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Optimization of Wear Behaviour of Al6061 Metal Matrix Composites Using Taguchi Approach

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Abstract

The paper's goal is to determine Al6061's wear behavior using Silicon carbide (SiC) reinforcement. When reinforcing is added, aluminum's strength to weight ratio rises, making it the ideal material for applications where a high strength to weight ratio is required. Aluminum-based metal matrix composites are favorable in many industries, including electronics, sports equipment, aircraft, and defense, because of their light weight, high strength, and low coefficient of thermal expansion when reinforced. Under dry sliding wear circumstances, the sliding wear behavior of aluminum matrix composites 6061-SiC has been studied. Stir casting is used to create Al6061 matrix metal and SiC particles with an average size of 44 µm as reinforced particles to create aluminum metal matrix composites (AMMCs). For Al6061, the examined AMMCs had 0%, 3.5%, and 7.0% weight percentage of SiC particles. The usual load of 10, 20, and 30 N, the sliding distances of 1000, 2000, and 3000 m, and the sliding velocities of 1.5, 2.5, and 3.5 m/s were all used in the wear testing. To collect data in a controlled manner, Taguchi orthogonal array techniques were utilized in the Design of Experiments (DOE). To find out how process variables affected composite wear loss, analysis of variance (ANOVA) was created. The findings demonstrated that adding Silicon Carbide reinforcements to an aluminum matrix composite greatly boosts the composite's resistance to wear.

1. Introduction

The transportation, aerospace, marine, oil and gas, automotive, and mineral processing industries are using more and more aluminum-based composites because of their exceptional strength, wear resistance, and low weight. However, the high cost of component production has prevented their widespread acceptance for engineering applications. Therefore, a lot of work has gone into creating composites with reinforcements that are lightweight, reasonably priced, and able to compete favorably in terms of strength and wear characteristics. However, the high cost of component production has prevented their widespread acceptance for engineering applications. Therefore, a lot of work has gone into creating composites with reinforcements that are lightweight, reasonably priced, and able to compete favorably in terms of strength and wear characteristics. A variety of alloy compositions are obtainable in the market

A pin-on-disc device was used to conduct a dry sliding wear test. Following the ASTM G99 standard ensured the greatest possible Pin-on-Disc test performance [1]. This paper examined the wear behavior of hybrid aluminum metal matrix composites (AMMC) since the presence of mica influences dry sliding [2-3]. investigates the effect of pumice, known as Karakaya pumice, and taken from the Isparta-Gölcük region, on clay's unconfined compressive strength and swelling pressure [4]. Algebra becomes important in school when we learn to work with variables, expressions and equations.[5].This work aimed to present the findings of a Taguchi analysis of the tribological behavior of an Al7075 alloy matrix augmented by weight nanoscale titanium dioxide (TiO2) particles at 0%, 1%, 2%, and 3% [6]. For many years, high-density materials have been replaced in modern manufacturing with metal matrix composites [7]. Compared to other materials, aluminum matrix composites (AMCs) offer a variety of benefits. Other characteristics include resistance to wear and abrasion, as well as a minimal coefficient of thermal expansion [8-9]. For uniformly spreading ceramic particles, mechanical stirring is a simple, low-cost technique [10-11]. Nowadays, composites are profoundly thriving as the replacement of ferrous alloys [12]. The technique used to make liquid composites is stir casting. To improve a matrix material's mechanical qualities, a hard particulate material can be added. [13-14]. Copper (Cu) matrix composite reinforced with Titanium Carbide (TiC) was fabricated by powder metallurgy (PM) method [15]. When compared to steel, aluminum matrix composites (AMCs) have better mechanical and tribological propertie[16].. This study examined wear control parameters, including sliding velocity, weights, reinforcements, and sliding distance, to see whether they had an impact on the rate of wear. [17]. One of the main factors influencing wear rate is load. Numerous factors, such as sliding velocity and structural reinforcement, among others, affect it. The relationship between the granular size, sliding distance, and strengthening volume portion is crucial because of wear [18-19]. As the TiC concentration in the AA7075 composite grew, wear and the coefficient of friction decreased. A laboratory study was conducted to investigate the wear resistance of a nickel-based compound based on the AA7075 alloy [20-21]. The way composite pipes that are used in undersea applications change mechanically has a significant impact on how long the material lasts. The density and hardness value of composite materials are two crucial mechanical qualities. [22-24]. Advanced engineering materials having better qualities than conventional materials are called composite materials [25]. Thus, it was determined how varied amounts of cumin black pulp added to the EPDM matrix affected the material's rheological, mechanical properties, and degree of crosslinking. [26]. Aluminium alloy (A6063) was reinforced with 2 – 10 wt. % of 80 μm QTs particulates using stir casting method. Microstructural, mechanical and wear characterisations were carried out on the composites [27]. Metal is used as a matrix material and can be reinforced with ceramic, metal, or organic compounds to create metal matrix composites. [28]. The results of the experiment showed that because hBN is self-lubricating, the insertion of secondary hBN particles significantly improved the wear characteristics of the hybrid composite [29]. Optical and scanning electron microscopy was used to examine the microstructures [30].

2. Materials Selection and Fabrication Process

2.1 Matrix Selection:

Matrix is the basic component of the composite. Many matrix materials is capable of producing metal matrix composites. however the most common ones are aluminum and its alloys. Aluminum alloys are reinforced with both soft and hard reinforcements, including Si-rice husk, graphite, MgO2, SiC, etc. Alloys like alloy 356; alloy 6063; and aluminum 6061 are commonly used. The base substance, The material utilized as the matrix is aluminum 6061 alloy. The pure aluminum 6061 alloy is displayed in the image (Fig. 1) below.

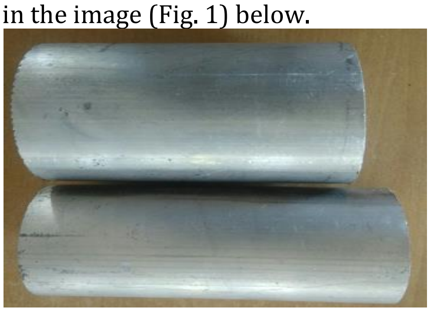

Figure 1. Matrix Material-Al6061

2.2 Reinforcement Selection

Silicon carbide can be used as reinforcements in a range of materials because it provides the strength, hardness, high fracture toughness, and extremely high resistance to crack propagation of the design structure. In this investigation, powdered silicon carbide (SiC) is used as AMMC reinforcement. The pure SiC powder is displayed in the image (Fig 2) below.

Figure 2. Reinforcement Material -SiC

2.3 Composites Producing Process

Aluminum matrix composites (AMC) reinforced with silicon carbide (SiC) was made via stir casting. Stir casting is a liquid state technique used to create composites, whereby mechanical stirring combines a molten matrix metal with a dispersion phase (SiC particles).Following that, normal casting procedures are used to cast the liquid composite material.. Stir casting is used to create the metal matrix hybrid composite of aluminum-silicon. For this, we have selected 1250 grams of aluminum 6061 alloy and the appropriate percentages of powdered SiC (0%, 3.5%, and 7.0%). The strength of mixing, the situation under which the particles are wet with the melt, the velocity of solidification, and the relative density all affect how the particles are distributed in the final solid. Aluminum melt temperature at 1000°C for 3 to 4 hours .The addition of SiC is done while maintaining the melt temperature at 700°C. A mild steel turbine stirrer is used to agitate the melt. To improve the wet ability, the stirring is continued for five to seven minutes at an impeller speed of 700 rpm. The permanent metallic mold is heated and filled with the melted material. A constant 680°C pouring temperature is maintained. After that, the melt is given time to harden in the mold. One obtains the metal matrix composites.

2.4 Design of Experiment Using Taguchi Method

Composites The Taguchi method was used to determine the number of experiments. With the least amount of experiments necessary, process performance can be improved using the robust and effective Taguchi method of experiment design. It lowers process cycle times, production costs, and rework expenses. Finding the ideal values for the objective function in manufacturing processes is the goal of the Taguchi design. In contrast to conventional experimental designs, the Taguchi technique uses a unique orthogonal array design to investigate the quality attributes with fewer experiments. The performance qualities are then assessed by converting the trial data into S/N ratios. Consequently, the Taguchi technique looks at how differences affect quality aspects rather than concentrating on averages. In other words, the Taguchi technique insulates process performance from fluctuations in unpredictable noise elements. The parameter design is then carried out to ascertain the ideal parameter conditions. The L9 orthogonal array's structure is displayed in Table 2, and the experiment's parameters were load, speed, and distance as listed in Table 1.

Table 1. Process parameters and levels

Level	Load (N)	Sliding Velocity (m/s)	Sliding Distance, D (m)
1	10	1.5	1000
2	20	2.5	2000
3	30	3.5	3000

Table 2. Structure of L_9 Array

Experiments	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3. Experimental Procedure of Wear Testing

In order to reduce wear rate and coefficient of friction, the experimental plan aims to discover the important elements and their combinations that influence the wear process. Using an orthogonal array, the studies were intended to determine a link between the impacts of sliding distance, applied weight, and speed. These design elements are distinct, built-in components of the mechanisms influencing and determining the overall performance. Taguchi suggests employing a conceptual approach to analyze the S/N ratio, which entails visualizing the important elements and graphing the impacts. The pin-on-disc test apparatus discussed earlier was utilized to determine the composite's sliding wear characteristics. From the cast samples, specimens measuring 8 mm in diameter and 50 mm in length were cut, and they were subsequently machined. In order for the cast sample (pin) to make contact with the rotating disc, its contact surface was made flat. Throughout the testa revolving disc made of EN31 carbon steel was in contact with the pin using a load that balanced it and acted as a counterweight. Track diameter was modified between 50 and 100 mm for each set of experiments, and parameters including load, sliding speed, and sliding distance were adjusted within the range given in Table 1. An LVDT (load cell) on the lever arm helps to measure the wear at any given time by monitoring arm movement. The arm is forced to stay in touch with the disc by the load when the surface in contact wears down. The signal generated by the arm's movement is used to determine the maximum wear. As wear occurs, the COF is continuously measured, and graphs illustrating the correlation between COF and time were noted for the three specimens—aluminum with 0% SiC, 3.5% SiC, and 7.0% SiC. A single pan electronic weighing machine with an accuracy of 0.0001g was also used to assess the weight loss of each specimen both before and after the experiment, after thorough acetone cleaning.

According to the orthogonal array, the experiment was carried out to acquire results for different combinations of parameters. Table 3 displays these findings. The obtained findings were analyzed using the commercial software MINITAB 15, which is generally used in DOE applications. The experimental values are converted into a signal to noise ratio in order to quantify the quality features. Using a signal to noise response table, the impact of control parameters on wear rate and COF has been examined. These factors include load, sliding speed, and sliding distance. Using the signal to noise ratios acquired at various wear rate and COF parameter values, the process parameters for aluminum are ranked at 0%, 3.5%, and 7.0% of SiC, respectively. The sliding distance is a crucial effect in both wear rate and coefficient of friction after applying load and sliding speed. The statistical significance of the control parameters is seen in the Signal to Noise ratio. S/N ratios can be used to examine these experimental results and identify the optimal parameters that result in the lowest COF and wear rate. Pin on the disc setup and wear test specimens, as shown in figure 3 and figure 4.

Figure 3. Pin on Disc setup

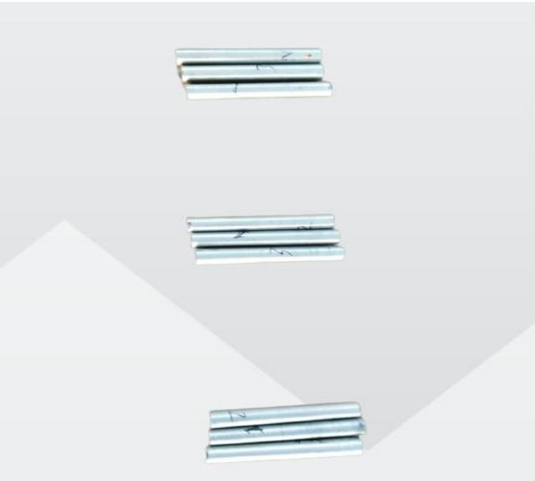

Figure 4. Wear Test Specimens

Table 3. Experimental result of wear test

S.No.	Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	Wear Rate(mm^3/m)	C.O.F	S/N ratio C.O.F	S/N ratio wear Rate
1	10	1.5	1000	0.0221	0.315	-78.2373	-73.5020
2	10	2.5	2000	0.0225	0.313	-82.6271	-79.2754
3	10	3.5	3000	0.0230	0.312	-71.8081	-82.3154
4	20	1.5	2000	0.0266	0.326	-73.5020	-78.2373
5	20	2.5	3000	0.0208	0.284	-79.2754	-82.6271
6	20	3.5	1000	0.0264	0.310	-82.3154	-71.8081
7	30	1.5	3000	0.0276	0.308	-82.9158	-80.9248
8	30	2.5	1000	0.0272	0.348	-70.5214	-72.5344
9	30	3.5	2000	0.0273	0.286	-75.8546	-76.8569

4. Results and Discussion

4.1 Effect of Wear Rate

The answer for S/N ratios is displayed in Table 4, and the most fluently decisive Control factor and ideal factor for SWR are found based on this information. Figure 5 illustrates the main influence of the control components, which will be further explained by examining the effects of each component on the SWR separately.. It was discovered that SWR wear rates increased as load and sliding velocity increased. It has been seen that when the sliding distance increases, the wear rate decreases.

Table 4 : Responses table for S/N ratio of Wear Rate

Level	Load (N)	Sliding velocity (m/s)	Sliding Distance (m)
1	-78.36	-77.55	-72.61
2	-77.56	-78.15	-78.12
3	-76.77	-76.99	-81.96
Delta	1.59	1.15	9.34
Rank	2	3	1

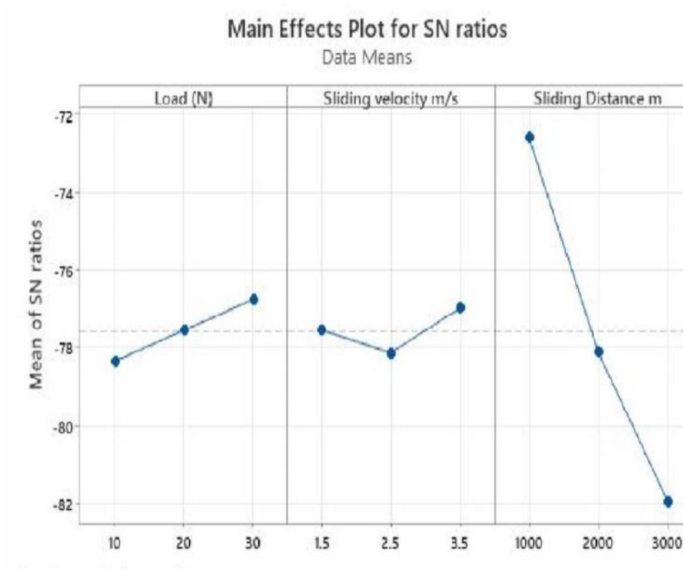

Figure 5: Main effects for plot for S/N ratios - wear rate

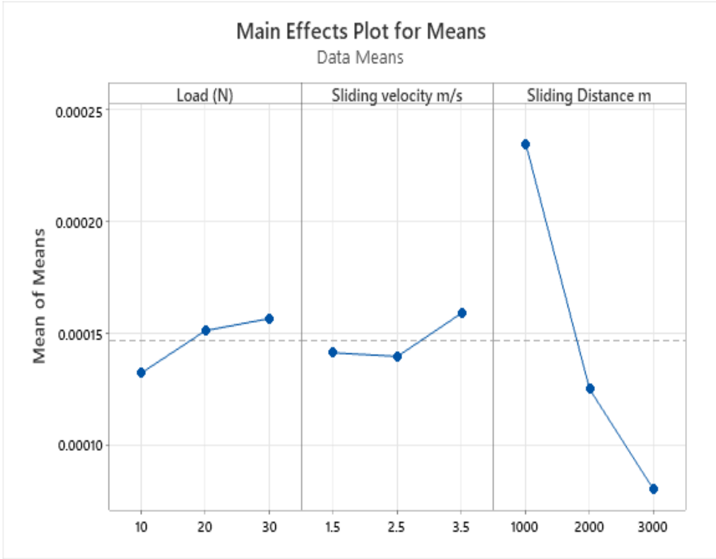

Figure 6: Main effects for plot for S/N ratios - coefficient of friction

4.2 Effect of Coefficient of Friction

The answer for S/N ratios is displayed in Table 5, and the most fluently decisive Control factor and the ideal factor for SWR are found based on this information. The primary impact of control parameters will be demonstrated by analyzing the effects of each individual factor on the SWR, as seen in Figure 6..It was found that when the weight and sliding velocity increase, so does the coefficient of friction of the SWR. It has been observed that the coefficient of friction reduces with increasing sliding distance. The parameters at their ideal state are shown in Table 6.

Table 5. Responses table for S/N ratio of coefficient of friction

Level	Load (N)	Sliding velocity m/s	Sliding Distance m
1	0.000132	0.000141	0.000235
2	0.000151	0.000140	0.000125
3	0.000157	0.000159	0.000080
Delta	0.000024	0.000019	0.000155
Rank	2	3	1

Table 6. Optimum level of parameters

S. No.	Parameter	Optimum level
1	Load	10 N
2	Sliding Velocity	2.5 m/sec
3	Sliding Distance	3000m

4.3 ANOVA Analysis

4.3.1 ANOVA of Wear Rate

Using ANOVA, the design features that had a significant impact on wear rate were found. Table 7 contains the wear rate ANOVA results. It was discovered that load had the largest statistical impact (11.79%) on the load wear rate of composites, followed by sliding distance (52.30%) and sliding Velocity (35.89%).When a parameter's P-value for this model is less than 0.05, it is considered statistically significant. Analyzing the information in Table 7 reveals how Sliding Distance and the proportion of SiC reinforcement affect the wear rate of composites.

Table 7. ANOVA Analysis of Wear Rate

Source	DF	Adj SS	MS	F Value	P Value	%
Load	2	16.654	8.3262	0.023	0.001	11.79
Sliding Velocity	2	5.584	2.7972	0.070	0.002	35.89
Sliding Distance	2	3.838	1.9197	0.102	0.006	52.30
Error	9	1.770	0.1968	-	-	-
Total	15	35.492		0.195		100

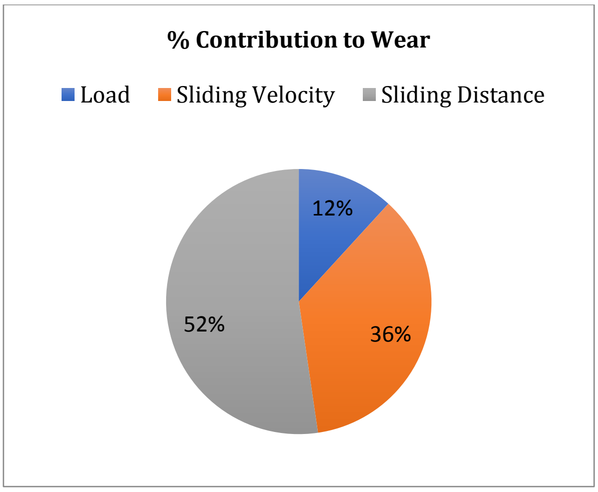

Figure 7. Percentage contribution of factors to wear

4.3.2 ANOVA of Coefficient of Friction

Table 8. ANOVA Analysis of Coefficient of Friction

Source	DF	Adj SS	MS	F Value	P Value	%
Load	1	72.00	36.00	0.64	0.001	11.18
Sliding Velocity	1	13.01	6.50	3.59	0.557	62.76
Sliding Distance	1	31.21	15.60	1.49	0.019	26.04
Error	23	46.68	23.34	-	-	-
Total	26	122.9		5.72		100

Table 8 shows the results of ANOVA for Cefficient of friction. It can be observed from the results obtained that Load was the most significant parameter having the highest statistical influence (62.76%) on the sliding Velocity of composites followed by Sliding distance (26.04%) and load (11.79% .When the P-value for this model is less than 0.05, then the parameter can be considered as statistically significant. From an analysis of the results obtained in Table 8, it is observed that the effect of sliding velocity is influencing wear rate of composites.

5. Conclusion

The development of an aluminum alloy with various reinforcements added at varied volume percentages served as the foundation for the current study. The created composites were intended to maximize wear and coefficient of friction by the application of the Taguchi method. Based on the response table of S/N ratio and Mean, it was found that the optimal set of parameters for improved wear behavior of the Al6061-SiC composite were Load 10N, Sliding Speed 2.5 m/sec, and Sliding Distance 3000m.The most important factor is found to be Sliding distance, which contributes 52.30% to wear rate. The next significant element was found to be the sliding Velocity and load, which contributed 35.89% and 23.32%, respectively, to the wear rate.

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Author contributions

Sathiyaraj Subramanian: Conceptualization, Methodology, Material selection , Fabrication.
Venkatesan Sendrayan: Experimental Testing, Writing-Original draft preparation, Results and Discussion .
Kumaran Pachaiyappan: Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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