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Research Article

Study of Wear Behavior on AA6061 Reinforced with Hybrid Ceramic Composites through Optimization

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This present work uses the three main components for alloying, silver nitrate, aluminium nitride, and titanium diboride. Stir casting was used to make AA 6061 composites with varying weights of 0, 3, 6, 9, and 12%. Microhardness, tensile strength, and compressive strength of produced composites were evaluated. Several wear tests were performed on the composites to measure their resistance to abrasion and erosion. The mass loss was calculated because of wear testing. Conventional and unconventional methods like the Taguchi technique and analysis of variance were employed to study and analyze the abrasive and erosion wear test outcomes to obtain better wear resistance for different weight % of AA 6061 compounds and to investigate the most important input and output characteristics employing the said optimal strategies. Reinforcement percentages were raised to improve mechanical quality.

1. Introduction

AMCs offer superior mechanical qualities, including thermal stability, high elastic modulus, and tensile strength over monolithic aluminium alloys and outstanding wear resistance properties in various situations, as evidenced by some recent research studies [1]. There are many applications in the automotive industry, which uses composite materials [2] that require sliding and abrasive characteristics of the materials [3]. Reinforcing particles include carbides, oxides, or nitrides and are responsible for the response between gas cavities and metal alloying components. Nonferrous metals are frequently employed as the matrix material [4], and the dispersion of particles ensures that the composite is chemically and thermodynamically stable. It is thought that casting is the best way to produce composites [5, 6]. In the stir, reaction was used to create successful interactions between the matrix and reinforcing particles. Aluminum nitride (AlN) is an ideal diffusing reinforcing particle for Al alloys, which have good strength, thermal stabilization, and thermal expansional coefficient [7]. When combined with a suitable ceramic particle, silver nitrite ($AgNO_3$) yields aluminium matrix compounds and titanium diboride (TiB_2), two materials that have high heat stability, electrical stability, and erosion and corrosion resistance [8, 9]. Together, these materials make up a class of materials known as high-heat and electrical stability ceramics. These composites were studied for their mechanical qualities like hardness, ultimate tensile strength, and ultimate compressive strength, as well as for their metallurgical characteristics, for instance, microstructure with varying weight % of strengthening in the in-stir composites [10–13]. In addition, the abrasive and erosion behaviours were examined under several testing settings, as well as the result findings were optimized using the Taguchi method, ANOVA [14, 15].

2. Materials and Methodology

2.1. Manufacture of AA 6061 Composites. Because of its reduced cost and higher adaptability, AA6061 is frequently used along with copper. The improved mechanical properties of AA6061 can benefit heating and thermal applications such as aviation, vehicle parts, and so on. An aluminum 6061 alloy was chosen as the matrix material for this experiment. There are many materials that can be used to make composites, including silver nitrite ($AgNO_3$), aluminium nitride, and titanium diboride (TiB_2). It is possible to make K2ZrF6 and KBF4 with the two TiB_2 powders. We next combined various weight percentages of the matrix material (AA 6061) with reinforcing powders ($AgNO_3$, AlN, and TiB_2) in wt% of 0, 3, 6, 9, and 12%. The weight of the matrix material was used to determine the number of reinforcements. It is possible to follow this technique for 6, 9, and 12 wt% during stir casting; the specifics are shown in Table 1 for a 1 kilogram matrix and reinforcement applied at a 2% rate, resulting in the addition of 20 g of reinforced particles. Module dimensions were met for abrasion testing.

2.2. Mechanical and Metallurgical Characteristics. The mechanical characteristics of AA 6061 compounds were determined by pressing the samples after they had been formed at various weights %. Using a Micro Vickers Hardness machine in accordance with ASTM accordance of E10-07, hardness values were acquired for every weight % of the specimen. The typical indent load was set at 0.5 kg for a duration of 25 s. Each sample had a different distribution of hardness levels, which could be found in several places [16, 17]. Depending on the quantity of reinforcement, five different specimens were employed in the experiment. Reinforcements of varying amounts were utilised to determine the composite samples' UTS, and the experiment was carried out with universal testing equipment in line with the ASTM E08-8 standard. Using 1200 grit SiC emery paper, we were able to minimize scratches and surface flaws on the samples [18]. The load was 10 kN, and the crosshead velocity was 2.5 m/min during the test. The ultimate compression strength of aluminum alloy 6061 compounds with varied reinforcing quantities was determined by the ASTM E09-9 standard [19]. Computerized universal testing equipment was used to conduct the test. The ultimate compression strength was determined using five specimens. The AA 6061 composites were examined under an optical microscope in accordance with the ASTM standard to determine their metallurgical composition and are discussed in the results and discussion.

2.3. Test for Abrasive Wear. Aluminum alloy 6061 compounds with weight % were measured using an abrasive jet machine (AJM) in this study. This experiment utilised a nozzle to spray an abrasive stream at high speed. There have been previous studies on the wear resistance of AA 6061 samples using the POD equipment with room and high temperature settings, and the titles are shown below; a different technique of the abrasive jet machine was employed to determine the wear resistance. Figure 1 depicts the schematic diagram of the abrasive jet machine.

Because the parameters could be precisely controlled, this machining approach differed from others used for ordinary sandblasting. Aside from cutting and milling hard and brittle materials, the AJM was commonly used to cut and manufacture workpieces. Abrasive particles are made of $AgNO_3$ and aluminium nitride (AlN). In order to determine the mass loss of the AA 6061 compound specimens, the common values were used as input parameters. Table 2 lists all the input parameters.

2.4. Erosion Wear Test. As a result of the tiny particles in semisolid conditions, slurry erosion wear produces gradual material loss. In a slurry erosion test, AA 6061 composites with varying weight % of reinforcement (0, 3, 6, 9, and 12) were used. The samples were damaged by the impact of hard particles during this test, and mass loss originated in the specimens at different input values [20–22]. A variety of slurry mixtures were tested in the erosion test. A spinning spindle was used to hold the pot with the slurry and the sample.

It was found that the sample lost mass regardless of how fast the spindle rotated or how long it was submerged in a slurry. The slurry erosion tester is shown in Figure 2, and the input parameters for the slurry erosion test are listed in Table 3.

2.5. Optimization Techniques. Optimizing the findings was performed using two different strategies with the Taguchi method and ANOVA. Software like MINITAB and MATLAB was responsible for creating the methodologies. It was discovered that the most influencing process parameters in abrasive and erosion tests were identified utilizing the Taguchi method. For the Taguchi design, a total of five elements were used in five different level designs, resulting in a total of 25 tests. The final result of the testing was a reduction in bulk. ANOVA methodologies were used to determine the percentage of every procedure variable's contribution to abrasive and erosion tests [23]. The AA 6061 composites were subjected to abrasion and erosion testing in this study. The different weight percentages of reinforcements were used to identify test results [24]. The samples were evaluated under various input settings, and both outcomes were influenced by those variables. Conventional and unconventional methodologies were utilised to find the finest input impacted variable, the most contributed variable, the finest and average values of input and output outcomes, and the finest specimens between the different weight % of reinforcements.

Table 1: Weight percentages of AA6061 and its reinforcements.

S. No	AA 6061 (kg)	Reinforcements			Weight percentage (wt%)
		Silver nitrite ($AgNO_3$) g	Aluminium nitride (AIN) g	Titanium diboride (TiB_2) g	
1	1	0	0	0	0
2	1	30	30	30	3
3	1	60	60	60	6
4	1	90	90	90	9
5	1	120	120	120	12

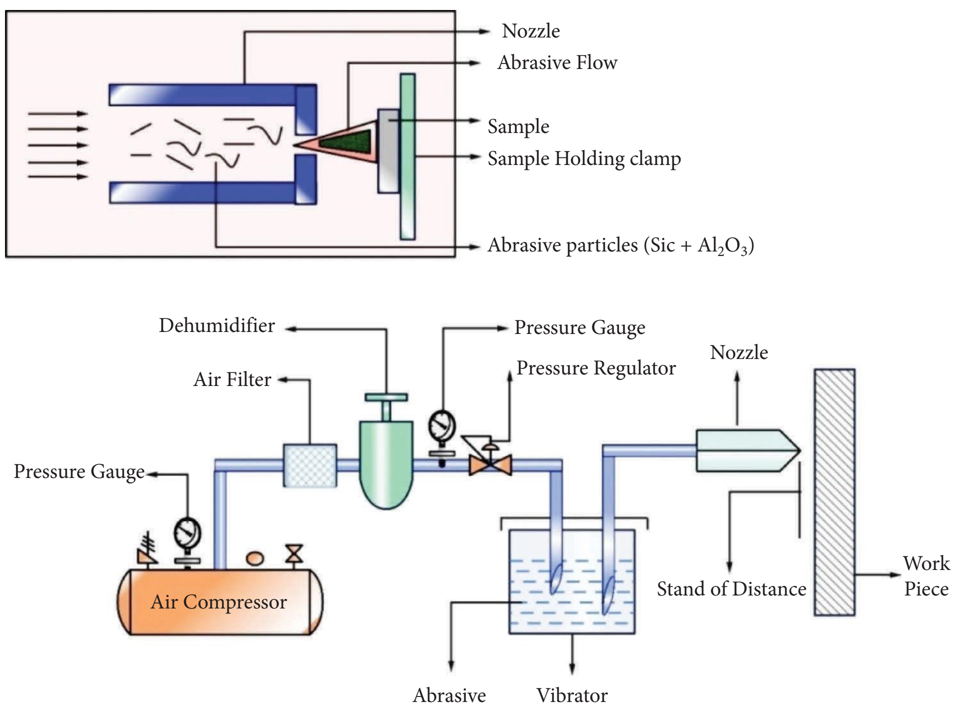

Figure 1: Flow diagram of the abrasive jet machine.

Table 2: Abrasive wear's input factors.

S. No	Input factors	Range
1	Composite weight (%)	0, 3, 6, 9, 12
2	Abrasive grain size (μm)	25, 50, 75, 100, 125
3	Abrasive flow rate (g/min)	10, 15, 20, 25, 30
4	Velocity (m/min)	200, 250, 300, 350, 400
5	Time (sec)	25, 50, 75, 100, 125

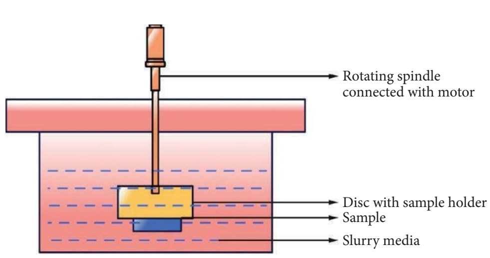

Figure 2: Slurry erosion tester.

Table 3: Erosion wear test's input parameter.

S. No	Input parameters	Range
1	Composite weight percentage	0, 3, 6, 9, 12
2	Addition of sand in slurry (wt%)	25, 50, 75, 100, 125
3	Speed (rpm)	200, 250, 300, 350, 400
4	Time (sec)	25, 50, 75, 100, 125

3. Result and Discussion

3.1. Analysis of Mechanical and Metallurgical Characteristics. This study used mechanically imposed reinforcement sample concentrations of AA 6061 at wt% weight percentages of 0, 3, 6, 9, and 12. The AA 6061 composite mechanical testing results are shown in Table 4. The in-stir technique used in this composition ensured a standardized circulation of strengthening particles throughout the matrix. Reinforcements have the greatest impact on the composites' hardness and tensile strength [25]. Compounds have an interface because of the strong interfacial

Table 4: Results of mechanical properties.

Reinforcement (wt%)	Tensile strength (MPa)	Vickers hardness (HV)	Compressive strength (MPa)
0	439	125	369
3	472	142	378
6	483	148	402
9	491	159	405
12	488	182	408

bond between the matrix and reinforcements. Dislocations are prevented from moving by the reinforcing particles, such as AlN and TiB_2. It was possible to avoid cracks in the composite structure because of the strong bonding, and the reinforcements were also limited by plastic deformation [26]. As plasticity is restricted, the strength of the AA 6061 composites is increased. It was forbidden to increase the volume fraction of reinforcing particles at the highest wt% of composites due to a decrease in the matrix's fluidity. Increased reinforcing particles, in turn, boosted mechanical characteristics.

Composite samples with different percentages of reinforcement were examined under an optical microscope for their microscopic structure. Observing the construction reveals that the reinforcements were mixed and placed uniformly and that the reinforcements were successfully attached to the matrix [27]. Interfacial bonding was created between the grains because of the in situ production. Because of this, oxidation in the matrix can be prevented. Due to the in situ approach of reinforcing particles, floating and sinking in the composite structure were reduced. Due to the high temperature synthesis of composites, the reinforcements were spread in the AA 6061 matrix; the addition of AlN particles seems to enhance oxidation for some reason, possibly due to nitride's increased oxygen concentration. Some oxidation occurs because of the increase in AlN during this phase. The bonding between the two matrixes and reinforcements had a positive effect.

3.2. Analysis of Optimum Results

3.2.1. Taguchi Technique-Abrasive Wear. Using the Taguchi technique, the abrasive and erosion wear of different input factors was calculated. With the AA 6061 composites, an L_{25} orthogonal array was used in varied wt% of composite samples for wear testing (0, 3, 6, 9, and 12) and is shown in Table 5. The MINITAB software was used to create a Design of Experiments (DOE) for the abrasive wear testing of 25 AA 6061 composite samples. In total, there were five factors: composite (wt%), abrasive granular size, flow rate (g/min), velocity, and duration, and each parameter had five trials; the total came to 25 readings; mass loss (g) was measured as the resulting factor for the wear test. This method was used to determine which process parameters had the greatest impact. The decrease in mass loss was seen as the outcome of the increase in reinforcement. AA 6061 composites are resistant to wear owing to their higher bonding strength and low plastic distortion. Compounds with mass losses of less than 12% were found to be the most stable in employed circumstances of 60 mm abrasive particle size, 10 g/min flow rate, 150 m/s velocity, and 150 s duration.

3.2.2. Taguchi Method-Erosion Wear. It was determined that mass loss (g) was a result of four separate parameters: the sample (wt%), the addition of sand (wt%), time (*s*), and speed (rpm). The L_{25} orthogonal array is also used for the erosive wear test. Every five-weight percent of the composite is run through five times. During erosive wear, there is no influence of the particles on the surface of the composite. A high-reinforced composite (12%) removed the least material during erosive wear tests. The AA 6061 composite had a material removal of 0.82701 g, less than 12% of the regulated input parameters of 50 weight %trappings of sand, 250 rpm speed, and 125 s time in erosion testing. Table 6 shows the outcomes of the input and output, and the main effect plots for the means and S/N ratio are shown in Figures 3 and 4.

3.2.3. S/N Ratio-Abrasive Wear. It was possible to determine the S/N and data means using the MINITAB software. Tables 7 and 8 display the response data for the mean and S/N ratio. Results using statistical software were obtained using AA 6061 composites in abrasive wear tests with diverse input circumstances and materials. It was possible to isolate the mean values for each of the input parameters. Based on the DOE, the mean values can vary. An abrasive wear test was used to classify the relative significance of various procedure aspects, and the results of the data mean and S/N ratio demonstrate the same. The data mean and S/N ratios are provided in the main effect charts.

3.2.4. Signal to Noise Ratio-Erosion Wear. The AA 6061 composites tested in erosion wear had the lowest material removal of the 12% composites. The wt% of particles added and the speed and time at which they were added were both varied. There was some microslicing and plowing at various shallow angles as the tiny particles came into contact with the composite surfaces. Figures 5 and 6 show data means and S/N ratios, respectively, and are included in Tables 9 and 10 of this section.

3.2.5. Analysis of Variance-Abrasive Wear. It is possible to analyze the relative importance of every process variable by performing an analysis of variance. There were five different variables taken into account when performing the abrasive wear test in this study. As shown in Table 11, composite weight (85.04%), duration (3.66 seconds), velocity (m/min) 3.78%, flow rate (3.57 g/m), and grain size (mm) 2.64% make

Table 5: With L_{25} orthogonal array, the input and output factors of abrasive wear.

S. No	Composite wt %	Granular size (μm)	Flow rate (g/min)	Velocity (m/min)	Time (s)	Mass loss (g)
1	0	25	10	200	25	0.02148
2	0	50	15	250	50	0.02607
3	0	75	20	300	75	0.03128
4	0	100	25	350	100	0.04542
5	0	125	30	400	125	0.04502
6	3	25	10	300	100	0.01824
7	3	50	15	350	125	0.01916
8	3	75	20	400	25	0.01824
9	3	100	25	200	50	0.01608
10	3	125	30	250	75	0.017238
11	6	25	10	400	50	0.01357
12	6	50	15	200	75	0.01114
13	6	75	20	250	100	0.01228
14	6	100	25	300	125	0.01268
15	6	125	30	350	25	0.01140
16	9	25	10	250	125	0.01050
17	9	50	15	300	25	0.00750
18	9	75	20	350	50	0.00105
19	9	100	25	400	75	0.00464
20	9	125	30	200	100	0.00458
21	12	25	10	350	75	0.00345
22	12	50	15	400	100	0.00468
23	12	75	20	200	125	0.00348
24	12	100	25	250	25	0.00367
25	12	125	30	300	50	0.00442

Table 6: With the L_{25} orthogonal array, the input and output factors of erosion wear.

S.No	Composites wt %	Adding of sand (wt %)	Time (S)	Speed (rpm)	Mass loss (g)
1	0	25	25	250	1.9836
2	0	50	50	500	1.48168
3	0	75	75	750	1.48049
4	0	100	100	1000	1.47327
5	0	125	125	1250	1.56055
6	3	25	100	250	1.33038
7	3	50	125	500	1.30363
8	3	75	25	750	1.32692
9	3	100	50	1000	1.37877
10	3	125	75	1250	1.22701
11	6	25	50	250	1.28103
12	6	50	75	500	1.24642
13	6	75	100	750	1.28642
14	6	100	125	1000	1.17507
15	6	125	25	1250	1.16803
16	9	25	125	250	1.18561
17	9	50	25	500	1.17841
18	9	75	50	750	1.02404
19	9	100	75	1000	1.01727
20	9	125	100	1250	1.08865
21	12	25	75	250	1.04782
22	12	50	100	500	0.97210
23	12	75	125	750	0.95249
24	12	100	25	1000	0.98721
25	12	125	50	1250	1.02161

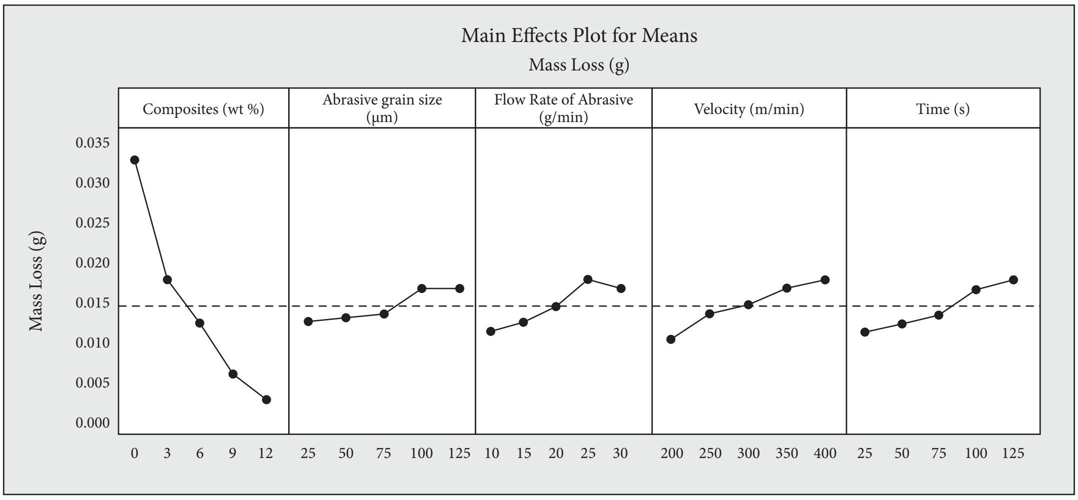

Figure 3: Main effect plots for means.

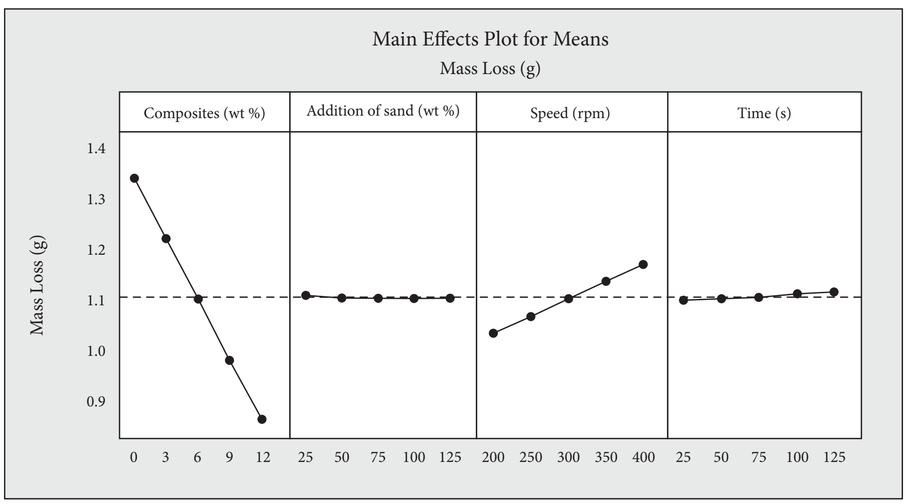

Figure 4: Main effect for the S/N ratio.

Table 7: Mean's response table (abrasive wear).

Level	Composite (wt%)	Granular size (μm)	Velocity (m/min)	Flow rate (g/min)	Time (s)
1	0.042586	0.023819	0.021420	0.021350	0.02426
2	0.027839	0.023798	0.023450	0.023420	0.02345
3	0.022198	0.024778	0.025130	0.024758	0.02432
4	0.01563	0.026698	0.025900	0.026985	0.02619
5	0.014139	0.026692	0.027659	0.027641	0.02798
Delta	0.040543	0.003894	0.017946	0.006998	0.01658
Rank	1	5	2	4	3

Table 8: S/N ratio's response table (abrasive wear).

Level	Composite (wt%)	Granular size (μm)	Flow rate (g/min)	Velocity (m/min)	Time (s)
1	30.18	40.15	41.96	43.01	41.08
2	36.42	40.18	42.15	40.56	40.57
3	40.15	41.38	41.05	40.53	40.43
4	46.72	41.09	39.63	40.68	40.16
5	51.68	41.06	40.21	40.41	39.06
Delta	51.64	2.05	3.78	3.69	3.02
Rank	1	5	3	2	4

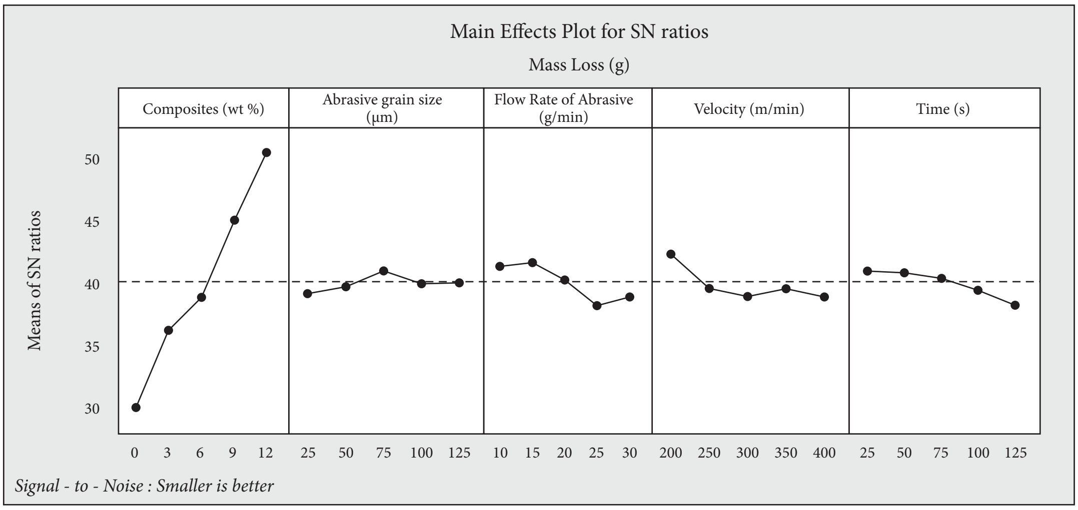

Figure 5: Main effects plot for means.

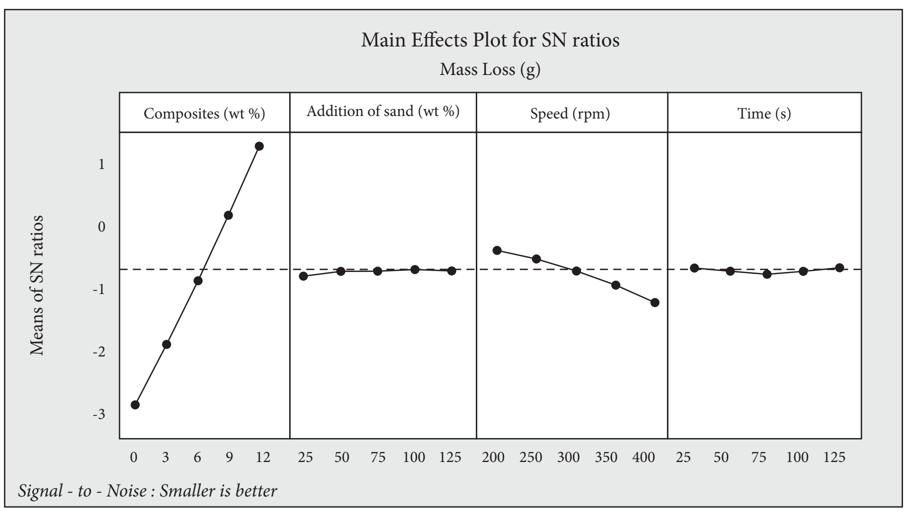

Figure 6: Main effect for the S/N ratio.

Table 9: Mean's response table (erosion wear).

Level	Composites (wt%)	Adding of sand (wt%)	Speed (rpm)	Time (s)
1	2.3582	2.1624	2.0765	2.1160
2	2.2386	2.1241	2.0864	2.1880
3	2.6145	2.6124	2.1612	2.1611
4	1.9398	2.1242	2.1683	2.1431
5	0.9572	2.6101	2.1565	2.1710
Delta	0.5370	0.0030	1.1800	0.9901
Rank	1	4	2	3

Table 10: S/N ratio's response table (erosion wear).

Level	Composites (wt%)	Adding of sand (wt%)	Speed (rpm)
1	−3.6021	−0.9753	−0.4845
2	−2.8642	−0.9376	−0.6898
3	−1.9316	−0.8834	−0.9519
4	0.7462	−0.8859	−2.1926
5	2.6716	−0.9128	−2.4207
Delta	4.7596	0.1874	0.9744
Rank	1	3	2

up the majority of the ANOVA results, and the best result is shown in Figure 7.

3.2.6. Analysis of Variance-Erosion Wear. ANOVA was utilised to determine the percentage of every processing variable that was studied in erosion wear. The composite contribution of 94.99% has the highest percentage of success, according to the findings. Depending on the operating conditions, different input parameters are affected. A speed (rpm) of 4.95% contributes to the erosion test because the disc speed is also being adjusted presently. Samples were exposed to higher concentrations of particles. Time (s) contributes less than 0.05%, while sand addition contributes less than 0.0017%. According to the preceding data, just 8% of the composite had a significant quantity of material

Table 11: ANOVA results (abrasive wear).

Source	DoF	Adj.SS	Adj.MS	F
Composite (wt%)	4	0.003142	0.000813	33.18
Velocity (m/min)	4	0.000229	0.000028	2.34
Time (s)	4	0.000262	0.000027	2.83
Flow rate (g/min)	4	0.000232	0.000027	2.54
Grain size (μm)	4	0.000108	0.000018	0.49
Error	4	0.000051	0.000009	—
Total	24	0.004483	—	—

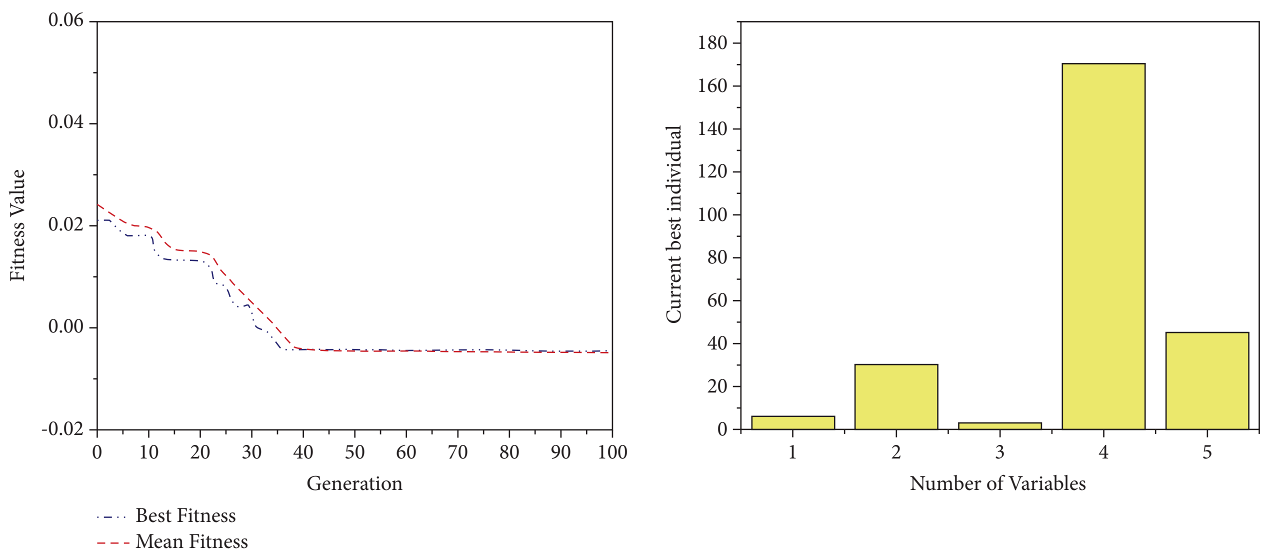

Figure 7: Best and mean values of output results of abrasive wear.

Table 12: ANOVA results (erosion wear).

Source	DoF	Adj.SS	Adj.MS	Percentage of contribution	Rank
Composites (wt%)	4	0.70872	0.28471	94.0772	1
Speed (rpm)	4	0.16345	0.01021	5.86	2
Time (s)	4	0.00048	0.00010	0.06	3
Adding of sand (wt%)	4	0.00001	0.00004	0.0028	4
Error	4	0	0	0	
Total	24	0.87266	—		

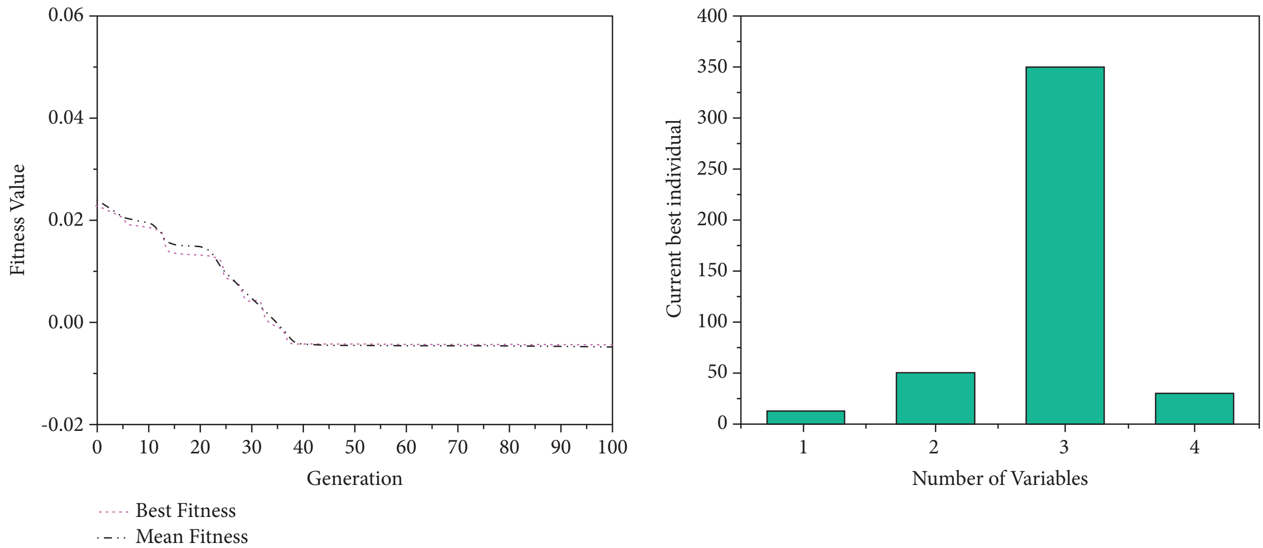

Figure 8: Best and mean values of output results of the erosion wear test.

removed, and the test outcome confirmed this. Table 12 indicates the outcomes of the erosion tests, and the best result is shown in Figure 8.

4. Conclusions

By using a stir casting technique, the strengthened particles were able to be formed for the composite preparation, and the following results were achieved:

(i) Because of their tensile strength, AA 6061 compounds in varied weight % had good bonding strength, reducing plastic deformation in the composites, which are achieved using an in situ technique, which binds particles together. Reinforcements increased mechanical qualities.

(ii) After being subjected to abrasion and erosion tests, surfaces were inspected. In abrasive wear testing, fine scratches and grooves are detected when minute particles come into contact with the composites' surface. With just 12% strengthening in AA 6061 compounds, the wear rate is practically nonexistent. Work-hardened layers formed on the composite surfaces during erosion at increasing velocities.

(iii) To further understand the relationship between the abrasive and erosion processes, Taguchi and ANOVA analyses were used to determine the most significant process variables. Specimen speed, time, flow rate, and abrasive granular size ranked highest in the abrasion test. Composites made up 85.04% of the total, followed by speed (m/min) 3.78%, time (s) 3.66%, abrasive flow rate (g/min) 3.57%, and also grain size (mm) 2.64%.

(iv) The most significant factors in the erosion test were the reaction of the mean of compounds, speed, time, and sand addition. Process parameters were discovered to be ordered compounds of 94.99%, speed (rpm) 4.95%, time 0.05%, and the addition of sand 0.0017% based on ANOVA's percentage contribution.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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