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Research Article

Optimization and Tribological Properties of Hybridized Palm Kernel Shell Ash and Nano Boron Nitride Reinforced Aluminium Matrix Composites

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The tribological properties of hybridized reinforced aluminium matrix composites were optimized using Taguchi and Grey Relational Analysis in conjunction with an L16 orthogonal array. The combination of palm kernel shell ash (PKSA) (0–5 wt. %) along with nano BN reinforcements was taken in interest. Loads and speeds (500, 750, 1000, and 1250 rpm) were employed as control parameters for the experiment. Using a Taber type abrasion machine, the wear samples were made, and the wear experiments were carried out. Speed and load were more important than the percentage of reinforcements in composites when it came to evaluating wear index and loss of volume. With respect to wear index and volume loss, Taguchi-relational Grey's analysis identified A3B1C1 (reinforcement = 5 wt. %; load = 500 g; speed = 500 rpm) as the optimal process parameter combination, with a reinforcement of 3 wt. %, load = 500 g, and speed = 500 rpm being the second-best option. Validation tests have revealed that the anticipated and experiment values at the optimal situations are both within the acceptable range. Performance is influenced more by speed than by load, which is influenced more by the weight percentage of composites, as demonstrated by the application of the Taguchi and Grey Relational Analysis methods.

1. Introduction

Metal matrix composites have been widespread use in advanced material development because of the improved properties of the base metals as a result of various reinforcement inclusions [1]. Metal matrix composites can be found in numerous industries, including automotive, sports and recreation, aviation, and maritime [2]. The outline of reinforcing elements into the metal matrix could enhance the mechanical and tribological characteristics of metal matrix composites. Metal matrix composites have been made using both monolithic and hybrid reinforcements. As a result, a wide range of metal matrix composites with various mechanical and tribological characteristics have been created. Metal matrix composites from Al6061 were produced by [3] using a hybrid reinforcement of boron nitride and boron carbide. Inorganic and organic ingredients can be combined in a variety of ways to create hybrid materials that have a wide range of applications. Aluminium metal matrix composites were investigated for their wear and mechanical properties without optimizing the procedures. This study examined the hardness and wear behavior of hybridized reinforcement composites using LM25 alloy ingots embedded with activated carbon and mica ingots [4]. All of the relevant physical factors were taken into account. As a result of this flaw, it appears that optimization strategies for Al6063 composite materials are underutilized.

Taguchi and response surface methodology have been studied extensively. They are helpful in giving data on the numerous criteria that go into ranking them. Composites produced by [5] employed an artificial neural network to increase their tribological qualities (ANN). We employed the sliding block-on-disc tribometer for the tribological experiments. The L27 orthogonal array was employed to optimize 3 variables: speed and load (40, 80, and 120 N), sliding distance (0.3, 0.6, and 1.2 m/s), and load (60, 90, and 120 N) [6, 7]. The optimization took into account all three variables (2400 m). Using a 95% confidence level ANOVA, the wear rate and coefficient of friction were examined. Hybridized mixtures containing 3% graphite have lower wear and friction values. To estimate the wear rate and the COF, ANN produced a regression coefficient of 0.98905 [8].

The wear of an Al 7050 alloy reinforced with boron nitride was studied using Taguchi's method. Data was gathered and analyzed using a L9 orthogonal array in the DOE. Reinforcement percentage level of 0, 4, and 6%; sliding velocity of 1, 2, and 3 m/s; and distance of 1000 to 14000 metres were used in this investigation. The sliding distance was found to have the greatest impact on the output characteristics. Fuzzy and Grey's relational analysis utilized by [9] to improve tribological characteristics of Al composites. In the Al6061 base metal, tungsten carbide and graphite were employed as reinforcement. In order to determine the COF (coefficient of friction) and to test different degrees of load, sliding distance, and sliding velocity, an experimental run of 30 runs was conducted at 9% and three different levels of water content [10, 11]. The wear rate and the COF were also calculated. Because COF and wear rate are closely related, FGRA was used to find optimal control variable values that would reduce both of these. The experimental results validated the appropriate tribological conditions, which were confirmed in the study [12, 13]. Powder metallurgy was used to produce MMCs with a monolithic boron nitride reinforcement in Al6082. By employing Grey-method Taguchi's of optimization, the tribological performance of synthetic MMCs was improved. A pin-on-disc tester was used to assess volume loss and frictional force using an L27 orthogonal array. When applying the Grey Relational Analysis, the ideal SWR and COF values were obtained [14, 15]. Friction and wear behavior were shown to be strongly influenced by % volume, the most important of the four variables. Taguchi's concept was adopted to enhance the tribological characteristics of Al hybrid composites incorporating A356 alloy, 10% boron nitride, and graphite [16]. Using compo-casting, hybrid composites were created. When it came to the wear tests utilizing the block-on-disc method, the sliding speed was 0.25, 0.50, and 1.25 m/s, as well as 10 and 30 N loads, and the graphite weight % ranged from 0, 3, and 5%. The SWR was analyzed using Taguchi's method to find the most effective settings [17, 18]. The study found that the SWR was influenced primarily by the percentage of load applied. Al hybrid metal composites were optimized using Gray-approach Taguchi's by [19] in another work. Molybdenum disulfide (varying from 2 to 4% of the total weight) was combined with 5% alumina and stir cast to make metal matrix composites. Once it came to testing for wear, we employed a pin-on-disc tribometer [20]. Calculating SWR and COF, volume loss and frictional force were considered. The experiment was constructed using Taguchi-Grey Relational Analysis, which was used to identify the ideal SWR and COF values as different factors can really be optimized concurrently in the Taguchi technique, allowing for the extraction of many more quantitative information from fewer experimentations, while the GRA is being used to identify the optimum condition for multiple input variables in order to obtain the best quality characteristics [21]. The control parameters have an impact on the tribological performance. It is well known that Taguchi-Grey Relational Analysis approach is used in improving wear properties of mixed reinforced composites, particularly by [22, 23]and others. Hybrid Al6063/palm kernel shell ash reinforcement with 2% BN is not clear how it can increase its tribological qualities. The PKSA concentration varies from 0% to 6%, with a 2% weight percentage gap between each percentage point. In an orthogonal array experimental design of L16, the Taguchi and Grey Relational Analysis methods were used to optimize dry sliding performance by modifying control factors. Analysis of variance is used to analyze tribological performance of the composite under examination and determine the relative relevance of the various factors and their interactions [24–26].

2. Taguchi and Grey Relational Analysis

Taguchi is amongst the best effective strategies for manufacturing high-quality orthogonal array trials. As long as process control settings are optimized, using an orthogonal array can assist decrease measurement variation. Designing for performance, cost, and quality in an integrated manner is a common practice in the industry. Taguchi differentiates out from other experimental methodologies because it focuses on the impact of variance on processing quality assessments moderately than mean. The Taguchi method uses a limited number of orthogonal array experiments to study the whole design space in order to control factors impact and their relations with all other factors. Since the optimal design parameters can be predicted, it is easier to minimize the objective function while still ensuring that constraints are maintained.

To help with the optimization process, Taguchi goes into great detail in Taguchi to describe the sequence in which Taguchi's technique is implemented. Reaction S/N ratio relies on the product or process that is being optimized for quality. Using three various forms of S/N ratios, Taguchi's

Table 1: Chemical constituents of (a) Al6063 and (b) palm kernel shell ash (PKSA).

Constituents (a)	Si	Fe	Mn	Mg	Cu		Ti	Zn	Cr	Sn	Al
%	0.45	0.18	0.04	0.49	0.01		0.03	0.01	0.01	0.01	Bal.
Constituents (b)	Na2O	MgO	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	Fe2O3	MnO	LOI
%	0.18	3.15	6.45	65.80	3.76	5.21	5.48	0.54	5.68	0.08	2.56

method makes use of HB, HB, and the nominal-is-best (NB). As AMC quality decreases, the better their tribological features become. This is why AMCs should be used to their fullest. In order to find statistically significant experimental variables, the analysis of variance is frequently performed. Thus, S/N ratios and analysis of variance analyses may be utilized to discover the optimal process parameters. Confirmation experiments are often carried out to confirm that the optimal process variables have been established. It is therefore necessary to introduce Grey Relational Analysis. Tribological characteristics such as wear rate and volume loss can be reduced by optimizing the tribological parameters in this study. In this case, the multiresponse optimization technique is being utilized. Grey Relational Analysis is a useful method for analyzing numerous answers, in which the target functions are first normalized between 0 and 1 before the analysis begins. Grey's connection score and the overall Grey relationship grade are then calculated. According to a number of performance metrics, the highest GRG value serves as an indicator of optimal process parameters. Analysis of variance is widely used to determine the relative relevance of numerous features and their relations on the tribological characteristics.

3. Materials and Method

These ashes are generated as a byproduct of palm oil mills, as it possesses pozzolanic activity and contributes significantly to the performance and toughness of mixed materials. The PKS had been sorted, cleaned, and dried. PKS ash extraction at 900 degrees Celsius [13]. The base alloy for the AMCs was Al6063, as aluminum 6063 is being used to achieve an appealing finish for architectural and building application fields that are visually appealing, which had the composition shown in Table 1. Boron nitride and PKSA with the chemical constituents listed in Table 1 were used as hybrid reinforcements. The BN and PKSA particle reinforcements have typical diameters of 30 m and 40 m. Many writers have described the two-stir casting procedure which was hired in the production process.

3.1. Hybrid Composite Synthesis. Stir casting, a well-known liquid metallurgy technology, was used to create the composites. The composites were made via dual stir casting. Between 0% and 10% reinforcement combinations can be generated with (40-60 μm) PKSA, 50 nm BN (1%), and Al6063. Strengthening particles of BN and PKSA were heated to 250°C in order to remove humidity and boost its ability to adhere to the base metal. The billets of Al6063 alloy were heated to 750°C in a gas-fired crucible furnace. In order to complete the cooling process, the partially formed metal was removed and put in a 600°F oven. When the Al6063 alloy was melted, the warmed reinforcements of PKSA and nano BN were applied. The slurry was ready for use after a 10-minute hand-stirring session. To achieve a temperature range between 780°C and 30°C, the semisolid composites were heated mechanically at 400 rpm for around 10 minutes. Mechanical stirring was used to break down particle agglomerates by enhancing particulate distribution in the molten metal matrix. It was then necessary to use an already prepared mould in order to harden the liquid composites. Figure 1 shows the schematic view of double stir casting process.

3.2. Tribological Characteristics. The ASTM D4060-16-compliant composites' wear resistance was tested using a Taber Type Abrasion Tester. Measurements of diameter and thickness were made for each test sample (5 mm). Taber abrasion machine turntable platform was used for the sample's surface to be scratched. Continual pressure was applied to the sample's surface using two abrasive wheels that had been lowered and secured in place. There were four different weights (masses) applied to each sample, and four different speeds (rpms) applied to each sample: 500, 750, 1000, and 1250 g and 1000 rpm, respectively. The sample was rubbed against itself by the machine's abrasive wheels, resulting in loose composite debris. After 15 minutes of abrasion testing, the starting and end weights were recorded.

Equations (2) and (3) were used to compute the wear characteristics of the composites. The mass (g) and volume (mm^3) lost were calculated by means of

$$\text{Mass loss} = \text{Initial mass}\,(m_i) - \text{Final mass}\,(m_f), \quad (1)$$

$$\text{Volume loss} = \frac{\text{mass loss}}{\rho}. \quad (2)$$

The Taber wear rate index was attained by the relation as shown as follows::

$$\text{Taber Wear Index}, I = \frac{m_i - m_f}{T} \times 1000. \quad (3)$$

3.3. Design of Experiment. These parameters are reinforced, load, and speed, with four levels of each element selected for consideration in this study. Reinforcement is available in levels 3, 5, 7, and 9 weight %, while load is available in a range of 500 to 1250 grammes, while speed is available in a range of 500 to 1250 revolutions per minute (RPM). Taguchi's technique was used to optimize the wear index and loss of volume for synthesized AMCs. On the basis of four main processing factors, the L16 orthogonal array was selected. S/

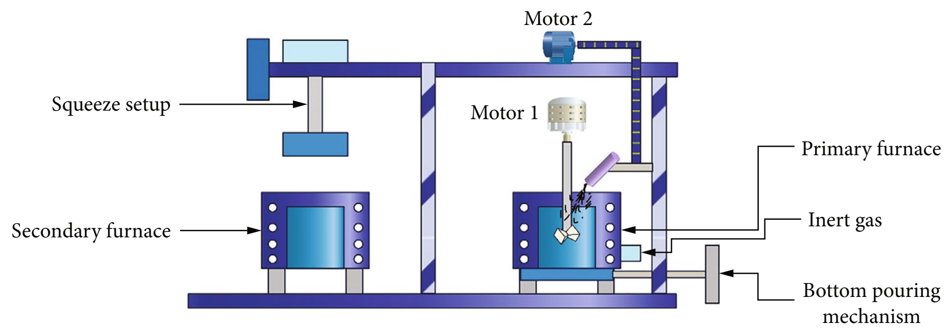

Figure 1: Schematic view of double stir casting.

N ratios are frequently employed in Taguchi's approach to express goal function values. In order to minimize the wear index and loss of volume, Equation (1) was employed to calculate the S/N ratio since the less the value, the better in

$$S/N = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right). \quad (4)$$

3.4. ANOVA. As a consequence of ANOVA, the relative importance of various process parameters in achieving the desired outcome was determined. Minitab 14 (statistics software) was used for the Taguchi and ANOVA analyses in this research.

3.5. Confirmation Test. In order to verify the Taguchi-based optimal conditions for wear rate (WR_{opt}) and volume loss (VL_{opt}), a confirmation test was carried out. For the purpose of estimating the optimal answers, we used the following:

$$WR_{opt} = m_W + (A_3 - m_W) + (B_1 - m_W) + (C_1 - m_W), \quad (5)$$

$$VL_{opt} = m_V + (A_1 - m_V) + (B_1 - m_V) + (C_1 - m_V). \quad (6)$$

There are two ideal levels of wear rate and volume loss: A3B1C1 and A1B1C1. The WR_{opt} and VL_{opt} averages from the study are mW and mV, respectively. In order to determine if the projected optimal responses are in agreement with the experimental results, in order to calculate individual response CIs, we used

$$CI = \sqrt{F_{\alpha,1,fe} V_e \left[\frac{1}{n_{eff}} + \frac{1}{R} \right]}, \quad (7)$$

$$n_{eff} = \frac{N}{1 + T_{dof}}. \quad (8)$$

3.6. Grey Relational Analysis (GRA). The first step in the GRA process is to normalize the investigational data to a value between 0 and 1. It was decided to use equation to evaluate the performance of each response based on the principle of the smaller, the better in

$$\text{The smaller – the – better}, \; y_i(s) = \frac{\max x_i(s) - x_i(s)}{\max x_i(s) - \min x_i(s)}. \quad (9)$$

After the experimental findings have been standardised using Equations (10) and (11), the grey relational coefficient (GRC) is commonly determined in (11).

$$\varepsilon_i(s) = \frac{\Delta_{min} + \varphi \Delta_{max}}{\Delta_{oi}(s) + \varphi \Delta_{max}}, \quad (10)$$

where $\Delta_{oi}(s)$ is the deviation sequence estimated by employing

$$\Delta_{oi}(s) = |x_0(s) - x_i(s)|. \quad (11)$$

For instance, the comparability sequence consists of the terms $x(s)$, min (s), and max (s). The term $xo(s)$ is the referential order, and the term ϕ is the coefficient of identification. The value can be anywhere from 0 to 1.

4. Results and Discussion

4.1. S/N Ratio Analysis of the Responses. Displayed in Table 2, the processing parameters' response characteristics and S/N ratios are analyzed. The results of the experiments varied from run to run. Subsequent sections go into greater depth on the outcomes and the analysis that will be done on them.

4.2. Analysis of a Response (Wear Index). Process parameters were ranked according to the wear index value, with the mean S/N ratio being the most important. The wear index of the synthetic aluminium metal composites is depicted in Figure 2, which reveals the substantial effect of each parameter. As a means of identifying, the best processing parameter variations, the best S/N ratios will help. A set of method settings was developed that resulted in the highest possible wear index. The applied load was 500 g, and the sliding speed was 500 rpm at the moment, with a reinforcement percentage of 5%. At a sliding speed of 500 revolutions per minute and a weight of 500 gm, the ideal wear index for Al6063 may be attained with the addition of 2% BN and

Table 2: Process parameters, responses, and S/N ratios.

Exp no.	Process parameters			Responses (target functions)		S/N ratio for various responses	
	Reinforcement (wt.%)	Load (g)	Speed (rpm)	Wear index (g/min)	Loss of volume (mm^3)	Wear index	Volume loss
1	3	500	500	0.00301	15.183	51.469	-23.621
2	3	750	750	0.00362	20.012	49.812	-26.015
3	3	1000	1000	0.01824	96.842	36.354	-40.528
4	3	1250	1250	0.07569	418.42	23.612	-53.412
5	5	500	500	0.00512	29.455	47.128	-30.182
6	5	750	750	0.00491	27.528	47.583	-29.512
7	5	1000	1000	0.06614	382.84	24.126	-52.654
8	5	1250	1250	0.02965	164.21	31.245	-45.349
9	7	500	750	0.00118	58.24	60.124	-36.345
10	7	750	1250	0.001785	97.415	36.354	-40.824
11	7	1000	500	0.006428	37.965	44.135	-32.168
12	7	1250	750	0.01884	104.24	35.012	-41.345
13	9	500	1250	0.01562	88.48	36.512	-39.934
14	9	750	1000	0.01247	70.18	39.754	-37.912
15	9	1000	750	0.01364	73.86	39.0963	-38.248
16	9	1250	500	0.00854	50.02	42.621	-34.812

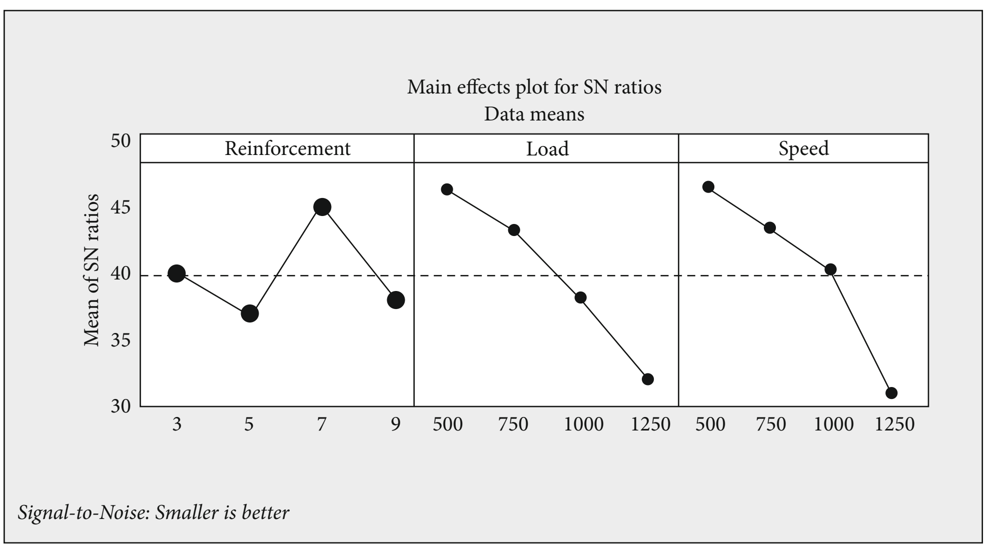

Figure 2: Analysis of the S/N ratio of each parameter's effect on wear index.

5% PKSA as hybrid reinforcements ($A_3B_1C_1$). As a result, this indicates that the wear index is in good shape. Optimal value was most strongly influenced by sliding speed and load, with reinforcing percentage weight having the least impact, according to the ranking.

4.3. Analysis of Volume Loss Target Functions. Mean SNR ratio and ranking order of reinforcement, load, and speed were used to calculate volume loss value. As each process parameter changes, so does the volume loss, as seen in Figure 3. The most significant effect on volume loss was found to be associated with the sliding speed. Furthermore, the reinforcing impact was considered as the least important. It is important to have 3% reinforcement in the AMCs to get the optimum volume loss value at 500 g applied load and 500 revolution per minute sliding speed, as can be shown in Figure 3.

4.4. ANOVA of the Responses

4.4.1. Wear Index. ANOVA has been recommended by [6] for verifying the statistical consistency of Taguchi analysis outcomes. The % of each AMC factor's impact on the wear index was calculated. It is shown in Table 3 that the ANOVA results for wear index of AMC samples reveal the percentage influence of each process parameter. In the ANOVA investigation, the applied load was demonstrated to be the most important component, accounting for 42.83%. Only 6.97%

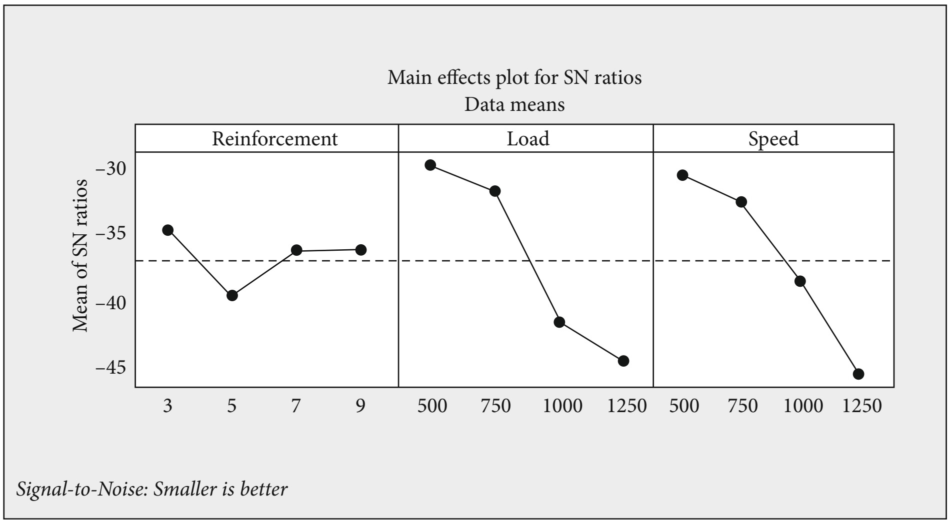

Figure 3: Analysis of the S/N ratio of each parameter's effect on volume loss.

Table 3: Analysis of variance for wear index.

Source	DF	Seq SS	Adj SS	Adj MS	*F* value	*p* value	Contribution (%)	*R*-sq
Reinforcement	3	98.46	100.4	34.16	1.48	0.342	6.85	0.915
Load	3	612.13	612.12	204.18	10.16	0.018	43.18	
Speed	3	582.62	581.45	194.15	9.42	0.016	40.45	
Error	6	135.54	135.62	24.45			9.52	
Total	15	1428.75						

of the total was accounted for by reinforcing weight, which had a 40.74% share. However, the main effect plots and ANOVA results of Taguchi's approach were ordered differently. An ANOVA test, however, indicated that speed and load were in that order, despite a Taguchi test indicating the opposite. As a result, the wear index is most strongly influenced by load and speed, whereas reinforcement has the least. Researchers [25] back up the findings of this investigation. When compared to the weights and sliding speeds they were tested against, the graphite addition to composites had no influence on their performance. With increasing applied load and speed, raising the AMC wear index is significantly impacted. According to [4], as the applied force increases, tribological characteristics such as wear rate and COF can rise. As the load increases, the plastic deformation increases as well. Each process parameter's p value revealed which ones have a significant impact on the wear index. There is no correlation between the wear index value and the reinforcing process parameter because the p value is much above the 0.05 level of confidence. The composites' wear index values are strongly influenced by the loads and speeds applied.

4.4.2. Volume Loss. Table 4 indicates the outcomes of the ANOVA as well as the volume loss contribution proportion of the three variables. After doing an analysis of process parameters using ANOVA, which indicated that speed had a 60.16% effect, followed by applied load (34.35%) and reinforcement (11.64%), reinforcement's percentage contribution to volume loss is negligible as compared to speed and load. Like the ANOVA findings, we can see how the process parameters affect volume loss. Strengthening ($p = 0.467$) was not significant, but speed ($p = 0.0001$) and load ($p = 0.002$) were highly significant in terms of volume loss ($p = 0.002$). Variables like load and speed have an effect on responsiveness when the p value is less than 0.05. The findings of the experiments showed that the composites' volume loss increased without reference to the reinforcing weight percentage as load and speed increased. As observed in the study from [14], sample volume loss increased correspondingly as speed and load increased. Following speed, applied load, and % reinforcement weight, Taguchi and ANOVA analysis indicated that % reinforcement weight was the least influential factor. If the findings from [24] are correct, then the use of optimization techniques is confirmed to be accurate, as indicated by [23].

4.4.3. Confirmation Test. These tribological properties underwent a confirmation test in order to ascertain their exact optimum values. As expected, the experimental results were within the CI computed using Equations (7) and (8). For this purpose, the following values were substituted into Equations (7) and (8). As shown in Table 5, the anticipated and experimentally optimal CI values for each of the goal functions are all within acceptable ranges.

4.5. Grey Relational Analysis (GRA). Multiple performance characteristics were the consequence of combining GRA's

Table 4: Impact of processing parameter loss of volume.

Source	Degrees of freedom	Seq SS	Adj SS	Adj MS	F value	p value	Contribution (%)	R-sq
Reinforcement	3	17.9	19.3	7.034	0.98	0.671	2.06	0.945
Load	3	348.46	348.64	116.84	19.64	0.003	34.46	
Speed	3	609.84	610.81	203.912	33.48	0.0001	59.00	
Error	6	38.6	38.3	6.348			3.72	
Total	15	1015.5					100	

Table 5: Predicted and actual results for each reaction at optimal conditions.

Response	Condition at optimum level	Predicted	Experiment
Wear index (g/min)	$A_3B_1C_1$ (reinforcement = 5 wt.%; load = 500 g; speed = 500 rpm)	0.00132	0.00267
Loss of volume (mm^3)	$A_1B_1C_1$ (reinforcement = 3 wt.%; load = 500 g; speed = 500 rpm)	14.915	15.016

Table 6: Optimized results for the Grey Relational Analysis.

S. no	Normalized		GRCs		GRG	Rank
	Wear index	Loss of volume	Wear index	Loss of volume		
1	0.96842	1.0134	0.9456	1.000	0.9834	2
2	0.9742	0.9976	0.9461	0.9842	0.9664	1
3	0.7914	0.8016	0.7052	0.7231	0.7161	16
4	0	0	0.3341	0.3342	0.3433	12
5	0.9541	0.9745	0.9125	0.9468	0.9287	3
6	0.9585	0.9812	0.9182	0.9543	0.9351	4
7	0.1283	0.0961	0.3743	0.3661	0.3712	14
8	0.6342	0.6419	0.2812	0.5758	0.5842	15
9	1.0124	0.9041	1.0146	0.8349	0.9114	5
10	0.7965	0.8074	0.7142	0.7124	0.7124	6
11	0.9347	0.9546	0.8832	0.9128	0.8972	11
12	0.7830	0.7816	0.6950	0.7042	0.6910	10
13	0.8124	0.8168	0.7346	0.7456	0.9398	13
14	0.8614	0.8342	0.7789	0.7954	0.7785	9
15	0.8431	0.8643	0.7632	0.7869	0.7769	7
16	0.9012	0.9243	0.8434	0.8661	0.8534	8

two primary goals (MPC). The key objectives are the wear index and loss of volume. As shown in Table 6, the GRC, the GRG, and the rankings generated by applying Equations (9)–(11) to the grey's relational grade are all shown. For the best MPC, a research with the maximum GRG in all of its runs will yield the most accurate results On the basis of GRG's responses, the order of each process parameter's rating was determined. Speed is listed first, followed by load, and then reinforcement. Reinforcement comes in at a distant third place, with rotational speed taking precedence. The results from experiment 1 were the most impressive.

Figure 2 shows the most important impact of each processing parameter on a typical wear specimen. A3B1C1 is the best answer for a wide range of questions. When evaluating A3B1C1's ideal values, it is important to take into account the weight of 6%, the loads applied of 500 gms, and the speed of 500 revolutions per minute (rpm). Using ANOVA, the GRG findings were analyzed, and the % contribution of each constraints was evaluated. 47.38% and 23.9%, respectively, of the MPC's impact are due to speed and load. According to the GRG response's ranking order, this is also true in Table 6. This characteristic, speed, outperforms both loads and reinforcement in terms of significance due to its p value being less than or equal to 0.05. Using the wear index and loss of volume and the S/N ratio as a proxy, Table 5 compares reinforcement, load, and speed. A correct response will be based heavily on these factors.

5. Conclusions

Aluminum metal composites were improved by combining Taguchi and Grey's Relational Analysis approaches. We found that reinforcing percentage weight, load, and speed all had an impact on wear index and volume loss. The experiment's outcomes were analyzed and verified using ANOVA. We can finally conclude the following:

(i) Reinforcement percentages of 5% and 3% were used to optimize wear indexes and volume loss at A3B1C1, while volume loss was optimized at the same location

(ii) Speed is the most important component in determining wear index and volume loss, according to Taguchi and GRA

(iii) A 95% confidence interval confirmation test was used to check that anticipated and investigational findings were within permitted range

(iv) The tribological characteristics of a material were improved using both of the methods utilized in this investigation

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.

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References

[1] V. Mohanavel, K. S. Ashraff Ali, S. Prasath, T. Sathish, and M. Ravichandran, "Microstructural and tribological characteristics of AA6351/Si3N4 composites manufactured by stir casting," *Journal of Materials Research and Technology*, vol. 9, no. 6, pp. 14662–14672, 2020.

[2] K. K. Alaneme, M. O. Bodunrin, and A. A. Awe, "Microstructure, mechanical and fracture properties of groundnut shell ash and silicon carbide dispersion strengthened aluminium matrix composites," *Journal of King Saud University-Engineering Sciences*, vol. 30, no. 1, pp. 96–103, 2018.

[3] M. L. Bharathi, S. Adarsh Rag, L. Chitra et al., "Investigation on wear characteristics of AZ91D/nanoalumina composites," *Journal of Nanomaterials*, vol. 2022, Article ID 2158516, 9 pages, 2022.

[4] B. P. Kumar and A. K. Birru, "Tribological behavior of aluminium metal matrix composite with addition of bamboo leaf ash by GRA-Taguchi method," *Tribology in Industry*, vol. 40, no. 2, pp. 311–325, 2018.

[5] T. A. Orhadahwe, O. O. Ajide, A. A. Adeleke, and P. P. Ikubanni, "A review on primary synthesis and secondary treatment of aluminium matrix composites," *Arab Journal of Basic and Applied Sciences*, vol. 27, no. 1, pp. 389–405, 2020.

[6] M. Sarıkaya and A. Güllü, "Taguchi design and response surface methodology based analysis of machining parameters in CNC turning under MQL," *Journal of Cleaner Production*, vol. 65, pp. 604–616, 2014.

[7] B. Stojanović and L. Ivanović, "Application of aluminium hybrid composites in automotive industry," *Tehnički vjesnik*, vol. 22, no. 1, pp. 247–251, 2015.

[8] A. S. Canbolat, A. H. Bademlioglu, N. Arslanoglu, and O. Kaynakli, "Performance optimization of absorption refrigeration systems using Taguchi, ANOVA and Grey Relational Analysis methods," *Journal of Cleaner Production*, vol. 229, pp. 874–885, 2019.

[9] K. K. Alaneme, M. H. Adegun, A. G. Archibong, and E. A. Okotete, "Mechanical and wear behaviour of aluminium hybrid composites reinforced with varied aggregates of alumina and quarry dust," *Journal of Chemical Technology & Metallurgy*, vol. 54, no. 6, 2019.

[10] S. Chamoli, P. Yu, and A. Kumar, "Multi-response optimization of geometric and flow parameters in a heat exchanger tube with perforated disk inserts by Taguchi grey relational analysis," *Applied Thermal Engineering*, vol. 103, pp. 1339–1350, 2016.

[11] K. Halil, O. İsmail, D. Sibel, and Ç. Ramazan, "Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy," *Journal of Materials Research and Technology*, vol. 8, no. 6, pp. 5348–5361, 2019.

[12] B. N. Sarada, P. L. S. Murthy, and G. Ugrasen, "Hardness and wear characteristics of hybrid aluminium metal matrix composites produced by stir casting technique," *Materials Today: Proceedings*, vol. 2, no. 4–5, pp. 2878–2885, 2015.

[13] P. P. Ikubanni, M. Oki, A. A. Adeleke, A. A. Adediran, and O. S. Adesina, "Influence of temperature on the chemical compositions and microstructural changes of ash formed from palm kernel shell," *Results in Engineering*, vol. 8, article 100173, 2020.

[14] A. Acır, M. E. Canlı, İ. Ata, and R. Çakıroğlu, "Parametric optimization of energy and exergy analyses of a novel solar air heater with grey relational analysis," *Applied Thermal Engineering*, vol. 122, pp. 330–338, 2017.

[15] M. Thangaraj, R. Annamalai, K. Moiduddin, M. Alkindi, S. Ramalingam, and O. Alghamdi, "Enhancing the surface quality of micro titanium alloy specimen in WEDM process by adopting TGRA-based optimization," *Materials (Basel)*, vol. 13, no. 6, p. 1440, 2020.

[16] V. R. Rao, N. Ramanaiah, and M. M. M. Sarcar, "Dry sliding wear behavior of TiC–AA7075 metal matrix composites," *International Journal of Applied Science and Engineering*, vol. 14, no. 1, pp. 27–37, 2016.

[17] N. H. Naqiuddin, L. H. Saw, M. C. Yew et al., "Numerical investigation for optimizing segmented micro-channel heat sink by Taguchi-Grey method," *Applied Energy*, vol. 222, pp. 437–450, 2018.

[18] P. J. Unnikrishna, S. Ikshit, S. T. M. Manikandakumar, and G. Moshe, "Optimisation of multiple response characteristics on end milling of aluminium alloy using Taguchi-Grey relational approach," *Measurement*, vol. 124, pp. 291–298, 2018.

[19] B. Stojanović, A. Vencl, I. Bobić, S. Miladinović, and J. Skerlić, "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*, vol. 40, no. 6, pp. 1–14, 2018.

[20] N. Mandal, B. Doloi, B. Mondal, and R. Das, "Optimization of flank wear using zirconia toughened alumina (ZTA) cutting tool: Taguchi method and regression analysis," *Measurement*, vol. 44, no. 10, pp. 2149–2155, 2011.

[21] S. S. Hiremath, N. S. Shanmugam, and B. R. R. Bapu, *Advances in Manufacturing Technology: Select Proceedings of ICAMT 2018*, Springer, 2019.

[22] V. Dharanikota, "Optimization of tribological properties of Al-6082/BN metal matrix composite by Grey-Taguchi's method," *International Journal of Scientific and Engineering Research*, vol. 5, p. 629, 2014.

[23] K. K. Alaneme, A. V. Fajemisin, and N. B. Maledi, "Development of aluminium-based composites reinforced with steel and graphite particles: structural, mechanical and wear characterization," *Journal of Materials Research and Technology*, vol. 8, no. 1, pp. 670–682, 2019.

[24] V. Mohanavel, M. Ravichandran, S. S. Kumar, M. M. Sridhar, S. Dineshkumar, and M. M. Pavithra, "Microstructural and tribological characterization of Al/egg shell ash composites

prepared by liquid metallurgy process," *Journal of the Balkan Tribological Association*, vol. 26, no. 2, pp. 319–326, 2020.

[25] S. Veličković, B. Stojanović, M. Babić, and I. Bobić, "Optimization of tribological properties of aluminum hybrid composites using Taguchi design," *Journal of Composite Materials*, vol. 51, no. 17, pp. 2505–2515, 2017.

[26] S. Dharmalingam, R. Subramanian, K. Somasundara Vinoth, and B. Anandavel, "Optimization of tribological properties in aluminum hybrid metal matrix composites using gray-Taguchi method," *Journal of Materials Engineering and Performance*, vol. 20, no. 8, pp. 1457–1466, 2011.