiC/Gr were investigated by Mitrović et al [7]. The wear volumes of the alloy and the composite were determined by varying the normal loads and sliding speeds. The tested sample contained 5% of SiC and 3% Gr particles.

The corrosion behaviour and artificial aging of ZA27/SiC composites synthesized via compocasting with addition of 1, 3, 5 and 10% SiC particles in the matrix alloy was studied in [8, 9].

2. DESIGN OF EXPERIMENTS

The tested composite material was successfully prepared using the compocasting procedure. Microstructure of ZA-27 alloy is given in Fig. 1 and microstructure of ZA-27/5%SiC composite is displayed in Fig. 2

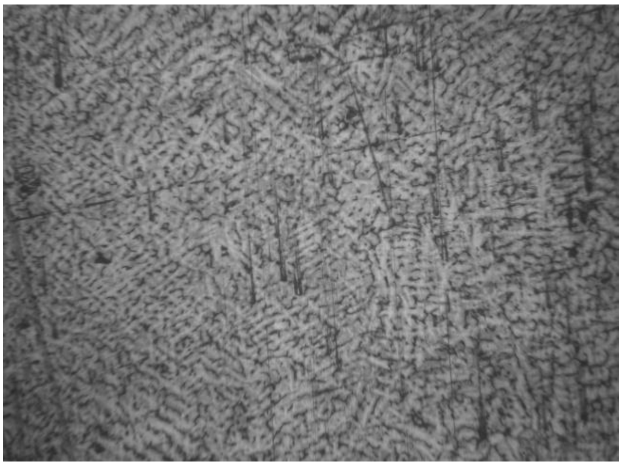


Figure 1. Metallographic structure of ZA-27 alloy

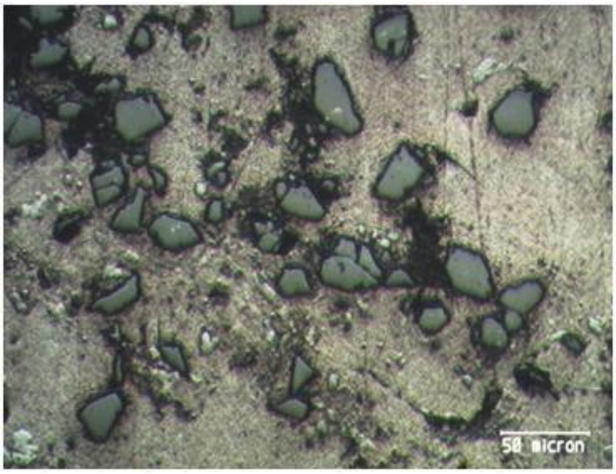


Figure 2 Metallographic structure of ZA-27/5%SiC composite

Microstructure of ZA-27 alloy and obtained ZA-27/5%SiC composite were observed by metallurgy microscope.

The wear rate of the ZA-27/5%SiC composite and ZA-27 alloy were analyzed for different values of contact load (10 N, 20 N and 30 N), sliding speed (0.25 m/s, 0.50 m/s and 1.0 m/s) and constant sliding distance of 600 m. The main factors influencing the wear rate (control factors) are: (A) SiC content, (B) the contact load and (C) the sliding speed. Factors and 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	%	0	5	
(B) Load	N	10	20	30
(C) Sliding speed	m/s	0.25	0.5	1.0

An orthogonal matrix L18 obtained by application of the Taguchi mixed level design was used in experimental design, Table 2. The statistical tool Minitab 18 was used to form the orthogonal matrix.

Generally, there are three types of S/N ratio: ”smaller is better”, ”larger is better”, and ”nominal is best”, which are used for measurement of quality [10, 11]. Characteristic S/N ratio ” smaller is better” was implemented for analysis of the wear rate in the paper. The equation for calculating S/N ratio for Taguchi characteristic ”smaller is better” can be calculated through the equation [12-15]:

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

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.

The S/N ratio for each level of influencing parameters is calculated based on the S/N analysis. The statistical analysis of variable is used to consider parameters statistically worth. The optimal combination of parameters can be predicted.

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

3. RESULTS AND DISCUSSION

The influence of control parameters, such as SiC content in composite, contact load and sliding speed was confirmed by the S/N ratio analysis.

3.1 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.

Table 3. Response table for signal to noise ratios for “smaller is better”

Level	SiC	Load	Sliding speed
1	-8.414	-6.371	-3.066
2	-6.154	-7.240	-8.501
3		-8.242	-10.285
Delta	2.260	1.871	7.219
Rank	2	3	1

The influence of control parameters on mean of wear rate is presented in Table 3. Based on ranking, it may be observed that the value of sliding speed is the most dominant parameter influencing the wear rate, followed by the SiC content. The contact load exerts the least influence on the wear rate.

Figure 3 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 sliding speed has the greatest influence on the wear rate, followed by the SiC content, while the contact load has the smallest influence.

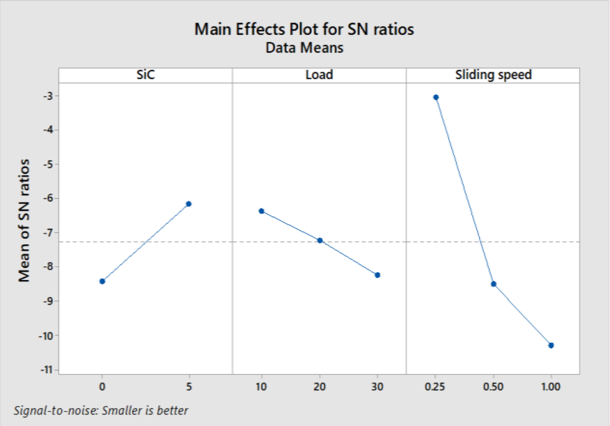


Figure 3. Main effect plots for means for the wear rate

Table 2. Experimental design using L18 orthogonal array

L18	SiC, %	Load, N	Sliding speed, m/s	Wear rate, mm^3x10^{-3}/m	S/N ratio, dB
1	0	10	0.25	1.329	-2.4705
2	0	20	0.25	1.603	-4.0987
3	0	30	0.25	2.029	-6.1456
4	0	10	0.50	2.706	-8.6466
5	0	20	0.50	2.907	-9.2689
6	0	30	0.50	3.202	-10.1084
7	0	10	1.00	3.299	-10.3676
8	0	20	1.00	3.812	-11.6231
9	0	30	1.00	4.466	-12.9984
10	5	10	0.25	1.096	-0.7962
11	5	20	0.25	1.253	-1.9590
12	5	30	0.25	1.401	-2.9288
13	5	10	0.50	2.323	-7.3210
14	5	20	0.50	2.383	-7.5425
15	5	30	0.50	2.547	-8.1206
16	5	10	1.00	2.699	-8.6241
17	5	20	1.00	2.801	-8.9463
18	5	30	1.00	2.868	-9.1516

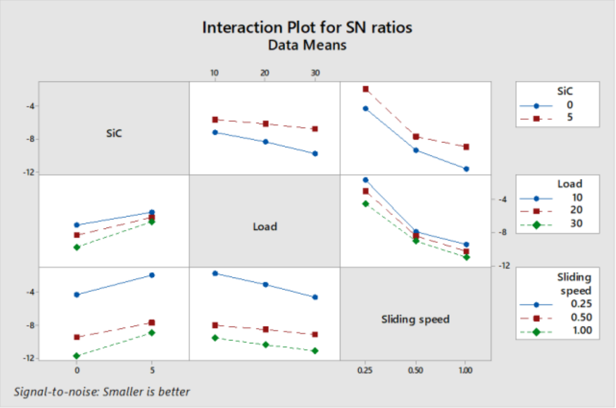


Figure 4. Interaction plot for means for the wear rate

The Figure 4 shows the interactions between some parameters and their mutual influence on wear rate for ZA-27/5% SiC and ZA-27.

3.2 Analysis of variance results for the wear rate

Experimental results were processed by using analysis of variance (ANOVA). This method is used for testing the influence of considered parameters (SiC content, contact load and sliding speed) on the 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 shows the ANOVA results for the 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.

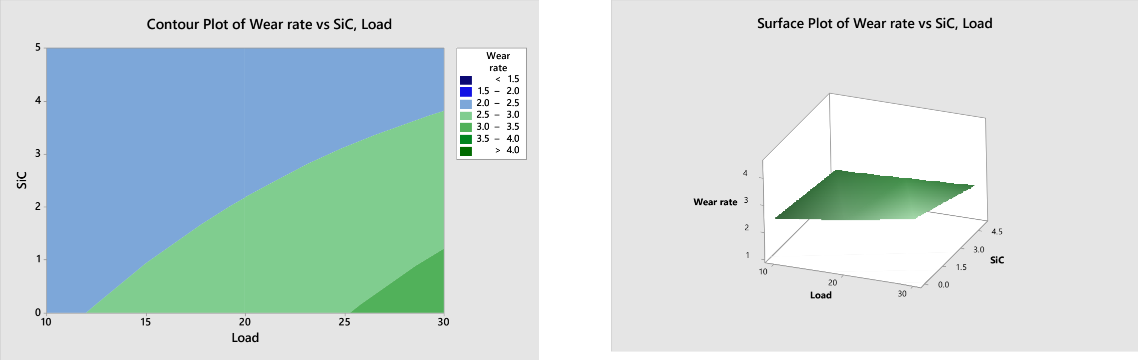
From Table 4 it may be seen that the sliding speed has the greatest influence on the wear rate (81.72%). The SiC content (11.07%) and contact load (5.07%) have smaller influence on wear rate.

As interactions are concerned, the biggest influence is attributed to Load*Sliding speed (0.83%). The impact of other interactions is smaller.

Figures 5 to 7 show 2D and 3D diagrams of dependence between the wear rate and the influencing parameters (SiC content, contact load and sliding speed).

Table 4. Analysis of Variance for S/N ratios for wear rate (DF – Degrees of freedom, Seq SS – Sum of squares, Adj SS – Adjusted sum of squares, Adj MS – Adjusted mean of squares, F – ratio, P – value, Pr – Percentage of contribution)

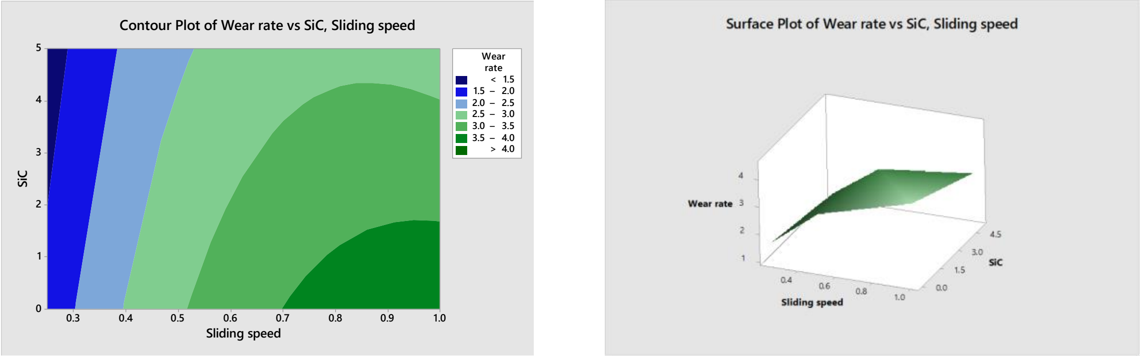
Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr%
SiC	1	22.979	22.979	22.9793	319.92	0.000	11.07
Load	2	10.522	10.522	5.2612	73.25	0.001	5.07
Sliding speed	2	169.659	169.659	84.8293	1181.01	0.000	81.72
SiC*Load	2	1.561	1.561	0.7803	10.86	0.024	0.75
SiC*Sliding speed	2	0.884	0.884	0.4419	6.15	0.060	0.43
Load*Sliding speed	4	1.714	1.714	0.4284	5.96	0.056	0.83
Residual Error	4	0.287	0.287	0.0718			0.14
Total	17	207.606					100.00



a)

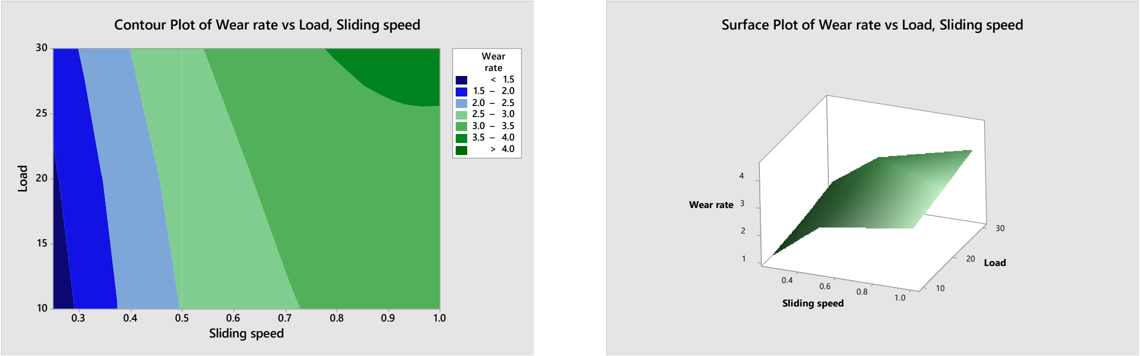
b)

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



a) b)

Figure 6. a) Contour plot and b) Surface plot for dependence between wear rate of the %SiC and sliding speed



a) b)

Figure 7. a) Contour plot and b) Surface plot for dependence between wear rate of the load and sliding speed

3.3 Multiple regression model

Multiple linear regression model has been developed using statistical software “MINITAB 18”. 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. SiC content, contact load and sliding speed. The regression equation developed for S/N ratio of wear rate is as follows [13-15]:

$$\begin{aligned} &Wear\ rate = 0.951 - 0.1329\, SiC + \\ &+ 0.0255\, Load + 2.324\, Sliding\ speed \end{aligned} \quad (2)$$

$$\begin{aligned} &S = 0.391162\, R\text{-}Sq = 85.09\% \\ &R\text{-}Sq(adj) = 81.89\% \end{aligned} \quad (3)$$

Equation (3) shows that the wear rate increases with the increase of the contact load and the sliding speed and decreases with increase of the SiC content.

4. CONCLUSION

Taguchi design method may be used for analysis of wear problem in composite materials with ZA-27 alloy base. Based on the analyses, the following conclusions can be drawn:

- The parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the wear test parameters.
- The ANOVA shows that the greatest impact on the wear rate has the sliding speed (81.72%), then the SiC content (11.07%), and the least the contact load (5.07%). The impact of interaction is considerably smaller.
- The estimated S/N ratio using the optimal testing parameters for wear rate was calculated, and a good agreement between the predicted and actual wear rates was observed for a confidence level of 99.5%.

- By the use of MINITAB program, the corresponding equation for the wear rate with the high coefficient of regression was formulated.

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.

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