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Parametric Optimization of COF of Fabricated AA6082/Si_3N_4/C/Al_2O_3 Composite

Dhananjay Kumar[1], Yashpal[1], Ratnesh Kumar Sharma[2,*]

Abstract

In the present experimental investigation AA6082/Si3N4/C/Al2O3 composite was successfully fabricated using stir casting technique combined with electromagnetic stirrer for wear resistance applications. The produced AA6082/Si3N4/C/Al2O3 composite exhibits improved tribological and me-chanical and properties, according to the experimental results. The generated composite has a micro-hardness range of 60 to 110 HV and an average UTS of 150 to 200 MPa. The tribological performance was evaluated using a pin on disc tribometer. The tribometer yields a COF reading be-tween 0.15 and 0.4 for test circumstances of load between 10N and 30N, temperature between 50oC and 100oC, and sliding velocity between 0.1 m/s and 0.3 m/s, respectively. Taguchi L9 OA was also used in the present investigation for optimization of COF of fabricated AA6082/Si3N4/C/Al2O3 composite. The percentage contribution of fabricated composite for COF was highest for velocity (76.37%) followed by 12.84 % temperature and 7.31 % load. The following are the predicted ideal values for the 95% confidence interval for COF for the fabricated AA6082/Si3N4/C/Al2O3 composite. 0.86 μ < 0.134 for CICE and CIPOP: μ < 0.0126 < 0.094

Keywords: AA6082/Si_3N_4/C/Al_2O_3 composite; SEM-EDAX; COF; Taguchi

INTRODUCTION

Important advancements in IC engine tribological performance these days are closely linked to surface geometry optimization, lubrication enhancement, and the use of composite materials and unusual coatings. Among engine components, piston rings are particularly important since friction causes 40–45% of the energy to be lost. The piston assembly's tribological performance has a significant impact on fuel economy, harmful exhaust emissions, and power loss. The research reports that surface topography [2–3], metal matrix composite [5], surface modification [4], and lubrication regime adjustment [1] are the most common methods used to improve the performance of piston components. Metal matrix composites are essential to the advancement of engineering science and technology in the modern world due to the growing demand for advanced materials. Most people are aware of the exceptional properties of metal matrix composites, including their high strength, stiffness, resistance to wear, and capacity for damping [6]. Reinforcements are added to the metal matrix of a metal matrix composite to improve the microstructural behavior or to achieve certain mechanical and customized qualities. Reinforcing particles like carbon, BN, Al2O3, TiO2, B4C, Si C, and so on are included in the reinforcement phase [7]. Due to its exceptional mechanical, tribological, and specific modulus, aluminum-based metal matrix composites (MMC) are extensively utilized in both industrial and research settings [7-8]. The mechanical properties of the manufactured AMC are examined by Tyagi et al. [9], who demonstrate improvements in tensile strength

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and hardness. Examining COF and wear of Si C reinforced composite, Mishra et al. [10] came to the conclusion that COF and wear rate of composite material reduce as the weight percentage of Si C grows, up to a certain point, and then increase as the weight percentage of Si C increases.I n a different study, Yadav et al. [11] looked at the behavior of an Al/Si C/Al2O3/fly ash based composite. According to the experimental results, the weight percentage of flyash gives push to the composite material's hardness and wear resistance. Composites experimental result demonstrates that the size and orientation of the grains have a significant impact on the composite material's enhanced capabilities. When compared to fine grain particles, the coarse flyash particles have superior wear resistance qualities, according to research by Kumar et al. [12]. The Research on the aluminium reinforced Si C composite by Maleque et al. [13] indicates that the addition of Si C particles to the matrix improves the tribological capabilities of composite materials.

According to Tyagi et al.'s [5] analysis of the behaviour of manufactured AA6082/Si3N4 Composites, density dislocation in the matrix causes the tensile strength and hardness of the composites to increase with regard to increment in weight % of Si3N4. Even yet, the recent work on ceramic and polymer particles is encouraging for both business and scholars. Composites made of ceramic materials with a metal matrix may have high mechanical, thermal, electrical, and tribological characteristics [14, 15].

The use of electromagnetic stirrers in combination with stir casting techniques to create composites such as AA6082/Si3N4/C/Al2O3 is currently lacking in study. A lot of promise was presented by the fabrication of AMC with enhanced mechanical and tribological characteristics with the use of Si3N4/C/Al2O3 reinforcement and an electromagnetic stirring technique. In the current work, the COF of the produced AA6082/Si3N4/C/Al2O3 composite was additionally optimised using Taguchi L9 OA.

Experimental Procedure

In the current work, the AA6082/Si3N4/C/Al2O3 composite was made using the stir casting method and an electromagnetic stirrer. AA6082 rods were cleaned with acetone, chopped into small pieces, and then melted in a crucible within an electric muffle furnace that was heated to 850 degrees Celsius. The crucible was continually supplied with argon gas to prevent contamination of the melt in order to produce high-quality composite material. After AA6082 melted, the heated Si3N4/C/Al2O3 particles were added to the melt. The melt of Si3N4/C/Al2O3 particles and AA6082 was continuously swirled for 15 minutes at a speed of 200 rpm using a mechanical stirrer. The ASTM E-8 guidelines were followed in the preparation of the UTS test specimens. Tests with an indentation duration of 20 seconds, a dwell period of 5 seconds, and a maximum applied stress of 1000mN on the stylus were conducted using the micro hardness tester with diamond stylus.

Table 1 displays the created composite experiment design for COF that was chosen for the Taguchi approach. In the present instance, three levels and three process factors were studied for nine different compositions. The produced AA6082/Si3N4/C/Al2O3 composite yielded 27 Taguchi L9 OA test results after each composition was tested three times. These findings allowed for the examination of the impacts of factors on COF, as shown in Table 2.

Table 1. Taguchi's Method for Design of experiments of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite

Parameters	Factors	Level 1	Level 2	Level 3
Temperature (ºC)	a	150	175	200
Sliding Velocity (m/s)	b	0.15	0.25	0.35
Load (N)	c	30	40	50

Table 2. Test Result of Taguchi L_9 OA of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite for COF

Composite compositions	Temperature (ºC)	Sliding Velocity (m/s)	Load (N)	COF			S/N ratio (db)
				Test 1(T1)	*Test 2 (T2)*	*Test 3 (T3)*	
1	150	0.15	30	0.45	0.45	0.45	6.86

2	150	0.25	40	0.3	0.3	0.3	8.87
3	150	0.35	50	0.1	0.1	0.1	14.89
4	175	0.15	40	0.32	0.34	0.34	8.71
5	175	0.25	50	0.32	0.32	0.34	9.71
6	175	0.35	30	0.2	0.2	0.22	13.68
7	200	0.15	50	0.28	0.28	0.28	11.05
8	200	0.25	30	0.3	0.32	0.32	10.07
9	200	0.35	40	0.16	0.16	0.15	16.09
T (∑ COF) = 0.32							

DISCUSSION AND RESULTS

Cof

Figure 1 shows the COF variation for the manufactured AA6082/Si3N4/C/Al2O3 composite. The composition 9 shows a minimum coefficient of friction (C/F) of 0.15 at 100°C, 20 N of weight, and 0.3 m/s of sliding velocity (SV). In contrast, composition 1 shows a maximum COF of 0.46 at 50°C, 0.1 m/s of SV, and 10 N of load. The COF result demonstrates that there was uniform mixing and strong bonding strength between the Si3N4/C/Al2O3 particles and the matrix alloy [14–20]. The experimental study came to the conclusion that the production of oxides and nitrides causes the COF of the manufactured composite to decrease as test circumstances of process parameters rise [5, 7]. The materialisation of displacement density in the current situation leads to a decrease in grain size when the formed composite solidifies, which might result in a decline in COF [5, 20–26]. The primary impacts of the AA6082/Si3N4/C/Al2O3 composite, which was made for COF, are shown in Table 3. For every parameter at every level, the S/N ratio is calculated and plotted in Figure 2.

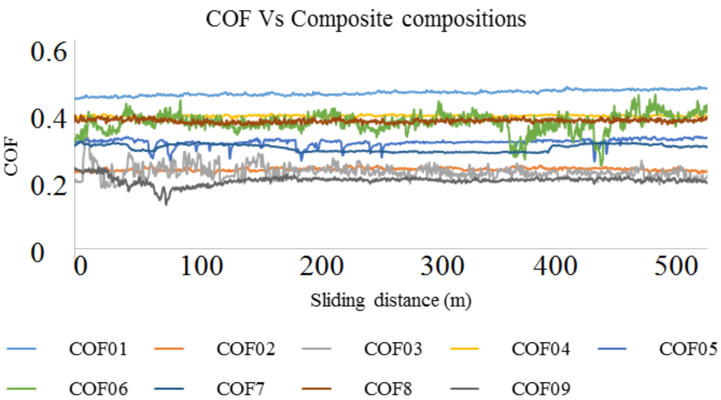

Figure 1. Variation of COF with composite compositions of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite

Table 3. Substantial outcome and average values of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite for COF

Parameter	**Level**	**Temperature**		**SV**		**Load**	
Data		RD	S/N	RD	S/N	RD	S/N
Average values (weight loss)	L1	0.33	10.21	0.36	8.87	0.32	10.21
	L2	0.3	10.70	0.33	9.55	0.29	11.22
	L3	0.25	12.41	0.18	14.89	0.26	11.88
Substantial outcome of weight loss	L2-L1	-0.03	0.49	-0.3	0.67	-0.03	1.01
	L3-L2	-0.05	1.70	-0.15	5.33	-0.03	0.66
Difference (L3-L2) (L2-L1)		-0.01	1.21	-0.11	4.66	-0.002	-0.35

Figure 2(a) shows the temperature fluctuation of the constructed AA6082/Si3N4/C/Al2O3 composite. The result shows that when the composite that was made at 100 OC was linked to 50 OC and 75 OC, its COF was lowest. The S/N ratio was lowest at 50OC when the created AA6082/Si3N4/C/Al2O3 composite was subjected to 75OC and 100OC temperatures. At the 100 OC temperature threshold, the manufactured composite's improved S/N value and lower COF lead to perfect test results with less noise and more signal.

Figure 2(b) shows that the COF of the created AA6082/Si3N4/C/Al2O3 composite decreases as the sliding velocity rises. The lowest COF was reached at the maximum sliding velocity of 0.3 m/s, while the highest COF was achieved at the lowest sliding velocity of 0.1 m/s. Starting at 0.1 m/s, the S/N ratio of the fabricated AA6082/Si3N4/C/Al2O3 composite grew as the sliding velocity increased.

As seen in Figure 2(c), the COF of the produced AA6082/Si3N4/C/Al2O3 composite fluctuates with load. The result shows that the produced composite's COF at a 30 N load was the lowest when compared to 10 N and 20 N loads. The manufactured AA6082/Si3N4/C/Al2O3 composite had the lowest S/N ratio at 10 N when subjected to 20 N and 30 N stresses. The produced composite shows optimum test results with less noise and greater signal at 30 N load, as seen by its lower COF and higher S/N ratio.

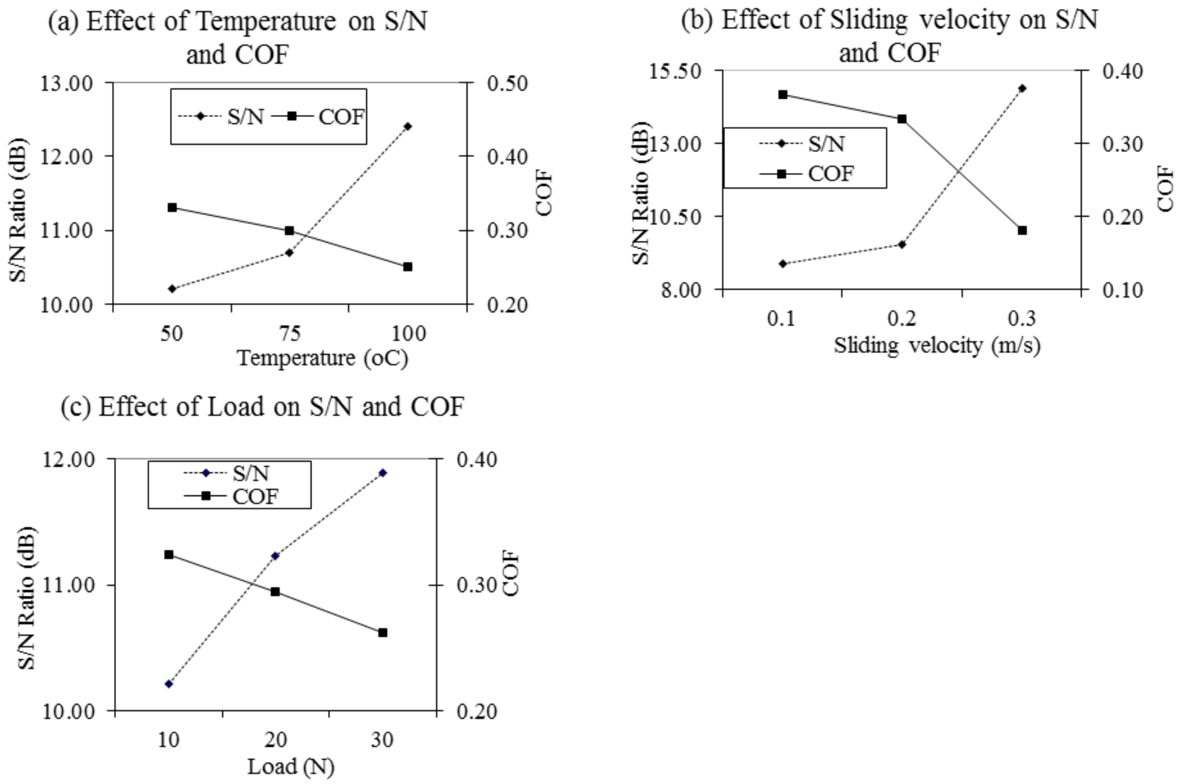

Figure 2. Shows the COF deviation using the following parameters: temperature (OC), sliding velocity (m/s), and load (N) in order of priority.

To enhance the manufactured AA6082/Si3N4/C/Al2O3 composite's performance, a reduced importance of COF was pursued using the superior form prominent physical features. The most advantageous COF was obtained at level 3 of parameters a, b, and c, as Figure. 1 illustrates. The COF of the produced AA6082/Si3N4/C/Al2O3 composite was analysed, and the ANOVA approach was used to analyse the impacts of each component. Table 4 shows the pooled ANOVA of the produced AA6082/Si3N4/C/Al2O3 composite for COF. It was immediately evident that variables A, B, and C of

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the artificial AA6082/Si3N4/C/Al2O3 composite had a considerable impact on the COF mean and variance values. The AA6082/Si3N4/C/Al2O3 composite that was made had the highest percentage of velocity (76.37 percent), followed by temperature (12.84 percent) and load (7.31%).

Table 4. Pooled ANOVA of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite for COF

Source	SS		DOF		V		F-Ratio		SS'		P (%)	
	RD	***S/N***	***RD***	***S/N***	***RD***	***S/N***	***RD***	***S/N***	***RD***	***S/N***	***RD***	***S/N***
Temp.	0.03	7.97	2	2	0.015	3.98	49.26	38.12	0.02	7.76	12.84	10.01
SV	0.17	65.09	2	2	0.088	32.54	287.88	311.1	0.17	64.88	76.37	83.64
Load	0.01	4.28	2	2	0.008	2.14	28.48	20.49	0.016	4.07	7.31	5.25
E (Pooled)	0.0061	0.20	20	2	0.00030	0.10	-	-	0.0079	0.83	3.46	1.07
Total	0.22	77.57	26	8	-	-	-	-	0.22	77.57	100	100

Estimation of optimal characteristics

Predicted response for COF

Table 5 shows the average COF of the produced AA6082/Si3N4/C/Al2O3 composite at the optimal level for significant parameters. The predicted mean for COF at the ideal level may be found using equation 2 [20–21].

Table 5. COF average values at optimal levels

Level	COF
A_3	0.25
B_3	0.18
C_3	0.26
T	0.29

$\mu_{cof} = A_3 + B_3 + C_3 - 2T$ (2)
$\mu_{cof} = 0.11$

Equations 3 and 4 can be used for calculation of 95 % CI_{CE} and CI_{POP} for Confirmation experiments [20-25].

$$CI_{CE} = \sqrt{F_a(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad (3)$$

$$CI_{POP} = \sqrt{\frac{F_a(1, f_e)V_e}{n_{eff}}} \quad (4)$$

The results of the ANOVA computation are as follows:
Using eq. 3 $CI_{CE} = \pm 0.024$
Using eq. 4 $CI_{POP} = \pm 0.016$

Predicted optimal values of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite for COF is:
CI_{CE}: $0.086 < \mu < 0.134$
CI_{POP}: $0.094 < \mu < 0.0126$

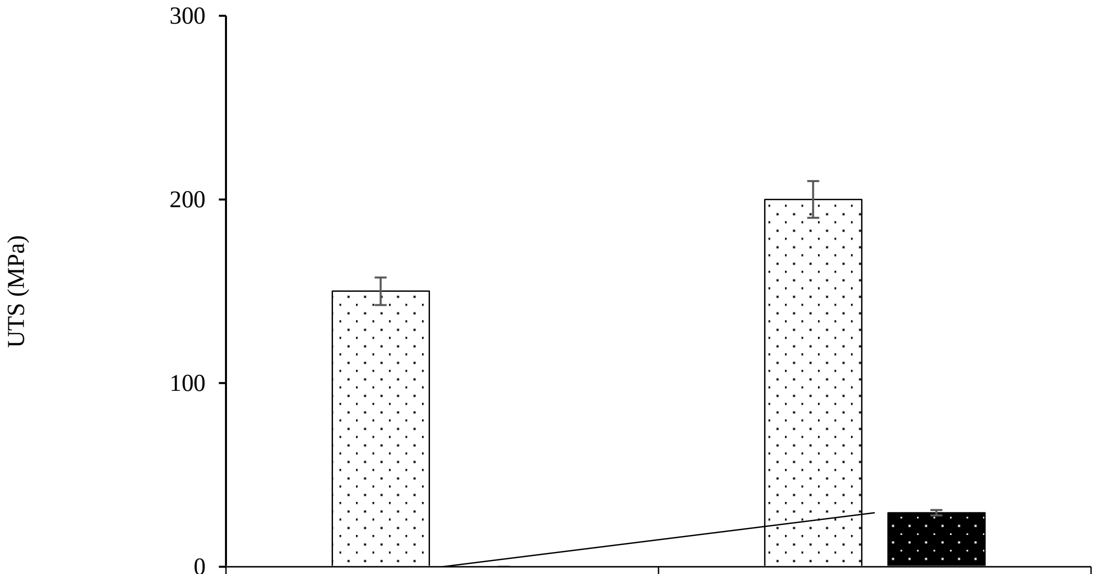
Predicted optimal values of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite for COF at significant parameters level were designated as:
Level 3 of A = 100°C
Level 3 of B = 0.3 m/s
Level 3 of C = 15N

Validation Tests

For the generated AA6082/Si3N4/C/Al2O3, three validation tests were carried out at the optimised level of parameters at level three of temperature (100oC), level three of sliding velocity (0.3 m/s), and level three of load (30N). The generated AA6082/Si3N4/C/Al2O3 composite had an average COF value of 0.11, which, as the likelihood 95% suggests, was within the COF optimum range.

Tensile Test

The produced composite has an average UTS of 200 MPa, compared to the as-casted AA6082 alloy's average of 150 MPa. Figure 3 displays variations in UTS for the manufactured AA6082/Si3N4/C/Al2O3 and the casted AA6082 alloy. The average UTS test indicates that the cast alloy AA6082 has a medium strength. When compared to the cast AA6082 alloy, the largest percentage increase in UTS was 29.41 percent. According to the UTS result, the Si3N4/C/Al2O3 particles mixed consistently with the matrix alloy and had a good bonding strength [16–17]. The results of the experimental study indicate that as test conditions of process parameters rise, the development of nitrides and oxides raises the UTS of the produced composite [5, 7]. The rise in UTS may also be due to the creation of dislocation density, which reduces grain size during the produced composite's solidification [5, 18–19].



	As-casted AA6082 alloy	AA6082/Si3N4/C/Al2O3
UTS (Mpa)	150	200
% increase in UTS	0	29.41

Figure 3. UTS results of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite

Micro-Hardness

The micro-hardness change between the fabricated AA6082/Si3N4/C/Al2O3 composite and the casted AA6082 alloy is shown in Figure 4. The resulting composite had an average hardness of 110 HV, compared to the as-casted AA6082 alloys about 60 MPa. When cast, AA6082 is a medium strength alloy based on the average micro-hardness result. The hardest ness increase, expressed as a percentage, was 71.40% as compared to the cast AA6082 alloy. Based on experimental study, it was shown that as test conditions and process parameters rise, the produced composite's micro-hardness increases due to the development of nitrides and oxides [5, 7]. The increase in micro-hardness might be attributed to the increasing of dislocation density, which results in a decrease in grain size during the solidification of the produced composite [5, 18-19].

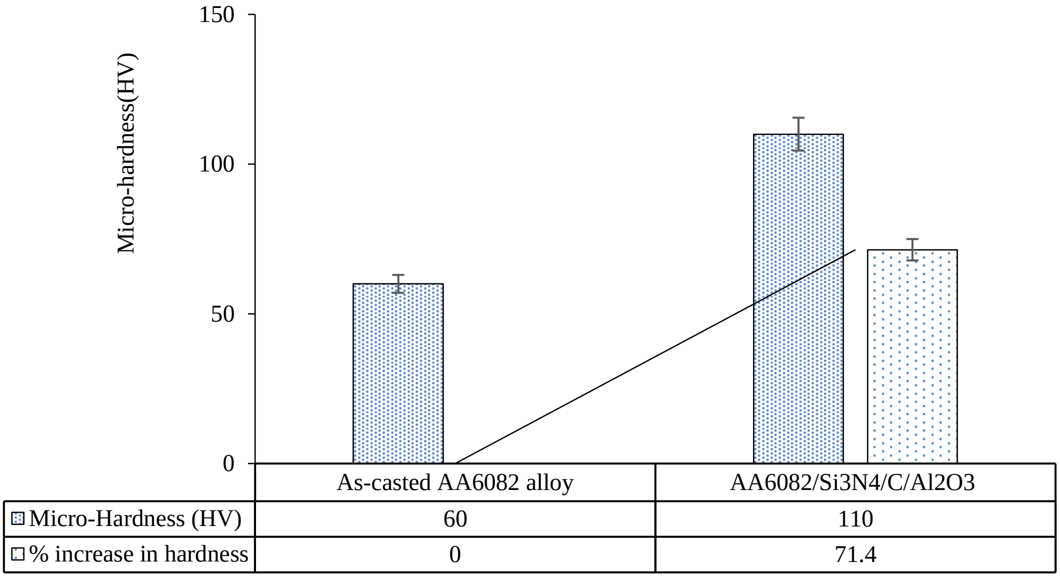


Figure 4. Micro-hardness results of fabricated AA6082/Si_3N_4/C/Al_2O_3 composite

CONCLUSIONS

In the current experimental work, the AA6082/Si3N4/C/Al2O3 composite was effectively manufactured using the stir casting approach in combination with an electromagnetic stirrer. After melting the AA6082 alloy to 850 degrees Celsius, preheated Si3N4/C/Al2O3 was constantly added to the molten alloy for 15 minutes at a time using a mechanical stirrer set to 200 revolutions per minute. Together with a mechanical stirrer, a 10 HP electromagnetic stirrer that rotated at 960 rpm for approximately 45 seconds was also used to create the AA6082/Si3N4/C/Al2O3 composite. The following are the conclusions that can be calculated:

- The constructed AA6082/Si3N4/C/Al2O3 experimental findings for UTS had a micro-hardness of 60 to 110 HV and a range of 150 to 200 MPa.
- Test results show a 67.39% drop in COF, a 29.41% rise in UTS, and a 71.40% increase in micro-hardness at 100oC temperature, 30N load, and 0.3 m/s sliding velocity.
- The tribological performance was assessed using a high temperature tribometer, which has a COF range of 0.15 to 0.4 under test conditions of load from 10 to 30N, temperature from 50 to 100oC, and sliding velocity from 0.1 to 0.3 m/s.
- The following are the predicted ideal values for the 95% confidence interval for COF for the fabricated AA6082/Si3N4/C/Al2O3 composite.:

  0.86.1.1.1 $\mu < 0.134$ for CICECIPOP: $\mu < 0.0126 < 0.094$

Of the produced AA6082/Si3N4/C/Al2O3 composite, velocity accounted for the largest percentage contribution to COF (76.37%). Temperature (12.84%) and load (7.31%) came next.

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