Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 2312076, 6 pages
https://doi.org/10.1155/2022/2312076

Research Article

Experimental Analysis on Tribological Characteristics of AZ60A/Gr/BN Magnesium Composites

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Received 16 February 2022; Accepted 23 April 2022; Published 31 May 2022

Academic Editor: Palanivel Velmurugan

In this particular instance, Taguchi methods are being used to look into how magnesium alloy (AZ60A) hybridized metal matrix composite wears. Using the stir casting method, they were made into the shape they were. Pin-on-disk tribometer instrument was used to figure out how much dry sliding wear happened on hybridized composites at different loads (30 N, 60 N, and 90 N), sliding speeds (1.045 m/s, 1.59 m/s, and 2.08 m/s), and compositions (1, 2, and 3 wt percent of each of boron nitride and graphite). We used the Taguchi strategy and the design of experiment method to look at how hybrid composites wear. The analysis of variance was used to look at the wear rate.

1. Introduction

Metal matrix composites have surpassed conventional alloys in areas including aerospace, automobiles, and mineral processing where high strength and stiffness are required [1]. To enhance the mechanical and tribological capabilities, hard ceramic particles or fibres that are evenly dispersed in the soft matrix phase can be added [2, 3]. Engineers may now customise the material properties to meet their specific requirements thanks to the emergence of composite materials as an important class of sophisticated materials. In terms of homogeneity, these materials differ from ordinary engineering materials [4–6]. Composites with metal particles in a matrix are most frequently made using the melt inclusion and stir casting methods [7]. With strong specific strength and modulus, these materials can be used in many technical applications everywhere sliding contact is anticipated [8].

As a result of its desirable characteristics, including less density and high specific strength, and excellent electrical and thermal conduction, magnesium alloys have emerged as prospective materials for industry, architecture, and transportation [9–11]. AZ60A is a common magnesium alloy with good mechanical and physical qualities that can used in many applications. This alloy is readily machinable and could be fused utilising fusion welding, and its application is commonly used on aerospace parts and other components. Depending on the expected service environment, degradation testing may be necessary after the material has been selected for a particular application. A variety of mechanisms degrade materials over time [12]. To further understand AZ60A's corrosion resistance, numerous researches have been conducted. Only a few researches have been done on the alloy's friction and wear behaviour and fatigue behaviour, and thus, this work is aimed at addressing the same [13].

A major source of wear in car and engine components occurs when AZ60A alloy is subjected to sliding action. The tribological behaviour of moving parts can be affected by frictional heat [14]. BN-reinforced metal matrix composites have been extensively studied by researchers utilising experimental design methods. Al2219-BN and Al2219-BN/graphite materials were tested using Taguchi and analysis of variance to find the most important parameters [15].

The tribological behaviour of AA2014 alloy with 10% boron nitride composites was studied using orthogonal arrays and analysis of variance techniques [9, 16]. An increase in the applied load had the largest impact on abrasive wear, tracked closely by adding BN particle reinforcement to the matrix alloy. There appears to be less of an impact on the sliding distance than previously thought [17, 18]. Several experts have investigated the tribological performance of hybridized composites with Al2024 aluminium alloy matrix. A powder metallurgy process using BN and graphite as reinforcing materials produced the hybrid composites [19, 20]. Additions of 5 percent graphite resulted in decreased abrasion, but 10 percent graphite caused an increase. The best tribological properties were found in an aluminium alloy hybrid composite containing 5% BN and 5% graphite, although adding graphite would lead to higher wear [21]. Across many advanced applications, hybrid composites are adopted due to the general wide range of useful features they possess including its ease of structure creation and are still used intensively in the auto market both by interior and exterior purposes. In the hybrid composite, delamination wear was found to be the predominant mechanism of wear [22].

Though only a few investigations have been made, there is still considerable uncertainty around the sliding friction behaviour of AZ60A alloy [23, 24]. Furthermore, Taguchi's approach has been used in only a few investigations on AZ60A alloy. In this study, a Taguchi statistical technique is utilised to investigate the impact of wear factors on the dry sliding wear of mixtures [25]. Transitions from moderate wear to severe wear, as well as indications of a correlation among load, speed, and composition, were all aspects of the studies that the authors thoroughly evaluated [26].

2. Taguchi Technique

The wear behaviour of aluminium-based metal matrix composites has been studied using an effective Taguchi approach. When compared to the full factorial design of trials, Taguchi's technique decreases the number of trials needed to display the response function. It is possible to see how parameters interact with this procedure. There is a lot of overlap between the planning, implementation, and analysis stages of the design of experiment process. Accordingly, selecting the right elements and amounts is a crucial stage in the design of experiment process. Using a signal-to-noise ratio, trial data can be used to discover the best process designs. It is possible to develop high-quality systems using the Taguchi technique because it is an effective instrument for gathering data in a control manner and analysing the impact of processing variables on exact variables that are unknown functions of these processes. In the examination of the wear performance of aluminium composites, this method proved to be effective. A conventional orthogonal array is created using the Taguchi technique to account for the influence of multiple factors on the goal value and to specify the experimental design. Parameters can be examined using mean and variance analysis. AZ60A-boron nitride/graphite hybrid metal matrix composites will be studied utilising the Taguchi method to investigate the influence of load, sliding speed, and composition on wear.

3. Experimental Description

3.1. Composition and Manufacturing of Composites. The present study's basis matrix alloy is the AZ60A magnesium alloy, which has the chemical composition listed in Table 1. By melting industrially existing pure magnesium, pure aluminium, and pure zinc master lumps to the appropriate proportions, the alloy was created during the melting process; Magrex 60 was used to prevent the melt's surface from oxidation at 953 K (680°C). To make hybrid composites, the nanoboron nitride and nanographite particle (40 nm) reinforcing percentages were mixed from 1 to 3%. These ceramic materials are exploited in elevated temperature devices since for their exceptional chemical and thermal resistance. The composite specimens were prepared using the vortex processing. The uncoated and preheated strengthening was inserted into the molten alloy under inert environment after being defluxed into the vortex produced. Additional information regarding the material preparation process is available from the same authors.

3.2. Wear Test. In pin-on-disk sliding wear testing, specimens were subjected to ASTM G99 standards without lubrication and the wear was measured. 100 millimeters in diameter, the test specimen was placed on an EN24 steel (BHN 229) disc. To conduct this study, pins with a diameter of 6 millimeters and a length of 15 millimeters were used as specimens. The disc was prepared with acetone before and after each test to eliminate any grease or other surface impurities that might have been present. Cleaning with ethanol and polishing the bearing test surface made the specimens flat. The LVDT was used to measure height loss during the 60-minute test, and measurements were recorded. Volume loss was evaluated by upward LVDT measurement by the cross-sectional area of the test samples, from 30 N up to 90 N were tried incrementally. Speeds from 200 to 400 rpm were measured with a distance of 100 mm from the disc centre, with disc speeds ranging from 1.045 to 2.08 m/s.

3.3. Design of Experiments. Standard orthogonal arrays are used to conduct all of the experiments According to our criteria, the orthogonal array must have more degrees of freedom than or equal to all the wear factors combined in order to be selected. There were three control elements that were used in the analysis: composition, sliding speed, and the load. There are a number of parameters and their levels in Table 2. Table 3 shows the 27 rows and 6 columns of the orthogonal L27 array used in this study. An *S/N* (signal-to-noise) ratio is employed in the Taguchi technique to calculate quality parameters based on the trial data. Magnesium hybrid composite wear rate was studied using "the-lower-the-better" quality feature since minimum wear rate values are necessary. The signal-to-noise ratio was determined for each processing parameter founded on the signal-to-noise study. Statistics ANOVA was also conducted to find the statistically significant factors. As a result, it is possible to forecast the best combination of test settings.

For Taguchi's "the-lower-the-better" performance, the signal-to-noise ratio for wear rate is

$$\frac{S}{N} = -10 \log \frac{1}{n}\left(y_1^2 + y_2^2 + \cdots y_n^2\right). \quad (1)$$

When combined with *S/N* ratio, "lower is better" features are ideal for reducing wear and the values are shown in Table 4. Statistical ANOVA is used to determine sliding speed and load. Using the study, you may figure out the percentage of influence each parameter has on wear rate for various values. Using ANOVA, the wear rate and the 3 components that differ in their levels and interactions with one another are presented in Table 5. $a = 0.05$, or a 95% level of confidence, is the significance criterion for this study.

P values less than 0.05 were regarded as statistically significant in the performance metrics. Each parameter's percentage influence and degree of influence on the final result are also shown. Data from this study's analysis of variance on wear rates for hybrid composites can be found in Table 5. A typical load ($P = 33.68\%$) has the largest effect on wear rate. The second most important factor is the speed. The composition has the least impact on wear rate ($P = 10.728\%$).

3.4. Testing of Wear Rate for Impact Factors. Both Figures 1 and 2 indicate primary effects of various testing parameters on wear rate. If a parameter's line is nearly horizontally in the main effect plot, the factor does not have a big impact. As a result of this, the parameter with the highest inclination to the line has the most influence. When it comes to wear rate, it is evident that load has a greater influence than the other characteristics combined. Normal loads and sliding speeds both contribute to wear, but composition has the reverse effect. Normal load: when the force and sliding speed are the least and the composition is the highest, the lowest wear rate is observed. According to a follow-up paper, comparable observations were made and a reasonable explanation was presented, and this observation is consistent with this one.

Table 1: Chemical alignment of AZ60A alloy (wt %).

Aluminium	Zinc	Silicon	Magnesium	Iron	Copper	Nickel
9.0	1.0	0.035	0.035	0.005	0.0005	0.001

Table 2: Various control factor levels.

Control factors	1	2	3
Composite percentage	1	2	3
Sliding speed	1.045	1.59	2.08
Load	30	60	90

Table 3: Design of experiments using L27 (orthogonal array).

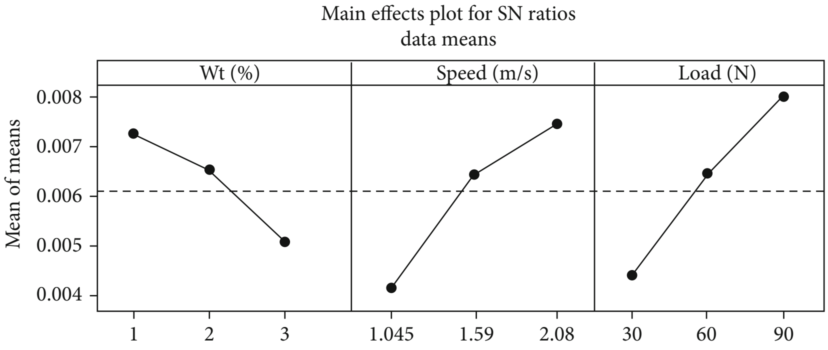
Ex. no.	Composite weight (%)	Speed at sliding	Load	Wear rate	Signal-to-noise ratio
1	1	1.045	30	0.0046	47.526
2	1	1.045	60	0.0048	47.541
3	1	1.045	90	0.0050	46.201
4	1	1.59	30	0.0052	46.105
5	1	1.59	90	0.0056	46.182
6	1	1.59	60	0.0128	38.104
7	1	2.08	30	0.0059	45.201
8	1	2.08	90	0.0061	45.124
9	1	2.08	60	0.0124	39.221
10	2	1.045	30	0.0042	48.801
11	2	1.045	90	0.0046	48.231
12	2	1.045	60	0.0049	47.526
13	2	1.59	30	0.0050	47.424
14	2	1.59	90	0.0052	46.952
15	2	1.59	60	0.0120	39.466
16	2	2.08	30	0.0056	46.281
17	2	2.08	90	0.0059	45.981
18	2	2.08	60	0.0119	39.441
19	3	1.045	30	0.0041	49.364
20	3	1.045	90	0.0039	48.286
21	3	1.045	60	0.0041	48.206
22	3	1.59	30	0.0041	48.206
23	3	1.59	90	0.0045	47.441
24	3	1.59	60	0.0051	46.526
25	3	2.08	30	0.0051	46.526
26	3	2.08	90	0.0052	46.321
27	3	2.08	60	0.0059	45.312

Table 4: *S/N* ratio response.

Level	Percentage (*A*)	Speed (*B*)	Load (*C*)
1	44.26	48.26	47.56
2	45.18	47.35	46.83
3	47.39	44.18	43.65
Delta	2.65	3.93	3.97
Rank	3	2	1

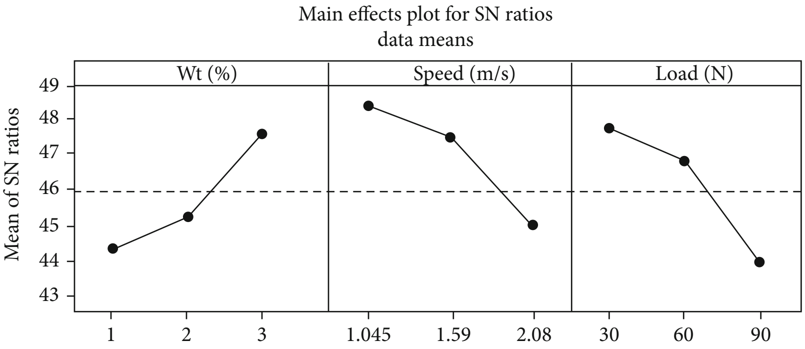
Table 5: Wear rate for means for analysis of variance.

Source	Degrees of freedom	Seq SS	Adj SS	Adj MS	F	P	Pr
A	2	0.000019	0.000019	0.000010	7.98	0.015	10.728
B	2	0.000041	0.000041	0.000019	13.97	0.003	19.652
C	2	0.000068	0.000068	0.000039	24.26	0	33.684
$A * B$	4	0.000005	0.000005	0.000002	1.29	0.426	3.283
$A * C$	4	0.000019	0.000019	0.000006	3.72	0.0061	9.726
$B * C$	4	0.000024	0.000024	0.000007	4.62	0.039	14.345
Residual error	8	0.000009	0.000009	0.000002			
Total	26	0.000201					



Signal - to - Noise : Smaller is better

Figure 1: Main effect plots for AZ60A/BN/Gr hybrid composites—means vs. wear rate.



Signal - to - Noise : Smaller is better

Figure 2: Main effect plots for AZ60A/BN/Gr hybrid composites—S/N ratio vs. wear rate.

4. Multiple Linear Regression Models

The MINITAB 17 statistical software was used to create the multiple linear regression models. The unknown variable's linear relationship to the known variables is depicted in this model. As a result, a linear relationship between the wear rate and the composition, speed of sliding (S), and load (L) is observed in this case. With the use of analysis of variance, the linear regression formula for composition, sliding speed, and load was created.

In order to calculate the rate of wear, we used the following regression linear equation:

$$\text{Wear rate}\left(\text{mm}^3/\text{m}\right) = 0.00049 - 0.001039\text{pct} + 0.002697\,\text{speed} + 0.000085\,\text{load}. \tag{2}$$

This equation can be used for any wear regime because only statistically important factors are comprised in the

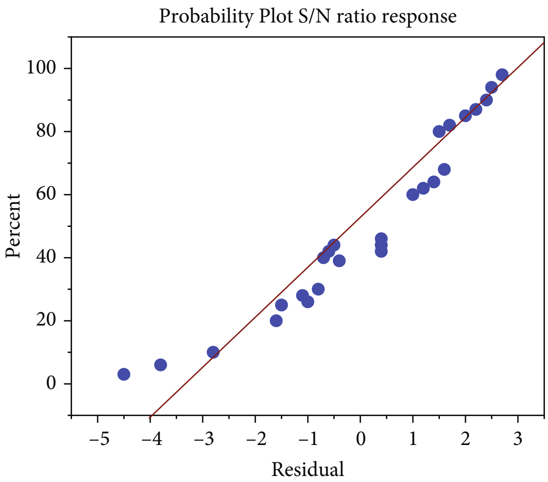


Figure 3: Wear rate of aluminium hybridized composites: probability graphs of residuals.

model. Substituting the recorded values for the variables in Equation (1) will provide information on the composite's sliding wear. Speed and load both contribute to wear, but composition does the opposite. Figure 3 shows the normal probability plot of residuals that was used to confirm the model's suitability. The model looks to be accurate based on the closeness of the data points to the normal distribution line. The wear rate of the AZ60A hybridized composite may be predicted using Equation (1), as has been shown by other studies.

5. Conclusions

The sliding wear of AZ60A hybridized composites was investigated using Taguchi's approach. Following this investigation, the following conclusions can be drawn:

(i) Taguchi's orthogonal array design methodology is a good fit for this article's wear sliding problem. A straightforward, systematic, and effective way for optimising the wear test parameters is found in the Taguchi parameter design

(ii) MINITAB 17 provides a linear regression equation for wear rate in terms of sliding speed, composition, and normal load

(iii) A 99.5% confidence level was obtained between the expected and actual wear rates when the *S/N* ratio was evaluated utilising the optimum wear rate testing circumstances

(iv) Sliding speed, as well as normal load, has an impact on the wear rate of AZ60A nano/BN/nano-Gr hybrid magnesium composite. With a load of 30 N and a sliding speed of 1.045%, hybrid composites had the lowest wear rate

(v) Normal load is the most significant in terms of impact (33.68 pct). $P = 19.65$ pct for speed and 10.728 pct for composition had the least effect on wear rate. Interactions between different factors do not have a major impact on wear rate

(vi) The interface among sliding speed and load exerts the greatest impact (14.345 pct). There was a reduced impact on the interaction due to the composition and load ($C * L$) (9.726 pct). The minimum effect comes from the interface among composition and sliding speed (3.28%)

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the supports from Kombolcha Institute of Technology, Wollo University, Ethiopia, for the research and preparation of the manuscript.

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