Experimental Analysis of Tribological Properties of Aluminum 6061-Al_2O_3-TiO_2 MMC

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Abstract

Composite materials have gained significant prominence in modern engineering due to their superior properties such as high strength-to-weight ratio, wear resistance, and adaptability in design. This research paper focuses on the development and application of aluminum matrix composites (AMCs) reinforced with Al2O3 and TiO2 particulates, which offer enhanced mechanical, thermal, and tribological properties. The study investigates the historical evolution, material characteristics, and manufacturing techniques of metal matrix composites (MMCs) while emphasizing their increasing use in automotive, aerospace, and other industrial applications. Particular attention is given to the role of Al2O3 and TiO2 reinforcements in improving wear resistance and other tribological properties of aluminum alloys. This work underscores the necessity of integrating innovative materials and processes to meet the demands of lightweight, high-performance, and cost-effective solutions in the engineering domain.

Introduction

The continuous advancement in material science has been driven by the need for innovative solutions to meet growing industrial demands. Composite materials, particularly metal matrix composites (MMCs), represent a critical leap in this progression. Since their inception in the 1960s, MMCs have transitioned from experimental phases to vital components in aerospace, automotive, and other industrial sectors. Aluminum-based metal matrix composites (AMCs) have emerged as a leading class of MMCs due to their lightweight nature, excellent thermal conductivity, and corrosion resistance. However, the relatively poor wear resistance of unreinforced aluminum alloys has prompted extensive research into reinforcement techniques using ceramic particulates.

Reinforcement materials such as Al2O3 (aluminum oxide) and TiO2 (titanium dioxide) have demonstrated remarkable potential in enhancing the mechanical and tribological properties of AMCs. Al2O3 contributes superior hardness, wear resistance, and thermal stability, while TiO2 offers high strength-to-weight ratio, thermal stability, and resistance to high-temperature deformation. The integration of these reinforcements into aluminum matrices not only addresses the wear resistance challenges but also opens new avenues for lightweight and durable materials suitable for high-performance applications.

The oxidation resistance of TiO2 composites, particularly at high temperatures, underscores their relevance in high-temperature applications. Passive oxidation above 1000°C forms a protective oxide layer that enhances durability, whereas lower temperature oxidation risks degrading the fiber-matrix interface. Addressing these challenges, research into environmental barrier coatings is underway to further improve their reliability.

This study also investigates the role of SAE 20 W 50 engine oil as a lubricant, highlighting its efficacy in reducing friction and wear during operation under extreme conditions. Its anti-foaming characteristics, resistance to thermal breakdown, and excellent anti-wear properties make it an essential component in tribological applications.

Additionally, the classification and design of composites are reviewed, emphasizing the geometrical contributions of particulate and fibrous reinforcements to mechanical performance. Particulate composites enhance stiffness and wear resistance, while fibrous composites significantly improve fracture resistance and load transfer efficiency. Furthermore, the properties of polymer and metal matrices, along with the importance of the matrix-reinforcement interface, are discussed to illustrate the multifaceted approaches to optimizing composite performance.

By examining wear mechanisms, including abrasive, adhesive, erosive, fatigue, and corrosive wear, the study contextualizes the practical implications of composite applications. This paper aims to contribute to the growing body of knowledge on AMCs reinforced with Al2O3 and TiO2, providing insights into their development, characterization, and potential for industrial applications.

2.1 Literature Review

The literature survey focuses on the evaluation of wear properties of Aluminium Metal Matrix Composites (AMMCs). Various parameters, including reinforcement type, applied load, sliding distance, microstructural effects, sliding velocity, and temperature, have been studied extensively. The Taguchi method and ANOVA are frequently employed by researchers to identify significant factors influencing dry sliding wear behavior in AMMCs. Key studies are summarized below:

Vineet Chaka, Himadri Chattopadhyayb [2020]: A tremendous rise in application of aluminium matrix composite in various engineering applications have been witnessed in the recent years. Aerospace, defense and automobile sectors are using increased number of parts made from aluminium matrix composites. Components made from aluminium based composites, as compared to monolithic materials, offer superior properties like high strength to weight ratio, strength, stiffness, hardness and tribological behavior. The properties of aluminium matrix composites are highly dependent of appropriate selection of aluminium matrix, reinforcement material and processing route for its fabrication. The current study attempts to present an overview on the available fabrication routes, reinforcement materials, pertinent research issues and challenges in production of aluminium matrix composites. Special attention is focused on the mechanical properties of fabricated aluminium matrix composites.

Adeolu Adesoji Adediran Abayomi Adewale Akinwande [2021]: In this study, an investigation was carried out on the effect of waste glass particles (WGP) (sieved to -23 μm) with varying proportions of 2, 4, 6, 8, and 10 wt.% on the properties of Al-6061 alloy. The produced composite samples were subjected to various tests; density, porosity, tensile, impact, compression, and wear. The results showed that increasing the addition of waste glass led to a progressive reduction in density, elongation, strain, and impact energy as WGP increased from 0 to 10 wt.%. The Brinell hardness was observed to increase progressively from 0 to 10 wt.% of WGP. There was an enhancement of yield and ultimate tensile strength, peaking on an incorporation rate of 6 wt.% WGP after which the strength deteriorated. As in the case of yield and ultimate compressive strength, the max- imum value was realized at 8 wt.% WGP addition while 10 wt.% led to a fall in strength. Analysis of wear performance revealed a lower wear rate at the lowest variables of applied load, sliding velocity, and distance. It was further observed that increasing the WGP con- tent has resulted in a better reduction of wear. Therefore, waste glass particle infusion of Al-6061 is good for enhancing the properties of the alloy for engineering applications.

G.Rajeshkumara, A.M.Harikrishnab (2020): Inparticular, these composites are used in aerospace, automobile and transportation application because of high strength to weight ratio, good wear and corrosion resistance and better damping properties etc. Among various metal matrix composites, aluminium based composites (Al6061) are used for such applications. These composites are manufactured by using various manufacturing techniques such as sand casting, stir casting, squeeze casting and friction stir welding. Moreover, these composites are prepared by reinforcing it with ceramic particles, hard metals and natural particles to enhance its properties and also to suit for various engineering applications. Hence, a complete understanding of the above is very much essential for selecting appropriate composites for various applications and also to prepare new composites with enhanced behavior. This paper reports the various manufacturing techniques used for the preparation of Al6061 composites, reinforcements used and its various characterization studies.

Renu a, Ajay Gupta (2021): Al6061 alloy nanocomposite reinforced with (0, 3, 6, 9 wt%) of nanozirconia were fabricated by stir casting technique. The physical properties such as void content, density and mechanical properties such as hardness, impact strength, flexural strength and fracture toughness were evaluated. It was found that nanozirconia has a significant effect as filler for the improvement in mechanical and physical properties. It was found that the addition of 3 wt% nanozirconia resulted in an increase in void content by 21%, hardness by 34%, impact strength by 32%, and flexural strength of 9.6 %. However, porosity was increased due to difficulty in mixing nanozirconia in the molten metal during stir casting. The addition of nanozirconia resulted in more strength, hardness and improved interface bonding between matrix and filler which led to improvement in fracture toughness..

K.V. Mahendra et al. (2019): Synthesized Al-Cu alloys with fly ash and TiO2.Improved wear resistance and mechanical properties were noted with increasing reinforcement percentages.

Md. Habibur Rahman et al. (2022): Studied TiO2-reinforced composites fabricated by stir casting.Hardness and wear resistance improved with increasing TiO2 content.

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3. SYSTEM DEVELOPMENT

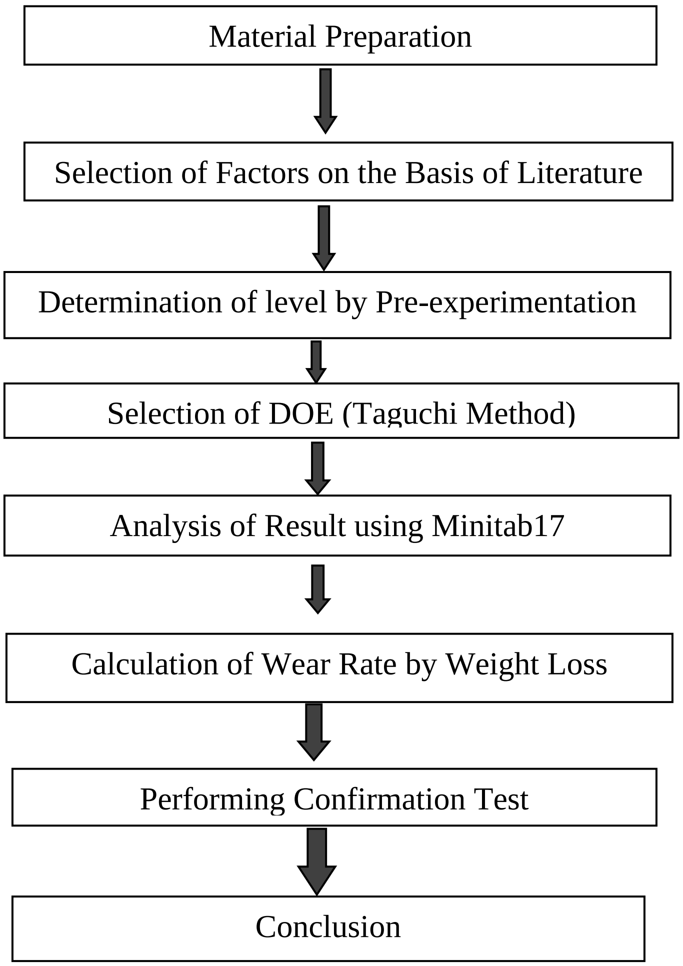


Figure :Experimental Flow Chart

Table No:-3.1-Layout of L_9 Orthogonal Array

Sr. No.	Load, N	Sliding Distance, m	Temperature, ˚C	Wt. % of TiO2 (Composition)
1	10	1000	100	0
2	10	1250	125	3
3	10	1500	150	6
4	15	1000	125	6
5	15	1250	150	0
6	15	1500	100	3
7	20	1000	150	3
8	20	1250	100	6
9	20	1500	125	0

Table No:-3.3-Standard Properties of Al 6061 Alloy

Property	**Values**
Density	2670 kg/m^3
Melting point	615˚C
Elastic modulus	71 GPa
Tensile Strength (T6)	250-280 MPa
Percentage Elongation	5%
Hardness (T6)	90 BHN

The required quantity of reinforcement viz. 0%, 3%, 6% by wt. of TiO_2 and 5% by wt of Al_2O_3 of total weight of aluminium was taken in the powder container. The Reinforcement TiO_2 and Al_2O_3 sieved and were preheated in the furnace up to 350˚C and maintained the temperature before mixing with aluminum melt. The weighed quantity of aluminum was melted to desired superheating temperature of 750±10˚C in graphite crucible using electrical resistance furnace with temperature controlling device. After melting was over, the temperature of the melt was lowered up to 650˚C to form slurry at lower temperature to have uniform mixing of reinforcements and to avoid the flow of it outside the matrix material. Required quantity of reinforcement particulates was added to the molten metal and stirred continuously by using mechanical stirrer to avoid segregation of the TiO2 and Al_2O_3 particles. The stirring time was maintained 80s at an impeller speed of 300 rpm. Good wetting between the solid and liquid is essential for the formation of satisfactory bonds between them during casting. It has been found that the addition of magnesium improves the wetting characteristics of aluminium-based composites because of its lower surface tension also it acts as scavenger of oxygen,

thereby increasing the surface energy of the particles. The melt at 650˚C was poured to prepare composite specimen.
The prepared composite was subjected to machining to produce a size of Φ 12mm and 25mm length to carry out the dry sliding wear test.

Pre- Experimentation

In the pre-experimentation for the study of dry sliding wear on aluminium 6061 + TiO_2 + Al_2O_3 MMC, the relationships of Load, Sliding distance, temperature and wt. % of TiO_2 versus wear rate is established. Relationship is obtained by varying one parameter and keeping all other parameters at minimum level i.e. OVAT analysis is used to find the levels of the parameter. Three point slope method is used to find the variation between consecutive slopes and to select the levels of parameter. Levels with larger variation in slopes are selected to conduct the experiment and to find the optimum levels of each parameter. Figure shows the different parts of pin on disc machine and Figure shows the complete arrangement of experimental set up

Chemical Composition of the Composite

The chemical composition of the composite is obtained using spectrotest machine. Spark optical emission spectroscopy is a technique used for direct analysis of solid metal samples.

Table :Chemical Composition of Al 6061+ 3%TiO2 + 5% Al_2O_3

Sr. No.	Element	Percentage
1	Si	11.3
2	Fe	0.215
3	Cu	0.09
4	Mn	0.3
5	Mg	0.08
6	Ni	0.1
7	Zn	0.07
8	Ti	0.019
9	Ca	0.025
10	Pb	0.016
11	Sn	0.0051
12	Zr	0.0003
13	Al	87.7

Table :Specification of Pin-on Disc Friction and Wear Monitor TR-20

Make	Ducom Ltd., Banglore, India
Pin Diameter Range	Φ3mm to 12mm
Disc Size	Φ165mm × 8mm thick
Wear Track Diameter	Φ20mm to145mm max
Sliding speed Range	0.20 to 12 m/s
Disc Rotation Speed	Min :100 rpm Max: 2000 rpm
Drive	1.5KW DC motor
Frictional Force	0 N to200 N (max),Digital readout with recorder
Normal Load	0 N to200 N (max)
Disc Material	EN-31
Disc Hardness	60 HRC
Wear Measurement Range	±2 mm, with least count of 1 micron, Digital readout with recorder
Power	230 V ±5%,16 Amps, Single phase, 50 Hz AC

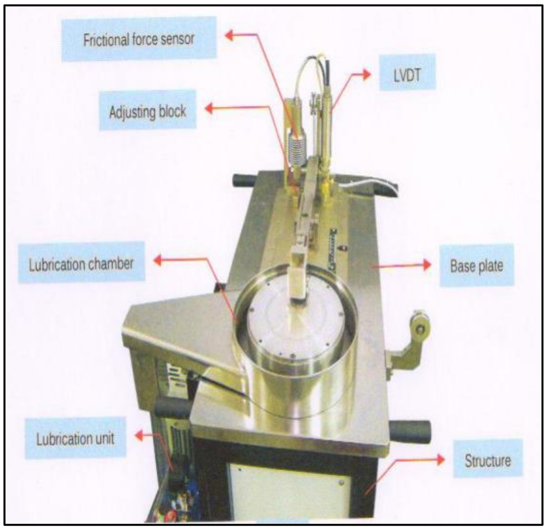
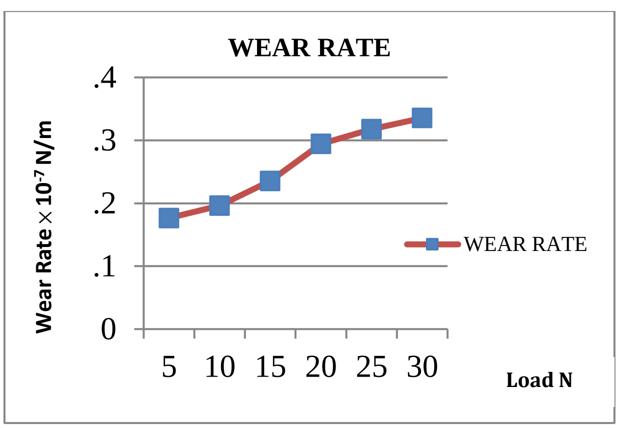


Figure :Different Parts of Pin on Disc Machine

Varying load

The load was varied from 5N to 30N with a step of 5N. The minimum applied load according to the machine specification is 5N. All other parameters are kept at minimum level to study the influence of load on wear rate of Al 6061 TiO_2 composite with 3% TiO_2 and 5% Al_2O_3. As shown in below



Graph:Variation of Wear Rate with Load (Al 6061 + 3% TiO2 + 5% Al_2O_3)

Calculations of slope

$m= (Y_2-Y_1)/(X_2-X_1)$

where,

Y_2 is wear rate at third level of parameter.

Y_1 is wear rate at first level of parameter.

X_2 is third level of load.

X_1 is first level of load.

1) $m_1= (0.2354-0.1765)/(15-05) = 0.00589$

Similarly all the values of slope are calculated and shown in below table

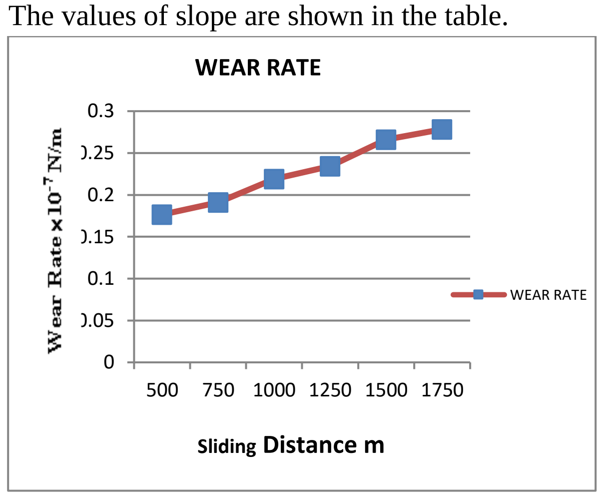
Table :Values of Slope for Variation of Load

Sr. No.	Slope (m)	m_1-m_2	m_2-m_3	m_3-m_4
1	0.00589	0.00392		
2	0.00981		0.00098	
3	0.00883			0.00295
4	0.00588			

From the above table it can be observed that the maximum variation in slope is in between m_1 and m_2. Therefore levels of load are selected from the slope with higher magnitude in variation i.e. 10N, 15N and 20N.

Varying sliding distance

Following graph shows the variation of wear rate with the variation in the sliding distance. The values of slope are calculated in the same manner as that for the load. The values of slope are shown in the table.



Graph:Variation of Wear Rate with Sliding Distance

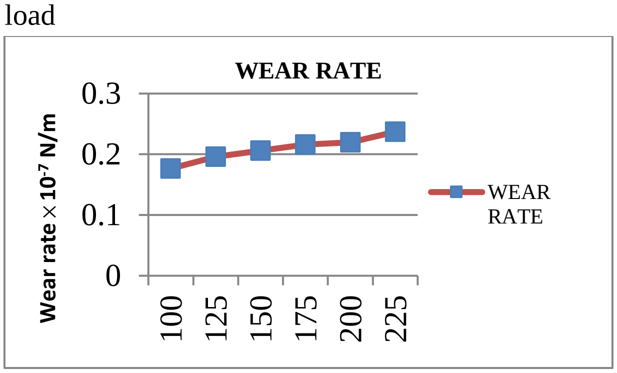
Table :Values of Slope for Variation of Sliding Distance

Sr. No.	Slope (m)	m_1-m_2	m_2-m_3	m_3-m_4
1	0.0000848	0.0000018		
2	0.0000866		0.0000074	
3	0.0000940			0.0000058
4	0.0000882			

From the above table 3.6 it can be observed that the maximum variation in slope is in between m_2 and m_3. Therefore levels of temperature are selected from the slope with higher magnitude in variation i.e. 1000, 1250 and 1500m.

Varying Temperature

Following graph shows the variation of wear rate with the variation in the temperature. The values of slope are calculated in the same manner as that for the load



Graph:Variation of Wear Rate with Temperature

From the below Table it can be observed that the maximum variation in slope is in between m_1 and m_2. Therefore levels of temperature are selected from the slope with higher magnitude in variation i.e. 100, 125 and 150.

Table :Values of Slope for Variation of Temperature

Sr.No.	Slope (m)	m_1-m_2	m_2-m_3	m_3-m_4
1	0.000590			
2	0.000392	0.000198		
3	0.000278		0.000114	
4	0.000424			0.000146

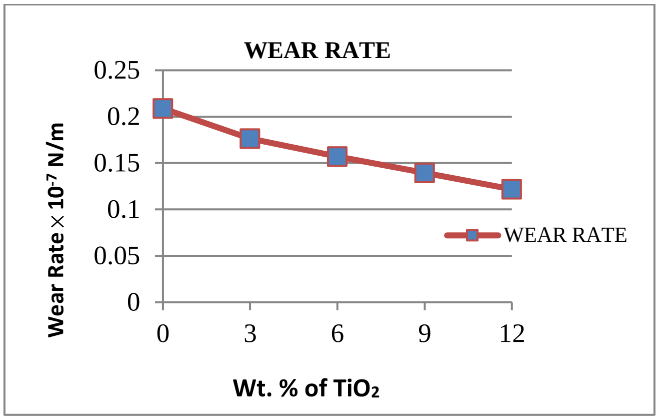
Varying Wt. % of Reinforcement

From the below table no3.8 it can be observed that the maximum variation in slope is in between m_1 and m_2. Therefore levels of wt. % of Reinforcement are selected from the slope with higher magnitude in variation i.e. 0, 3 and 6.

Table :Values of Slope for Variation of Wt. % Reinforcement

Sr. No.	Slope (m)	m_1-m_2	m_2-m_3
1	0.00864	0.00248	
2	0.00616		0.00030
3	0.00586		

Following graph shows the variation of wear rate with the variation in the wt. % of TiO_2. The values of slope are calculated in the same manner as that for the load.



Graph:Variation of Wear Rate with Wt. % of Reinforcement

Following Table shows the parameters and their levels based on the above pre experimentation results.

Table :Sliding Wear Test Parameters and Levels

Sr. No.	Parameter	Level 1	Level 2	Level 3
1	Load (N)	10	15	20
2	Sliding Distance (m)	1000	1250	1500
3	Temperature (˚C)	1000	1250	1500
4	Wt. % of TiO2p (5% Al_2O_3constant)	0	3	6

The specimen is prepared by grinding to obtain a uniform, clean area about 1 to 2 cm across. The prepared sample is placed in the spark OES instrument and flooded with argon. A rapid series of high energy sparks are created across the argon filled gap between an electrode and the prepared sample's surface.

The spark first ionizes the argon, creating conductive plasma. Secondly, the spark melts, evaporate, and excite the sample elements at the spark point of impact. When the excited atoms in the plasma relax to a lower energy state, they emit light at characteristics wavelengths for each element. The intensities of these emissions at the characteristics wavelengths are detected, measured, and compared to intensities to known standards to provide quantitative results. The total duration of sparking is only few milliseconds. Prior to actual measurements, the sample surface may be subjected to high power discharge to melt the surface and create more homogeneous material.

Table :Chemical Composition of Al 6061 + 6% TiO2+ 5% Al_2O_3

Sr. No.	Element	Percentage
1	Si	11.5
2	Fe	0.215
3	Cu	0.07
4	Mn	0.3
5	Mg	0.06
6	Ni	0.1
7	Zn	0.07
8	Ti	0.020
9	Ca	0.025
10	Pb	0.016
11	Sn	0.0051
12	Zr	0.0003
13	Al	87.57

The above table shows the chemical composition of the aluminium 6061 TiO2 Al_2O_3 composite. The chemical composition is obtained by average of three tests results. In Fabrication of Composite Material, all the oxides contained in reinforcement are reacted and only element metals are identified. The above table no.3.10 and 3.11 shows the chemical composition of aluminium 6061 TiO2 and Al_2O_3 metal matrix composite with 3%TIO2 & 6% TiO2 and 5% Al_2O_3. We have practiced aluminium 6061 TiO2 and Al_2O_3 metal matrix composite.

PERFORMANCE ANALYSIS

Table :Data for S/N Ratio Al 6061 +TiO2+ Al_2O_3 MMC for Dry Condition

Run	Load N	Sliding Distance m	Temperature °C	Wt.% of TiO2	Wear Rate × 10^{-7} N/m		S/N Ratio
					Exp-1	Exp-2	
1	10	1000	100	0	0.1317	0.1277	20.5940
2	10	1250	125	3	0.1471	0.1493	19.0305
3	10	1500	150	6	0.1826	0.1767	17.3398
4	15	1000	125	6	0.1371	0.1472	19.1628
5	15	1250	150	0	0.1921	0.2198	15.1547
6	15	1500	100	3	0.2422	0.2224	15.0370
7	20	1000	150	3	0.1763	0.1866	16.8039
8	20	1250	100	6	0.1234	0.1337	20.1440
9	20	1500	125	0	0.2516	0.2619	13.4093

Table : Data for S/N Ratio Al 6061 +TiO2+ Al_2O_3 MMC for wet condition

Run	Load N	Sliding Distance m	Temperature °C	Wt.% of TiO2	Wear Rate × 10^{-7} N/m		S/N Ratio
					Exp-1	Exp-2	
1	10	1000	100	0	0.05714	0.05479	27.3704
2	10	1250	125	3	0.05533	0.05439	29.3067
3	10	1500	150	6	0.05565	0.05708	30.1489
4	15	1000	125	6	0.05924	0.06279	27.6811
5	15	1250	150	0	0.06390	0.06393	27.1931
6	15	1500	100	3	0.06709	0.06535	33.8139
7	20	1000	150	3	0.05885	0.06591	28.3257
8	20	1250	100	6	0.06764	0.06428	28.7349
9	20	1500	125	0	0.06769	0.06723	29.5035

The Table shows the L_9 orthogonal array with repeat measurement of responses for runs one to nine. Repeats of response measurement technique is used overcome the drawback of saturated design in MINITAB software. It also shows that the SN ratio for first and second run is same as it is calculated for the repeats measurement and by taking average value. The SN ratio values are calculated with help of MINITAB 17 software.

Analysis of Variance Analysis

The adequacy of the models is tested using the analysis of variance (ANOVA) technique. It is a statistical tool for testing null hypothesis for designed experimentation, where a number of different variables are being studied simultaneously. ANOVA is used to quickly analyze the variances present in the experiment with the help of fisher test (F test). This analysis was carried out for a level of significance of 5%, i.e. the level of confidence 95%. Table shows the result of ANOVA analysis. One can observe from the ANOVA analysis that the value of P is less than 0.05 in all three parametric sources. Therefore it is clear that (1) Load, (2) Sliding Distance, (3) Temperature of the pin; (4) Wt. % of TiO_2 Reinforcement have influence on the wear of the composite. The last column in Table shows the percentage contribution of each factor on total variation indicating their degree of influence on the result.

Table :Analysis of Variance of Al 6061 + TiO2 + Al_2O_3 for Dry Condition using ANOVA

Source	DF	SS	Adj MS	F Value	P Value	%
Load	2	0.0060 3	0.002 8	30.76	0.001 0	17. 44
Sliding Distance	2	0.0182 0	0.006 3	69.26	0.002 0	52. 60
Temper ature	2	0.0035	0.001 1	11.74	0.003 0	10. 01
Wt%	2	0.0061	0.003 1	33.95	0.003 0	17. 60
Error	9	0.0009	0.000 01			
Total	17	0.0346				

Table shows the ANOVA of aluminium 6061 alloy + TiO_2 + Al_2O_3 composite on dry and wet condition. The result show that for dry condition, sliding distance (52.60%) have the highest influence on wear rate of the composite while Temperature (10.01%) have least influence on wear rate of composite. In case of wet sliding wear Load (75.91%) have highest influence on wet sliding wear of the composite, while Temperature (3.07%) have least influence on wet sliding wear of composite. The interaction between them is also significant. The wt. % of TiO_2 in case of dry sliding wear has contribution of (17.60%) indicates that, it affects the wear rate. while for wet sliding wear wt% of TiO_2 (1.45%) indicates that, it affects the wear rate.

Table : Analysis of Variance Al 6061 + TiO2 + Al_2O_3 for wet condition using ANOVA

Source	DF	SS	Adj MS	F	P	%
Load	2	0.0003 10	0.00014 4	30.2 9	0.00 101	75.9 1
Sliding Distance	2	0.0000 4	0.00001 7	3.45	0.00 31	9.25
Temper ature	2	0.0000 13	0.00000 6	1.20	0.03 9	3.07
Wt%	2	0.0000 059	0.00000 29	0.64	0.03 00	1.45
Error	9	0.0000 41	0.00000 47			
Total	17	0.0004 12				

Model Summary for Dry Condition:

S	R-Sq	R-Sq (adj)	R-sq (Pre)
0.009465	97.65%	95.58%	96.61%

Model Summary for Wet Condition:

S	R-Sq	R-Sq (adj)	R-sq (Pre)
0.008560	94.87%	93.11%	91.42%

Main Effects Plots

The influence of each control factor (Load, Sliding Distance and Temperature of the Pin) on wear rate was analyzed from the S/N ratio response table, which expresses the S/N ratio at each level of control factor. The control factor influence is determined by its level difference values. A bigger control factor level difference means a greater influence on the wear.

Calculation of SN ratio:

SN ratio with smaller is better characteristics was used and calculated with help of MINITAB software for the experimental runs. The values of the entire SN ratio are shown in the Table 5.1 shows the S/N ratios for aluminium-silicon alloy TiO2 and Al_2O_3 composite.

$$SNratio = -10 \times \log(Wearrate)$$

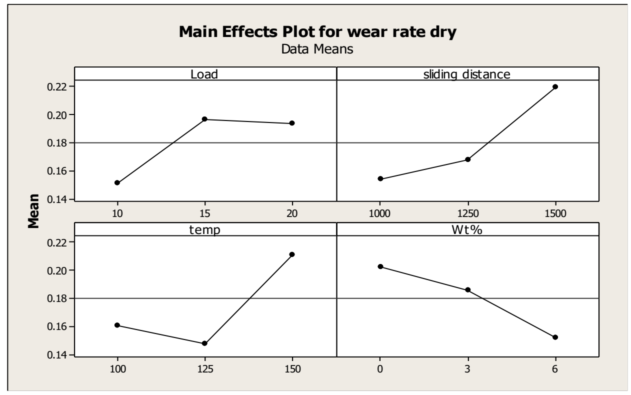
SN ratio for trial one:

$$SNration = -10 \times (0.1297)$$

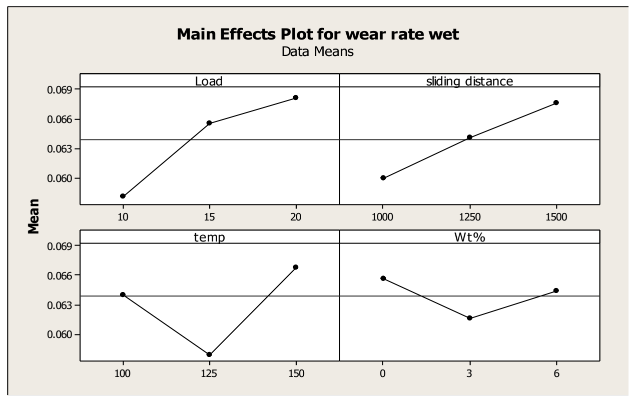
SN ratio=20.5940

Similarly SN ratio values for other experimental runs are obtained.

The graphs show the Main Effect plot for S/N ratio for aluminium 6061 alloy reinforced with TiO_2 and Al_2O_3 in dry and wet condition. The level for a factor with the highest S/N ratio was the optimum level for response measured. From the plot, it is observed that the minimum wear was at the higher S/N values in the response graph. The optimal wear parameters were 1.0 Kg Load (level 1), 1000 m sliding distance (level 1) and 100°c temperature (level 1) and Composite with 6 wt% of TiO2 and 5% Al_2O_3. Graph shows graphically the effect of control factors on wear. Process parameter settings with highest ratio always give the optimum quality with minimum variance. The graph show the change of ratio when setting of the control factor was changed from one level to another



Graph:Main Effect Plots for S/N ratio of Aluminium 6061 + TiO_2 + Al_2O_3 MMC for Dry Condition



Graph:Main Effect Plots for Wear rate Means of Al 6061 + TiO_2 + Al_2O_3 MMC for Wet Condition

From the main effect plot for means it is observed that Wear is a function of load, sliding distance and temperature of the pin and Wt% of TiO_2. Load and Sliding distance are the dominant factors affecting wear rate of composite and temperature is less dominant factor for aluminum composite. These Taguchi results compared with regression analysis shows close agreement. The main effect plots for parameters such as load, sliding distance, wt% of TiO_2 and temperature is obtained from regression analysis using Minitab Version 17 statistical software to predict the optimum level for response measured.

Multiple Linear Regression Models

To establish the correlation between the wear parameters (1) Load, (2) Sliding distance, (3) Pin temperature, (4) Wt% of TiO_2 and the dry sliding wear loss the wear multiple linear regression model was obtained using statistical software "MINITAB R 17".The terms that are statistically significant are included in the model. Final Equation obtained is as follows,

Wear equation for Al 6061 TiO_2 and Al_2O_3 composite:

The regression equation for wear rate in dry condition

Wear Rate = - 0.0865 + 0.0038 Load + 0.00013 sliding distance

+ 0.0004 temp - 0.0076Wt% …. (1)

The regression equation for Al 6061 TiO2 and Al_2O_3 composite in wet condition:

Wear Rate= 0.0430 + 0.00099 Load + 0.0000079 sliding distance

- 0.000039 temp - 0.000276Wt%... (2)

Substituting the recorded values of the variables in the above equation (1) and (2) the wear rates of the materials are calculated. The positive value of the coefficient suggests that the wear rate of material increases with their associated variables. Whereas the negative value of the coefficient suggest that the wear rate of the material will decreases with the increase in associated variables. The magnitude of the variables indicates the weightage of each of these factors. It is observed from the Equation (1) that the Sliding Distance is the more effective on wear rate of the composites in case of dry sliding wear, which is followed by Load, Wt% of TiO_2 and Temperature for tested range of variables for aluminium 6061 alloy reinforced with TiO_2 and Al_2O_3 metal matrix composite. It is observed from the Equation (2) that Load is the more effective on wear rate of the composites in case of wet sliding wear, which is followed by Load, sliding distance, Wt% of TiO_2 and Temperature for tested range of variables for aluminium 6061 alloy reinforced with TiO_2 and Al_2O_3 metal matrix composite.

Confirmation Test

To test the efficiency of the model the confirmation tests were performed by selecting the set of parameters as shown in Table for aluminium 6061 alloy reinforced with TiO_2 and Al_2O_3. Following table shows the comparison of wear results from the mathematical model developed in the present work equation (1) with values obtained experimentally respectively.

Table : Optimum Level of Parameters for Dry Condition

Sr. No.	**Parameter**	**Optimum level**
1	Applied Load	10N
2	Sliding Distance	1000m
3	Temperature	125 ºC
4	Wt. % of TiO2	6 %

Table :Optimum Level of Parameters for Wet Condition

Sr. No.	**Parameter**	**Optimum level**
1	Applied Load	10N
2	Sliding Distance	1000m
3	Temperature	125 ºC
4	Wt. % of TiO2	3 %

Table:Confirmation Experiment Result for Dry Sliding Wear

Parameter	**Model value**	**Experimental value**	**Error %**
Wear rate	0.1057	0.1006	4.79

Table:Confirmation Experiment Result for Wet Sliding Wear

Parameter	Model value	Experimental value	Error %
Wear rate	0.0551	0.05290	3.82

By comparing the results of values obtained from wear rate equation and results of confirmation test, we have concluded that the confirmation test holds the equation for the values which are not included in the orthogonal array. It can be observed from table and that the calculated error varies from 3% to 5% for wear. Therefore the multiple regression equation derived above correlate the evaluation of wear rate in the composite with the degree of approximation

CONCLUSION

Following conclusion can be drawn based on test results: Wear rate has increased with increase in load, speed, and SD due to the surface elimination and formation of pits & masses of the aluminum alloy under dry condition.

The sliding Wear resistance under lubricated situation showed the same trend, but the wear rate was comparatively very low for the same parametric condition as that of the dry situation.Because, lubricants are typically used to separate moving parts in a system this separation has the benefit of reducing friction and surface fatigue, together with reduced heat generation, operating noise and vibrations. Typically the lubricant-to-surface friction is much less than surface-to-surface friction in a system without any lubrication.

Influence of input parameters on the wear rate was estimated, It was found that in case of dry sliding wear most influencing factor is Sliding distance (52.60%), while the least influencing factor is Temperature (10.01).Because as the sliding distances increases temperature increases causes fatigue failure of the material after some interval of time. This fatigue failure occurs because of localized tensile stresses.

In case of Wet sliding Wear the most influencing factor is Load (75.91%), While the least influencing factor is Wt% (1.45%).Because as the load increase contact Pressure increases In general, higher contact pressures between the abrasive particle and the wear surface in abrasive wear situations cause higher wear rates. As the contact pressure nears and exceeds the yield strength of the wear surface in the contact zone, the depth of abrasive penetration increases.

In the case of lubricated wear condition, load, and SD factors dominate on the wear rate whereas wt% factor is almost negligible.

Addition of TiO_2 content has been found to be reducing wear rate, compared to matrix alloy. Because addition of TiO_2 causes increase in hardness of the composite. The hardness of the wear material, or more particularly, the hardness of the worn surface, is an important parameter in determining the resistance of a material to abrasion. An increase in the surface hardness of the wear material reduces the depth of penetration by the abrasive particle, leading to lower wear rates.

Within the operating range temperature is found to be influence wear rate marginally.

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