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OPTIMIZATION OF WEAR BEHAVIOUR IN ALUMINIUM HYBRID COMPOSITES USING TAGUCHI METHOD

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Abstract: *Tribological behaviour of a hybrid composite with the aluminium alloy base A356 reinforced by 10 wt. % SiC and 5 wt. % of graphite is treated in this paper. The optimization of tribological behaviour was conducted through the application of Taguchi method. Hybrid composites were obtained in the compocasting procedure. Tribological examinations were executed on the block on disc tribometer with the variation of two different load values (20 and 30 N), three sliding speed values (0.25, 0.5 and 1 m/s) and three sliding distance values (30, 90 and 150 m). All the examinations were carried out in conditions with no lubrication existing. The analysis of the wear rate was conducted using the ANOVA method of analysis. The greatest impact on the wear rate has the load (62.11 %), then the sliding speed (32.88 %), and the least the sliding distance (2.57 %). The interaction of the factors does not have a significant impact on the wear rate.*

Keywords: *aluminium hybrid composites, A356, SiC, graphite, wear, Taguchi, optimization.*

1. INTRODUCTION

Hybrid composites are composites which contain two or more types or forms of reinforcement elements and/or improvement elements. SiC is the most widely used for reinforcing a composite with the aluminium base, and graphite is used for improving (above all for its friction characteristics). Characteristics of composites depend a lot on the shape, the dimension and the percentage rate of the reinforcement element, that is improvement element, as well as on the applied technique for obtaining a composite [1-4].

Composite materials based on the aluminium are more and more present in car, air and electronic industry. By increasing the use of composite materials their scope of application is also widening, which leads to reduction in prices. The annual growth in aluminium based composites manufacturing and their alloys is 6 %. Aluminium composites are used for the construction of breaks, engine blocks, cylinder liners, connecting rods, valve tappets, shafts, helicopter propellers, turbocharger turbines etc [5-8].

Ravindran et al. [9-11] studied tribological behaviour of aluminium alloy base A2024 hybrid composites. Hybrid composites were obtained in the powder metallurgy method with 5 % of SiC and (0.5 and 10 %) of graphite. Tribological examinations were executed on the tribometer with the pin on disc contact pair with the variation of two load values (10 N and 20 N), two sliding distance values (1000 m and 2000 m) and two sliding speed values (1 m/s and 2 m/s). The analysis of the obtained results has been conducted through the ANOVA method and it shows that hybrid composites wear rate increases with the increase of the load and the sliding distance, and decreases with the increase of the sliding speed. The best tribological characteristics manifests Al/5SiC/5Gr, whereas further increase of graphite content leads to the increase of wear.

Stojanovic et al. [12-14] analyzed tribological behaviour of aluminium alloy base A356 hybrid composites reinforced by 10 wt. % and 1 wt. % and 3 wt. % of graphite, obtained in the compocasting procedure. In the given examinations the hybrid composites show better characteristics than hybrid composite materials reinforced just by SiC.

Marwaha et al. [15] analyzed the wear of the hybrid composites reinforced by 10 wt. % SiC and 5 wt. % of graphite. Composites were obtained in the stir casting procedure, and tribological examinations were conducted on the pin on disc tribometer. The wear analysis was carried out using Taguchi method with orthogonal array L27.

With respect to the above mentioned, this research aims to examine tribological behaviour of Al-Si alloy base A356 hybrid composites reinforced by 10 wt. % SiC and with the addition of 5 wt. % of graphite in conditions with lubrication and to supply new information and spread the knowledge. The impact of the load, the sliding speed and the sliding distance on tribological behaviour of hybrid composites, that is the wear rate, was analyzed using Taguchi method.

2. EXPERIMENTAL DESIGN AND OPTIMIZATION

The first step in the use of Taguchi method is the choice of the corresponding orthogonal array. When the number of factors and the number of levels is known, it is possible to choose the right orthogonal array. In this work it was chosen the orthogonal array L18 for the determination of optimal wear rate values and for the factor effects analysis [16].

The main factors used are: the load (A), the sliding speed (B) and the sliding distance (C). 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) Load	N	20	30	
(B) Sliding speed	m/s	0.25	0.5	1.0
(C) Sliding distance	M	30	90	150

Table 2. Experimental design using L18 orthogonal array

L18	Load [N]	Sliding speed [m/s]	Sliding distance [m]	Wear rate [mm^3 x 10^{-3}/m]	S/N ratio [dB]
1	20	0.25	30	1.577	-3.9566
2	20	0.25	90	1.834	-5.2680
3	20	0.25	150	1.712	-4.6701
4	20	0.50	30	2.084	-6.3780
5	20	0.50	90	2.354	-7.4361
6	20	0.50	150	2.098	-6.4361
7	20	1.00	30	3.049	-9.6831
8	20	1.00	90	2.915	-9.2928
9	20	1.00	150	2.533	-8.0727
10	30	0.25	30	2.815	-8.9896
11	30	0.25	90	3.354	-10.5113
12	30	0.25	150	2.799	-8.9401
13	30	0.50	30	3.856	-11.7227
14	30	0.50	90	3.890	-11.7990
15	30	0.50	150	3.400	-10.6296
16	30	1.00	30	4.622	-13.2966
17	30	1.00	90	4.757	-13.5467
18	30	1.00	150	4.299	-12.6673

The loss function in Taguchi method is used for the calculation of deviation between the experimental value and the expected values. This loss function is transformed into S/N ratio. There are three types of S/N ratio: smaller is better, bigger is better, and nominally better, which are used for measurement of quality [17-18].

The characteristic of S/N ratio "smaller is better" is used for the wear rate in this paper, which can be calculated through the equation:

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

Experimental wear rate results, together with their transformations into S/N ratio, are shown in Table 2. The analysis based on Taguchi methods was conducted in the program MINITAB 16 in order to determine the main factor effects on the wear rate, to conduct an analysis of the variables (ANOVA) and to determine optimal conditions.

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

Level	Load	Sliding speed	Sliding distance
1	-6.799	-7.056	-9.004
2	-11.345	-9.067	-9.642
3		-11.093	-8.569
Delta	4.545	4.037	1.073
Rank	1	2	3

Based on the S/N ratio results it can be determined which control factor has the greatest impact on the wear rate (Table 3). Optimal wear rate parameters of these controlled factors can be determined on the base of S/N ratios shown in Table 3 and Figure 1.

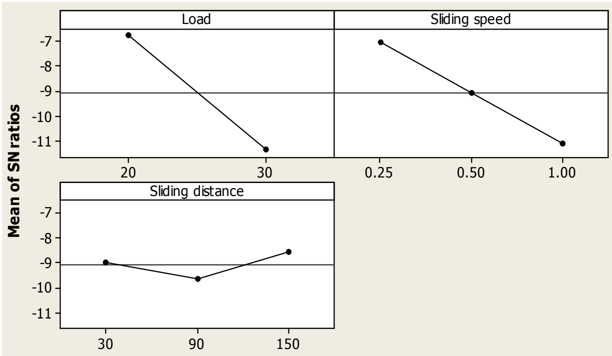

Figure 1. Effects Plot for the wear rate of A356 10SiC 5Gr

The greatest impact on the wear rate has the load, and then the sliding speed. The optimization of parameters of the wear rate according to the given factors and levels, with respect to the criterion smaller is better, results in the combination of control factors: A1, B1 and C3, as can be seen in Figure 2. This combination gives the lowest wear rate value.

Experimental results were processed by the variable analysis (ANOVA), which is used for identification of significance of the factors that can have an impact on the wear rate [15].The ANOVA results are shown in Table 4.

The last column in Table 4 shows the percentage ratio (Pr) of each of the factors and their interactions. It can be seen that the greatest impact on the wear rate has the load whose ratio is 62.11 %, then the sliding speed with its impact of 32.88 %. The influence of the sliding distance and factors' interaction on the wear rate is slight, with the sliding speed

Table 4. Analysis of variance for means

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr
Load	1	10.3300	10.3300	10.3300	540.84	0.000	62.11
Sliding speed	2	5.4685	5.4685	2.7343	143.16	0.000	32.88
Sliding distance	2	0.4269	0.4269	0.2134	11.17	0.023	2.57
Load*Sliding speed	2	0.1498	0.1498	0.0749	3.92	0.114	0.90
Load*Sliding distance	2	0.0464	0.0464	0.0232	1.21	0.387	0.28
Sliding speed*Sliding Distance	4	0.1331	0.1331	0.0333	1.74	0.302	0.80
Residual Error	4	0.0764	0.0764	0.0191			0.46
Total	17	16.6311					100

impact of 2.57 % and the interaction impact below 1 %.

Since the load and the sliding speed have the greatest impact, 2D and 3D diagrams of the dependency of the sliding speed and the load on the wear rate, respectively, are shown in Figures 2 and 3.

Because of the slight interaction between the load factor and the sliding speed the lines in the diagram (Fig. 2) are slightly curved. The lowest wear rate is achieved when the load is at 20 N, and the sliding speed at 0.25 m/s, whereas the highest value is achieved with the load at 30 N and the sliding speed at 1.0 m/s (Figs. 2 and 3).

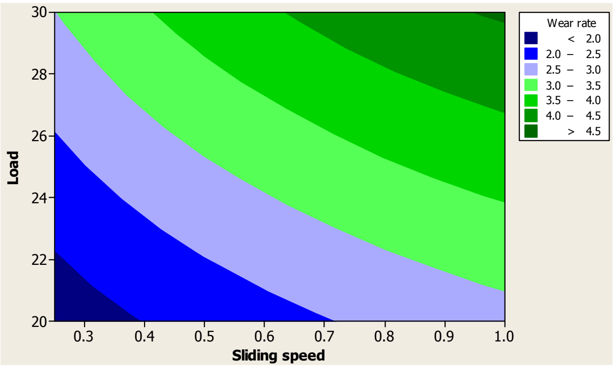

Figure 2. Contour plot for dependence between wear rate of the load and sliding speed

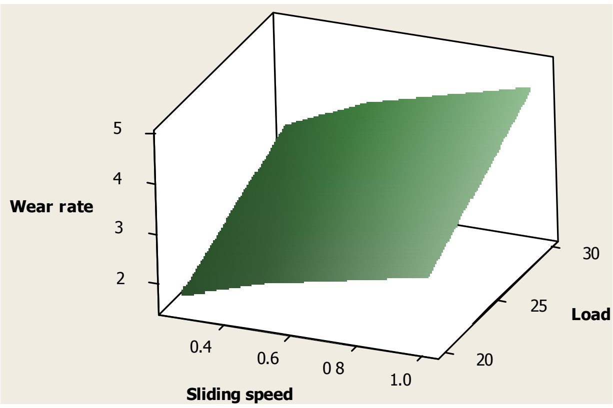

Figure 3. Surface plot for dependence between wear rate of the load and sliding speed

2.1 Linear regression

The model of linear regression was obtained through statistic software MINITAB 16. Linear regression model was developed in order to establish correlation between significant terms (Terms) achieved by ANOVA analysis and those are the applied load, the sliding speed and the sliding distance [19]. The coefficients of the equation of regression are shown in Table 5. The equation of regression for the wear rate is as follows:

$$Wr = -1.67 + 0.152 \cdot Load + 1.75 \cdot Sl.speed - \\ -0.00161 \cdot Sl.distance \quad . (2)$$

Table 5. The equation of regression coefficients

Predictor	COEF	SE COEF	T	P
Constant	-1.6684	0.3242	-5.15	0.000
Load	0.15151	0.01131	13.39	0.000
Sliding speed	1.7538	0.1814	9.67	0.000
Sliding distance	-0.001614	0.001554	-1.40	0.184
S = 0.239954 R-SQ = 95.2% R-SQ(ADJ) = 94.1%				

Linear regression line obtained on the base of experimental results of the wear rate is given in Figure 4. Normal probability plot represents the comparison between the actual experimental results and the predicted values. The model given in the equation (2) corresponds to the diagram in Figure 4.

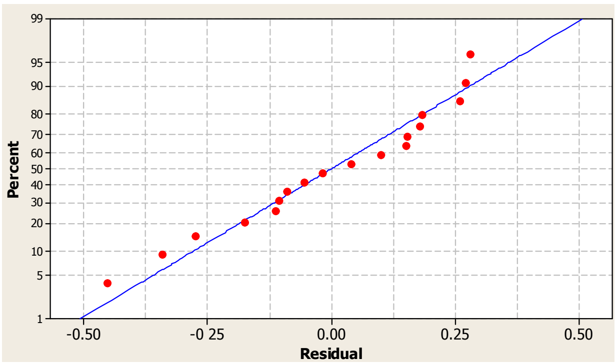

Figure 4. Comparison of the linear regression model with experimental results for the wear rate

3. CONFIRMATION TEST

In order to support statistically acquired optimal factor variable, apart from Taguchi optimization method, the confirmation test is used as well. Predicted optimal value of the wear rate is acquired by considering individual effects of factors A1, B1 and C3 and their levels. The estimated optimal value can be calculated using the following equations [15, 20]:

$$Wr = Tw + (Al - Tw) + (B1 - Tw) + (C3 - Tw), \quad (3)$$

where T_w is the specific wear rate total mean value, and A1, B1 and C3 the S/N response for the main factors at the designated levels. The calculated optimal value of the wear rate is -4.28 dB.

The confidence interval for the predicted optimal value is calculated with this formula:

$$CI = \sqrt{F_{\alpha:1,V_2} \cdot V_e \cdot (\frac{1}{n_{\mathrm{eff}}} + \frac{1}{r})}, \quad (4)$$

where $F_{\alpha:1,V_2}$ is the value from the F table at a required confidence level α, V_2 is degree of freedom of pooled error variance, V_e is pooled error variance, r is number of repeated trials and n_{eff} is number of effective measured results defined as:

$$n_{\mathrm{eff}} = \frac{\text{total experimantal trials}}{1 + \left(\begin{array}{c}\text{total degree of freedom of} \\ \text{factors for prediction}\end{array}\right)}, \quad (5)$$

Three confirmation experiments were carried out to evaluate the performance of the experimental trials for the wear rate under optimal conditions, s' of that is r = 3. For the confidence level of 95 %, α = 0.05, and V_2 = 4, the value is $F_{\alpha:1,V_2}$ = 7.7086. The confidence interval was calculated as ± 1.021 using equations (4) and (5). The confirmation test results for the wear rate were expected to be in the confidence interval of – 5.301 to – 3.259 dB. The average value of measurement for the three experiment confirmations was conducted for the optimal levels (A1B2C3). The average value is within certain confidence interval (– 5.301 – 4.67 < – 3.259).

Table 6. Results of the confirmation experiments for the wear rate

		Optimal parameter combination	
		Prediction	Experimental
Wear rate x 10^{-5} [mm^3/Nm]	A1, B1, C3	1.637	1.712
	S/N ratio(dB)	– 4.28	– 4.67

The experiment for A1, B1 and C3 a factor level was carried out and the result were compared to the values obtained using the previous equations (Table 6).

4. CONCLUSION

The use of Taguchi method for optimization of tribological behaviour of hybrid composites provides good and applicable results.

The ANOVA shows that the greatest impact on the wear rate has the load (62.11 %), then the sliding speed (32.88 %), and the least the sliding distance (2.57 %). The impact of interaction is negligible.

The slightest wear is the result of the load being at 20 N, the sliding speed at 0.25 m/s and the sliding distance at 150 m.

The dependence between the wear rate and the two most influential parameters, the load and the sliding speed, is given using 2D and 3D graphs. The values of the influential parameters could be precisely defined on the base of these diagrams.

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

The verification of the experiment proves appropriateness of the application of Taguchi method for the optimization of the wear of hybrid composites.

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