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Optimization of Tribological Properties of AA7129 Alloy Reinforced with B4C and TIC Composites using Taguchi Technique

C. Aliya Parveen[1] | Dr. B. Chandra Mohana Reddy[2] | Madri Rajesh[3]

[1]PG Research Scholar, Department of Mechanical Engineering, JNTUA College of Engineering Anantapuramu ,A.P, India.
[2]Associate Professor, Department of Mechanical Engineering, JNTUA College of Engineering Anantapuramu ,A.P, India.
[3]Research Scholar ,Department of Mechanical Engineering, JNTUA College of Engineering Anantapuramu ,A.P, India.
*Corresponding Author Email ID: parveenshaik932@gmail.com

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ABSTRACT

Aluminum and its alloys are employed in almost every technological area, including aerospace, marine, automotive structural, and a range of other applications. Due to its many characteristics, it is widely used to produce different types of matrix composites. Long-term applications wherein weight reduction is a goal, including such robots, high-speed gear, high-speed rotating shafts, or vehicle engines, might benefit from aluminium matrix composites (AMMCs) having high specific stiffness. The present study focuses on the sliding wear behaviour of the B4C and TiC-enhanced AA-7129 alloys. The hybrid composites were manufactured using the Powder Metallurgical method—stir casting process, with the number of Tic particles ranging from 1,3 to 5% by weight, and the number of B4C remaining constant at 2 wt%. The specimens are examined using Rockwell hardness testing equipment, Pin on Disc, and a scanning electron microscope (SEM). A Taguchi technique was used to produce a plan of experiments for data analysis, as it was used to run tests using an A L27 orthogonal array. The purpose of this research is to determine the impact of applied load, sliding speed, and the sliding time, percentage of reinforcement on the wear rate and coefficient of friction (COF) of a hybrid AA-7129 reinforced with B4C and TiC composite, and the ideal parameters for achieving the lowest wear rate. The samples were examined and evaluated utilizing scanning electronic microscopy after they had undergone wear testing

KEYWORDS: Hybrid Aluminum Metal Matrix composites, Stir Casting, Rockwell Hardness, Pin on Disc, L27 orthogonal array, Taguchi method, Wear rate, Coefficient of friction ANOVA, Scanning Electron Microscope.

1. INTRODUCTION

1. Introduction:

These are unique materials composed of a matrix material reinforced by exceedingly hard and brittle ceramic reinforcements. Boron Carbide (B4C) and Titanium Carbide (TiC) are reinforcing elements used in aluminium metal matrix composites (AMMC) [2].MMCs have improved physical and mechanical properties due to the combination of a soft alloy matrix with stiff, brittle reinforcing. Depending on the type of reinforcement used and its volume percentage in the metal matrix, aluminium matrix composites (AMCs) may achieve better strength, rigidity, fatigue strength, fatigue life, corrosion resistance, and creep. The AA7129 matrix was

reinforced with powdered titanium (TiC) and Boran carbide (B4C) in stages of 5% weight fraction. The stir casting method was used to make the metal matrix composites.

1.1 PROPOSED WORK

The main goal of this research would be to use a mineral processing simmer technique to make blended aluminium matrix composites (HAMMCs) and to investigate the impacts of TiC and B4C particulate matter on the mechanical characteristics of AA7129 based on HAMMCs with differing quantities of TiC (1 wt. percent–5 wt. percent) and a continual percentage of B4C (2 wt. percent). Variations in physico-mechanical characteristics and wear behaviour were considered. The goal of the research was to examine how changing the composition percentage influenced wear prediction and microhardness testing. The experiment was carried out using a stir-casting process to make samples with different composition percent, which were then submitted to dry sliding conditions on a computerized pin-on-disc wear test equipment as well as a Rockwell microhardness tester. A brief microstructure examination was performed using an optical microscope and a scanning electron microscope (SEM) to check that the reinforcing particles within the metal matrix were present.

2.MATERIALSANDSAMPLE PREPARATION

The work focuses on TiC and B4C particles reinforcing AA7129 alloy-based composite materials, as previously indicated. The aluminum matrix alloy of the AA7129 alloy was selected because of its exceptional strength-to-weight ratio.

2.1 PERCENTAGE OF COMPOSITION

The weight percentage of titanium nitride or boron carbide inside the composite is set via weight because this is the optimal amount of these reinforcements for producing outstanding composite properties, while the number of aluminums is varied by weight percent.

Table 1. Weight of various composition

Compositions	Material	AA	TiC	B_4C	Total weigh
1	A_1	97% (1940 grams)	1% (20grams)	2% (20grams)	2000grams
2	A_2	95% (1900 grams)	3 (60grams)	2% (20grams)	2000 grams
3	A_3	93% (1860grams)	5% (100grams)	2% (20grams)	2000 grams

2.2FABRICATIONOFHYBRIDCOMPOSITES:

Aluminum 7129 (Al7129) was used as the basic alloy, with (TiC) and (B4C) powders as reinforcements, with varying weight percentages of TiC (1,3 and 5 wt percent) as well as a constant weight percentage of B4C (2 percent). In this technique, an electric furnace heats the composite materials, Al7129, to 850 °C. When the temperature is elevated to such a high degree and the mixture is vigorously stirred with a manual stainless-steel stirrer, the base metal melts. Because of the vigorous swirling, a vortex develops at the melt's surface. After the vortex has been created, the reinforcement, heated (TiC) and (B4C) powder, is applied from the side of the formed vortex. The pouring temperature was set at 850 °C, the stirring speed at 200–250 rpm, and the silicon carbide reinforcement temperature was set at 350 °C.The amount of (TiC) and (B4C) reinforcement is varied in percent weight fractions of 5 to 25 wt. percent in increments of 5 percent weight to generate metal matrix composites. To make (TiC) and (B4C) powder to improve the wettability of the reliability matrixStir casting is indeed a liquid-state composite material fabrication technique that involves physically mixing a dispersed phase with a molten matrix. Following that, the fluid composite material is cast using typical casting procedures and may be processed utilizing conventional metal forming techniques.

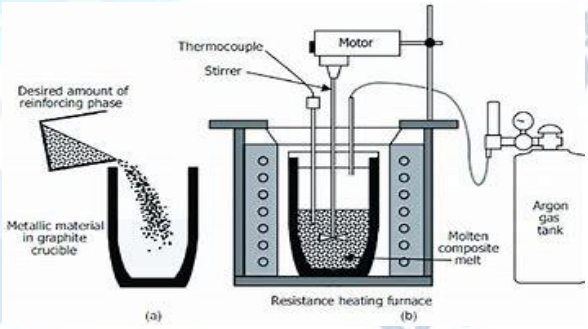
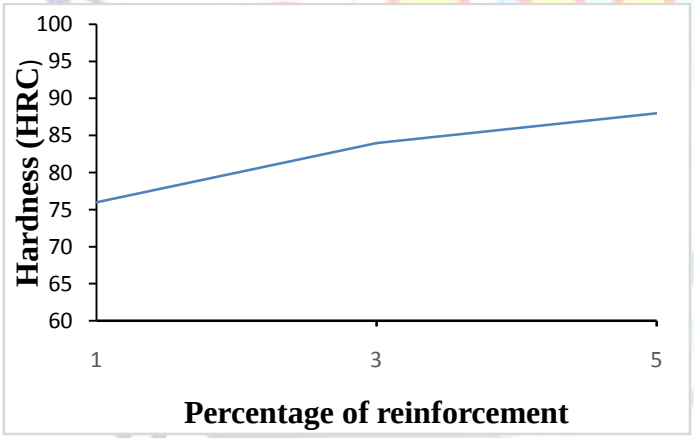


FIG 1. STIR CASTING SETUP

The experimental arrangement was put together using a connecting gearbox motor and a mild steel four-blade stirrer. Aluminum billet material (97%), tic (1%), and b4c (2%), are melted in a graphite crucible in a coal-fired furnace. Finally, the item was left to cool in its natural environment (room temperature). The composite material had taken the shape of a cylinder. The solidified composite test sample was removed from the die and cut to the appropriate specifications, yielding cylinder needles with a 6 mm diameter and a height of 30 mm.

2.3 HARDNESS TEST

The Rockwell hardness test was used to measure the toughness of composite specimens at room temperature, considering differences in the percentage of reinforcing components. The micro-hardness was determined using Rockwell hardness testing equipment. The additional depth at which a carbide ball is pressed by 100 kg (f) indentation forces is measured by the Rockwell testing equipment, and the findings are read using the B scale. The composite specimens' hardness values were tested to use at least 6 indentations of each sample, with average values utilised to calculate the hybrid composite's hardness. The toughness of hybrid metal matrix composites is improved by the volume percentage of particles in the matrix. The inclusion of Tic and B4C particles increased the hardness of the hardness, the property of particulates being their hard phase as opposed to the alloy matrix, as well as the hardness characteristic of specimens as illustrated in fig.



Hardness concerning wt% of Tic

3. DRY SLIDING WEAR TEST

The technique used for studying dry sliding wear of composites is described in the following section.

Pin-on-disc Apparatus

The pin-on-disc wear test experimental setup is shown in the diagram. The slider disc is made of 0.95 to 1.20 percent carbon (EN31) steel, has a hardness of 62 HRC, and measures 165mm in diameter. All the investigations used a 100mm broad track with a 60mm track diameter. The steel disk's surface has a 1 m finish. Pins with a length of 6 mm were used as samples for the Aluminum Matrix Composite. It's also 30 mm in length. To prepare for wear testing, the contact region of an aluminum composite sample was flattened and cleaned using metallographic methods.

Figure 3. Pin on disc sliding wear testing machine

4. TAGUCHI METHOD :

The Taguchi design was created by Dr. Genichi Taguchi as a design of experimentation (DOE) approach to improve the quality of manufactured things in Japan. The Taguchi design is more successful than a fractional factorial because it employs balanced (orthogonal) trial combinations. In this study, the Taguchi approach using orthogonal arrays was utilised to generate a planned sequence for finishing the experiments. This method has been used to rank several parameters, as well as the degree of relevance of a variable's influence or the interaction of factors on a specific output response. The Taguchi technique was utilised to identify the optimal wear settings for AA MMCs with the lowest wear rate.

4.1 STEPS IN EXPERIMENTAL LAYOUT

Process Parameters

The process parameters are as follows:

1. Load
2. Speed
3. Time
4. Percentage of reinforcement

For each processing parameter, three layers have been selected to define the experimental zone. The aspects that will be researched and the categories to which they'll be allocated are listed in Table 2. Because it has 27 rows, which correspond to the sequence of tests (26 degrees of freedom), and 13 columns over three levels, the L 27 [3 13] array was chosen. The factors and interactions are organized into columns. There were 27 tests in all, with the first column dedicated to sliding velocity [S], the third to applied load [L], one fifth to sliding time (T), the ninth to reinforcing ratio (R), and the other columns devoted to interactions. The total number of studies covered in this study is 27. Because of this, the dof is calculated to be 26. The values of a sample L27 orthogonal array are listed in

Table 2.

Table 2. Control factors of process parameters and their level

Level	Sliding Velocity (m/s)	Load (N)	Sliding Time (min)	Percentage of Reinforcement (%)
1	1.5	10	5	1
2	2	20	10	3
3	2.5	30	15	5

Table 3. Orthogonal Array $L_{27}(3^{13})$ OF Taguchi Method

L_{27} (3^{13})	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

5. RESULTS AND DISCUSSION

5.1 Experiment Results and Taguchi Analysis

A series of wear tests were conducted to investigate the influence of wear behaviour on the AA 7129 composite. The experimental findings of an AA 7129 composite with various wear parameters are shown in Table 5.3. The S/N ratio of the wear mean friction coefficient is also calculated. For every L27 (313) experiment, the S/N ratios have also been calculated. The purpose of using the S/N ratio as a performance indicator is to create items and processes that are noise insensitive. Tables 3 and 4 provide the medium-effect response tables. Using experiment data, the moderate effect reaction value and average S/N response ratios of wear rate and coefficient of friction were determined, and a value for the S/N ratios was discovered.

5.2 STATISTICAL ANALYSIS OF EXPERIMENTS

5.2.1 Calculation of Wear Rate and Coefficient of Friction

Under dry conditions, the Wear Rate & Coefficientof Friction were computed using the Taguchi method's L27 Orthogonal array sequence. Using a Pin on Disc machine, these values were calculated by adjusting the speed, load, duration, and reinforcement. The findings for different combinations of parameters have indeed been given in Table 4, which were acquired by executing the tests using the orthogonal array. The reaction of the parameters Wear Rate and Friction coefficient to the signal to noise ratio has been summarized in Tables 3 and 4.

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Table 5. Response Table for Signal to Noise Ratios for Wear rate

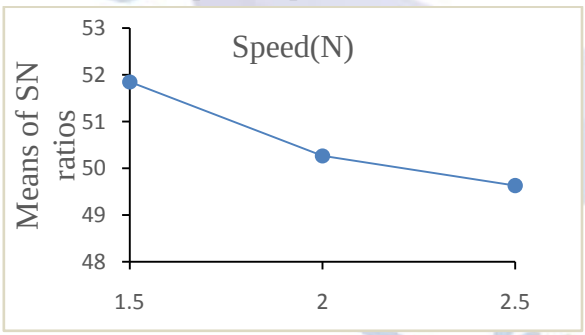
Level	Speed	Load	Time	Reinforcement
1	51.85	52.12	48.3	52.81
2	50.27	51.37	48.5	50.61
3	49.63	48.96	49.5	48.75
Delta	2.22	3.16	1.2	4.06
Rank	3	2	4	1

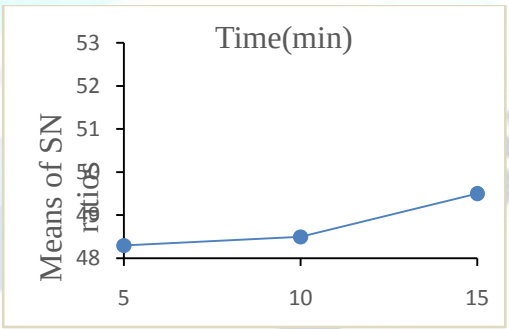
Level	Speed	Load	Time	Reinforcement
1	9.532	9.654	9.352	9.633
2	9.272	9.156	9.074	9.251
3	8.575	8.691	8.921	8.545
Delta	0.945	0.963	0.431	1.088
Rank	3	2	4	1

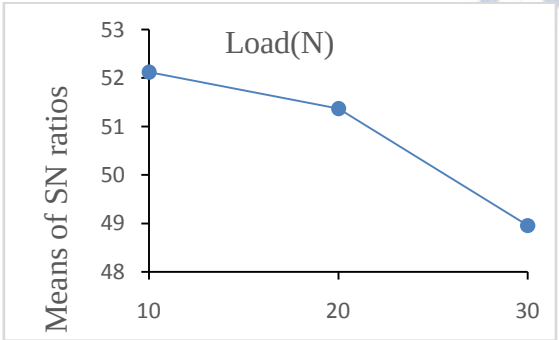
Table:6. Response table for signal to noise ratios for coefficient of friction

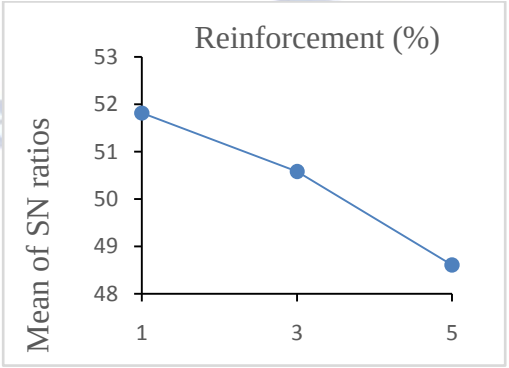
Ex. No	Speed (m/s)S	Load (N)L	Time (min) t	Reinforcement (%) R	Wear Rate (mm^3/m) Wr	S/N Ratio for Wear (db)	Coefficient of friction Cf	S/N Ratio for Coefficient of friction (db)
1	1.5	10	5	1	0.001052	49..754	0.377	8.495
2	1.5	10	10	3	0.001784	52..268	0.332	9.602
3	1.5	10	15	5	0.000431	53.786	0.311	10.117
4	1.5	20	5	3	0.001647	59.402	0.342	9.344
5	1.5	20	10	5	0.001568	52.975	0.337	9.472
6	1.5	20	15	1	0.001564	58.223	0.312	10.182
7	1.5	30	5	5	0.002134	50.845	0.357	8.972
8	1.5	30	10	1	0.00425	54.248	0.325	9.7890
9	1.5	30	15	3	0.00842	53.895	0.308	10.285
10	2	10	5	3	0.001543	57.799	0.389	8.2459
11	2	10	10	5	0.00314	50.058	0.357	8.9711
12	2	10	15	1	0.00249	52.070	0.3324	9.8430
13	2	20	5	5	0.00301	50.195	0.370	8.5890
14	2	20	10	1	0.00247	52.069	0.348	9.1933
15	2	20	15	3	0.00210	50.195	0.322	9.8698
16	2	30	5	1	0.00290	52.556	0.345	9.2942
17	2	30	10	3	0.00235	53.199	0.332	9.5253
18	2	30	15	5	0.00183	56.020	0.318	9.9514
19	2.5	10	5	5	0.000502	65.3142	0.124	13.2113
20	2.5	10	10	1	0.00397	50.736	0.371	8.6361
21	2.5	10	15	3	0.00291	57.054	0.362	8.8850
22	2.5	20	5	1	0.00443	59.267	0.401	7.9372
23	2.5	20	10	3	0.00349	55.499	0.365	8.7781
24	2.5	20	15	5	0.00265	51.495	0355	9.010
25	2.5	30	5	3	0.04513	56.908	0.390	8.2010
26	2.5	30	10	5	0.003292	59.652	0.352	9.0693
27	2.5	30	1.5	1	0.000693	51.399	0.345	9.2690

Table 4. Experimental results for a different combination of process parameter



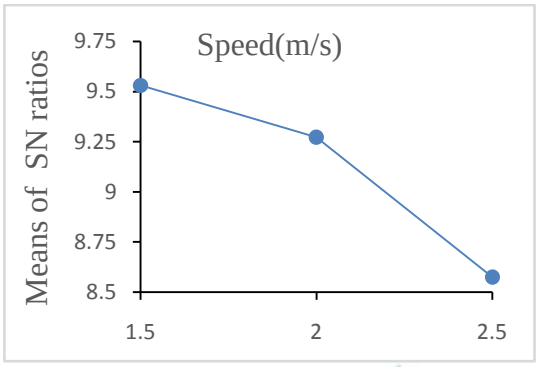


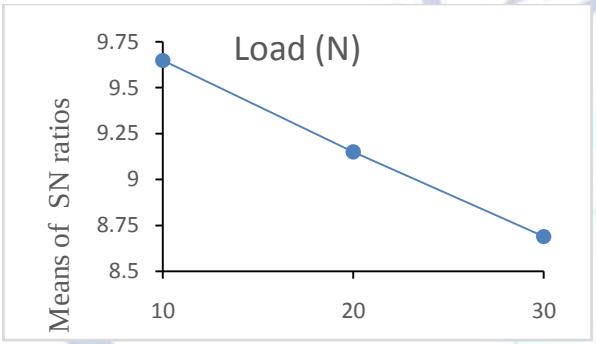


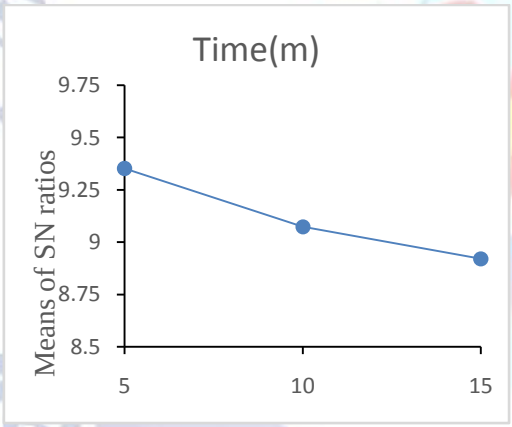


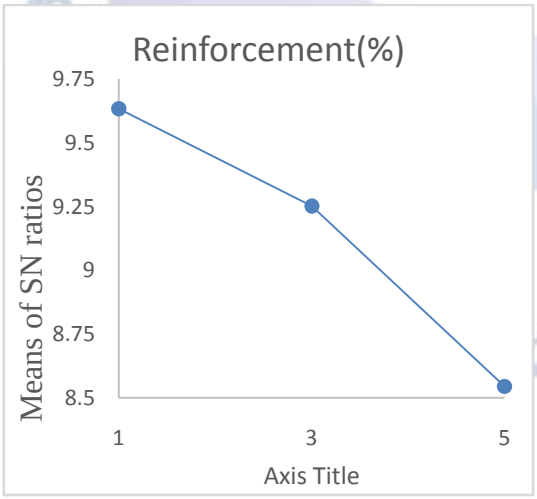
Signal to noise: Smaller is better

Fig 5. Main effects of SN ratios – wear rate









Signal to noise: Smaller is better

Fig 6. Main effects plots for SN ratios –

The results for various parameter combinations were analysed using the commercially available MINITAB 18, which is generally used for experimental design. From the trials, Table 5.8 shows the average wear rate and coefficient of friction. To analyse the quality qualities, the experimental data was converted into signal-to-noise ratios. The effects of control elements such as speed, load, duration, and reinforcing material on wear rate and coefficient of friction were explored using a signal-to-noise response table. Based on the interpretation of these experimental results with the help of signal to noise, the ideal condition parameters ending in wear rate or the coefficient of friction are depicted in ratio figures 5 and 6 respectively. The third level of both sliding speed and load, the first level of sliding time, and the third level of percent of reinforcement, are the ideal positions. However, these conditions do not exist in the L27 factorial design. The best conditions are looked at separately, with the results shown in table 7 below.

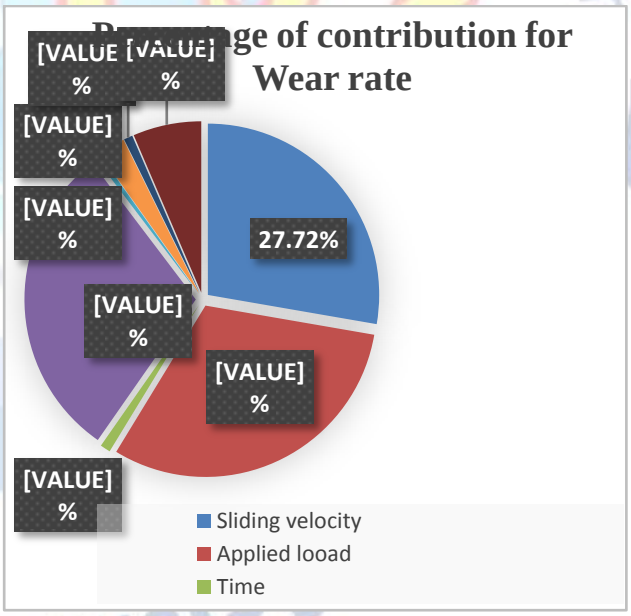
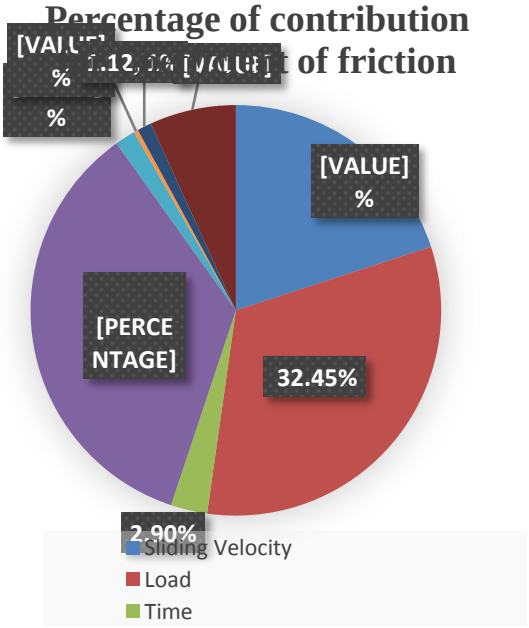


Table 7. Optimum level parameters for wear and COF

Ex No	Sliding velocity S(m/s)	Applied load, L(N)	Sliding time, t(min)	Percentage of reinforcement R (wt.%)	Wear rate (mm^3)	SN ratio for wear (db)	Coefficient of friction	SN Ratio for coefficient of friction
1	2.5	30	5	5	0.000453	68.31402	0.145	14.512

Table 8. Analysis of variance -Wear rate

Source of variance	DF	Seq SS	Adj SS	Adj MS	F-test	P-test	Pr-factor effect (%)
S(m/sec)	2	0.0000026	0.000029	0.0000014	35.10672	0.000608	27.7254
L (N)	2	0.0000031	0.0000031	0.0000015	38.14753	0.000526	30.9941
t (Min)	2	0.000001	0.000001	0	0	1	0.9722
R (%)	2	0.0000031	0.000003	0.0000015	36.11324	0.000517	29.9764
S(m/sec) ×L(N)	4	0.000001	0.000001	0	0	1	0.5421
L (N) ×R (%)	4	0.000004	0.000004	0.000001	1.97542	0.7364	2.554
R(%) ×S(m/sec)	4	0.000001	0.000001	0	0	1	0.8321
Error	6	0.0000015					6.458
Total	26	0.0000176					100



The wear parameters of sliding velocity do about slide duration, and % of reinforcement was correlated using the statistical programmed MINITAB 18. The dry sliding wear loss was determined using multiple linear regression analysis, which involves fitting a linear equation to observed data to represent the connection between two or more predictor factors and a response variable. For tribological research, the linear regression analysis has indeed been proven to yield excellent results among alternative regression models. The regression equation developed for the wear rate of AA7129 HAMMCS has been,

Wr = 0.04697+0.002737 S - 0.001398 L +0.000001T- 0.00016 R (5.1)

R^2=87.3%

The regression equation developed for the coefficient of friction of AA7129 HAMMCS has been Wr=0.309+ 0.002470

Multi Linear regression Models

S- 0.002119 L+0.000285 T-0.005237R (5.2)

R^2=86.3

The R^2 values for wear rate and coefficient of friction found from the above equations have been used to predict the tribological behavior of hybrid metal matrix composites. The regression of coefficient values for wear rate and the coefficient for AA7129 have been 0.863 and 0.854 respectively.

Table 9. Analysis of variance -Coefficient of friction

Source of variance	DF	Seq SS	Adj SS	Adj MS	F-test	P-test	Pr-factor effect (%)
S(m/sec)	2	0.016758	0.016758	0.015421	26.3174	0.00612	20.10245
L (N)	2	0.024635	0.024635	0.015467	40.2354	0.00031 4	32.45512
t (Min)	2	0.001487	0.001487	0.005734	3.9215	0.34215	2.90146
R (%)	2	0.026752	0.026752	0.015846	44.7035	0.00029 1	35.21475
S(m/sec) ×L(N)	4	0.001543	0.001543	0.000721	2.1453	0.6561	1.621124
L (N) ×R (%)	4	0.000142	0.000142	0.000521	1.0952	0.10554	0.35468
R(%) ×S(m/sec)	4	0.001754	0.001754	0.000711	1.9726	0.78584	1.12785
Error	6	0.002145					6.8547
Total	26	0.001821					100

Table 10. Parameters used in the testing for AA7129

Level	Applied Load (N)	Sliding Velocity, S (m/s)	Sliding Time, t (min)	Percentage of Reinforcement, R (wt.%)
1	15	1.8	6	1
2	25	2.3	9	3
3	35	2.8	12	5

Validation of Test Results through Regression Model and by Experiment:

To corroborate the regression model, a dry sliding wear test was performed, and the results were examined using specified combinations of the original values at various levels. Table 10 shows the different parameters and levels used in the confirmation tests for AA7129 hybrid metal matrix composites (HMMCS). The experimental wear rate

values and the computed values obtained from the regression model for AA7129 hybrid metal matric composites have been obtained and compared (HMMCs). Tables 10 and 11 display the outcomes According to the findings, the actual wear rate and coefficient of friction for hybrid metal matric composites differ from those calculated using the regression model. For AA7129 HMMC, the percentage of error for wear rate goes from 5.92 percent to 10.12 percent, and for coefficient of friction, it ranges from 5.61 percent to 9.41 percent.

resulted in the lowest wear rate and coefficient of friction. According to the confirmation test, the wear rate error varies from 5.92 percent to 10.12 percent, while the coefficient of friction error ranges from 5.61 percent to 9.41 percent, indicating that the Taguchi technique was effective in computing wear and coefficient of friction. These validated numbers were almost identical to actual data, except for a few minor flaws. The wear rate and coefficient of friction were successfully calculated using the Taguchi design of experiments method from the regression equation. The regression model developed in this study has been shown to be a practical and accurate method of predicting the wear rate and coefficient of friction for hybrid meta matrix composites. It was decided that the Taguchi design of experiment method would be used in the current investigative setup.

6.SCANNING ELECTRON MICROSCOPE EXAMINATION

Microstructural studies have been carried out using a scanning Electron Microscope (SEM). Wear rate depends on the presence of the carbide phase in the matrix. The figure shows the sem worn surface micrographs of reinforced samples. The Scanning electron microscope machine is shown in ablow figure 7 and fig 8 to 9 shows SEM worn surface of reinforced

samples.

Fig 7. SCANNING ELECTRONMICROSCOPE

Table :11. Comparison results of AA7129HAMMCS

EXP. No	Exp. Wear rate (mm/m)	Reg. model equation (5.1), Wear rate (mm/m)	Error (%)	Exp. Coefficient of friction (mm/m)	Reg. model equation (5.1), Coefficient of friction	Error (%)
1	0.002175	0.001986	7.34	0.3721	0.3410	8.21
2	0.001924	0.001712	5.92	0.3545	0.3154	9.41
3	0.001782	0.001432	10.12	0.2915	0.2810	5.61

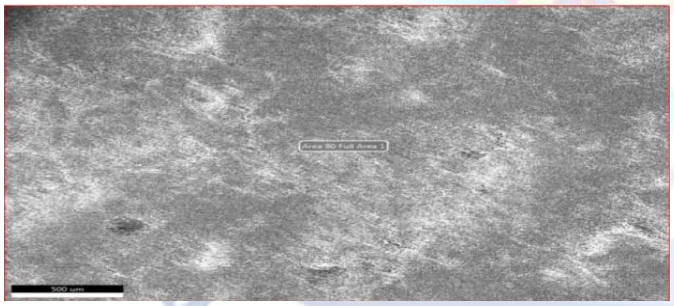


Fig 8. Sem texture of 1% Tic+2% B_4C particulate reinforced AA7129 Composite after wear

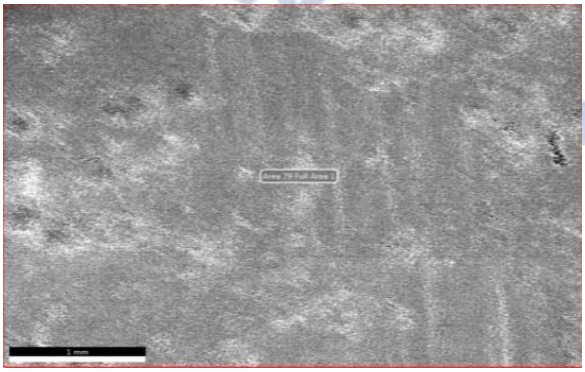


Fig 9 .Sem texture of 3% Tic+2% B_4C particulate reinforcedAA7129 Composite after wear

Fig 10. Sem texture of 5% Tic+2% B_4C particulate reinforcedAA7129 Composite after wear

Non-uniform wear caused by the reinforcing material, such as micro-cutting, grooves, and scratch marks, was detected in composite specimens after wear. The morphologies just on the worn surface starting to form the long thin dress surface of a composite's samples were studied under various conditions, including 2.5m/s sliding velocity, 30N load, 15min sliding time, and 15% weight percentage of reinforcing particles, denoting that wear was caused by abrasion wear. The composites' worn surface is coarser than the parent alloy, according to Sem's examination of samples after wear.

7. CONCLUSION:

Stir casting was used to create hybrid aluminum matrix composites comprising an AA7129 matrix augmented with titanium carbide (Tic) or boron carbide (B4C) particles. On the AA7129 HAMMCS, hardness testing was performed using a Rockwell hardness machine. Tribological wear tests were performed with the aid of a pin on a disc machine. The use of a scanning electron microscope allows researchers to investigate the wear surface morphology and wear mechanism of pins after they have been used and compared to experimental findings. When compared to an unreinforced alloy, the hybrid metal-matrix composite has higher wear resistance. Increased reinforcing content, on the other hand, improves wear resistance while lowering the coefficient of hybrid metal matrix composites. The best parameters were discovered to be 2.5 m/s sliding velocity, 30 N applied load, 5 min sliding duration, and 5 wt% reinforcement, which resulted in the lowest wear rate and coefficient of friction. According to the confirmation test, the wear rate error varies from 5.92

percent to 10.12 percent, while the coefficient of friction error ranges from 5.61 percent to 9.41 percent, indicating that the Taguchi technique was effective in computing wear and coefficient of friction.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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