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INVESTIGATION AND OPTIMIZATION ON TRIBOLOGICAL DRY WEAR BEHAVOUR OF LM24 ALUMINUM COMPOSITE ALLOY

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Abstract *: Due to their high strength, superior wear resistance, high stiffness, and stability at high temperatures, metal matrix composites have been extensively used in applications related to the aerospace, automotive, communication, transport, marine engineering, and defence industries. Businesses have been concentrating on using innovative materials that give high strength to weight ratios, high stiffness to weight ratios, and desired wear resistance. In this study, stir casting was used to try to reinforce the graphite in the LM24 aluminium alloy, and response surface methods was used to assess and optimise the wear rate of the composite. Three parameters, including load, sliding distance, and sliding velocity, were chosen, and each parameter had three levels of variation. The tests will be conducted using 15 experimental designs based on the Box Behnken Design. Experimental evaluations of dry wear are conducted. Mathematical models were created and RSM-based optimization was used to lower the minimum wear rate. The wear rate on reinforced LM24 aluminium alloy with graphite is investigated using surface plots, and the best ideal solution is determined. The surface plot shows that 11 N load, 1 m/s sliding speed, and 2000 m sliding distance are the best process parameters for dry wear rate.*

keywords **-** *Dry wear rate, LM24 aluminium alloy, stir casting, graphite coating, and Response surface approach.*

I. INTRODUCTION

A solid is melted, heated to the suitable temperature, and sometimes treated to change its chemical composition before being poured into a cavity or mould where it is contained in the correct shape while solidifying. This manufacturing process is known as casting. Consequently, any metal that can be melted can be used to create basic or complicated forms in a single operation. The final product can be configured almost however the designer wants. Also, it is possible to make a beautiful look, control directional qualities, and maximise the resistance to working pressures. Sizes of cast pieces range from a thousandth of an inch and an ounce to over 30 feet and many tonnes.The fabrication of complex shapes, parts with hollow sections or internal cavities, parts with irregularly curved surfaces, very big parts, and parts formed from metals that are challenging to machine all benefit significantly from casting. Casting is one of the most crucial production processes due to these clear benefits. In stir casting, the molten metal matrix is stirred with a stirrer. The material used to make the stirrer often has a greater melting point than the matrix temperature. Graphite stirrers are typically used in stir casting. The stirrer primarily consists of two parts: a cylindrical rod and an impeller. The rod's other end is attached to the motor shaft, while its other end is connected to the impeller. The stirrer is typically kept upright and rotates at different speeds thanks to a motor. Afterward, the molten metal is poured into a die for casting. Stir casting can be used to create composites with reinforcement volume fractions up to 30%. The following conditions are utilised to reduce casting flaws, such as blow holes and cracks: melt temperature of 730 oC, stirrer speed of 600-750 rpm, preheating temperature of reinforcements of 225oC, material used as cylindrical die, and rapid impact pressure. Aluminum is the main metal in alloys made of aluminium. Copper, magnesium, manganese, silicon, tin, and zinc are common alloying elements. Casting alloys and wrought alloys, which are further separated into the categories of heat-treatable and non-heat-treatable, are the two main classifications.Around 85% of aluminium is utilised to make wrought goods. In engineering constructions and parts where light weight or corrosion resistance are needed, aluminium alloys are frequently used. Since the invention of metal-skinned aircraft, alloys mostly made of aluminium have played a significant role in the aerospace manufacturing industry. If aluminium alloy surfaces are not anodized and painted properly, a protective film of white aluminium oxide will form on them. This process, also known as dissimilar-metal corrosion, can take the form of exfoliation or intergranular corrosion. The Society of Automotive Engineers standards organisation, specifically its aerospace standards division, and ASTM International are just two organisations that issue more detailed standards for the production of aluminium alloy. The primary goal of this research project To create a metal matrix composite by stir casting graphite reinforcement into an aluminium alloy, and to analyse the composite's dry and wet sliding wear behaviour. to enhance the tribological properties of the LM 24 Aluminum alloy's dry and wet sliding wear behaviour. With the use of changing parameters, such as normal load, sliding velocity, and sliding distance, the effect of sliding wear was examined. The range of the usual load was 10-30N. The range of the sliding velocity was 1-3 m/s. The sliding distance ranged from 1000 to 2000 metres. ANN is used to anticipate output responses, and prediction values from mathematical models are contrasted with experimental results.

II. MATERIALS AND METHODS

One of the most often used alloys in its series is the aluminium alloy of grade LM 24. Being a wrought alloy, it is not utilised in casting but is normally made through extrusion and rolling. Although it is uncommon to forge and clad this alloy, it can be done. Although it cannot be work-hardened, heat treatment is frequently used to create tempers that have a higher strength but less ductility. Physical characteristics are those that can be seen without affecting a substance's identity The Table depicts the LM 24 Aluminium Alloy's physical and mechanical characteristics.

PROPERTIES	VALUE
Coefficient of Thermal Expansion (µm/mK)	23.1
Tensile Yield Strength (MPa)	280
Ultimate Tensile Strength (MPa)	140 - 330
Density (g/cm^3)	2.71
Melting Temperature (°C) approx.	575

Table provides the LM 24 Aluminum alloy's chemical make-up.

ELEMENTS	CONTRIBUTION (%)
Silicon (Si)	7.5
Iron (Fe)	1.3
Copper (Cu)	3.0
Manganese (Mn)	0.5
Magnesium (Mg)	0.3
Nickel (Ni)	0.5
Zinc (Zn)	3.0
Titanium (Ti)	0.2
Aluminium (Al)	83.7

2.1 Design Of Experiments Using Response Surface Methodology

To improve the quality of products and processes, Response Surface Methodology has recommended a standardised way to apply the Design of Experiments technique. RSM is used to build approximation models based on experimental findings, computer simulations, and physical experiments. An experiment is a series of checks, referred to as runs, in which changes are prepared inside the enter variables in order to recognize the reasons for modifications within the output response. The relation between the process parameters and the output response surface function (Y) is shown in $Y=\Phi(H,Vc,f,ap)$.

Equation illustrates how an RSM-based polynomial equation is used to mathematically represent the hard turning process in the current investigation.

$$Y=b0+\Sigma biXi+ \Sigma bijXiXj+ ki,ki=1\Sigma biiXi2$$

Where, Y is the response surface, Xi and Xj are the input variables, Xi2 and Xi ,Xj are quadratic and interaction terms of input variables, respectively. The bi, bii and bij are unknown regression coefficients, where b0 is the free term of the regression equation.

The approximation of Y is proposed by using a non-linear (quadratic) mathematical model, which is suitable for studying the contour and interaction effects of process parameters on machinability characteristics.

2.2 Box-Behnken Design

The main benefit of Box-Behnken designs is that they handle the problem of where the experimental limits should be, specifically to avoid treatment combinations that are harsh. Taking into account the corner and star points, which may be the most extreme places in the area where our experiment was conducted. 3k factorial designs are significantly less effective than BoxBehnken designs.

They estimate all linear effects, all quadratic effects, and all linear 2-way interactions. They are almost orthogonal designs.

To optimise the parameters, a total of 15 tests would be needed. According to three Level, the variables are assigned to columns based on the major component. The experiments are chosen in accordance with the level combinations once the three levels have been chosen. It is crucial to carry out every experiment. Each experimental run's performance parameter (output) is recorded for analysis. To calculate the wear rate, sliding wear tests were carried out using a pin-on-disc friction and wear tester in base oil under varied working conditions, such as variable loads, sliding velocities, and sliding distances.

Parameters and Levels

PARAMETERS	LEVELS		
	Low	Medium	High
Load (N)	10	20	30
Sliding Speed(m/s)	1	2	3
Sliding Distance(m)	1000	1500	2000

Experimental Design using RSM

S. NO	LOAD(N)	SLIDING VELOCITY (m/s)	SLIDING DISTANCE (m)
1	10	2	1000
2	20	1	1000
3	20	2	1500
4	10	2	2000
5	20	1	2000
6	10	1	1500
7	20	2	1500
8	30	2	1000
9	20	3	2000
10	30	3	1500
11	20	3	1000
12	30	1	1500
13	30	2	2000
14	20	2	1500
15	10	3	1500

To perfect the parameters, 15 trials would be necessary. Three Level requires that the variables be assigned to columns based on the primary component. After choosing the three levels, the experiments are chosen based on the level combinations. Doing each and every experiment is crucial. During each experimental run, the output (performance parameter) is recorded for analysis. In order to calculate the wear rate, sliding wear tests were carried out using a pin-on-disc friction and wear tester in base oil under varied operating conditions, such as variable loads, sliding velocities, and sliding distances. A key technique for analysing the influence of categorical variables on the answer is the analysis of variance (ANOVA). The goal of an ANOVA is to identify variations between the means of several populations; the method necessitates the examination of various variance types related to the study's random samples. It displays the variation in the response variable across many circumstances.

III. EXPERIMENTAL DETAILS

Stir casting is a liquid state technique for creating composite materials in which a dispersed phase is mechanically stirred into a molten matrix metal. In stir casting, liquid metal is agitated with a discontinuous reinforcement before being allowed to harden. With a stir casting machine developed by Swam Equip, the trials were carried out. A specially created furnace in which the melt is poured into the mould from the bottom by means of a remote control switch. With this kind of furnace, the melt does not need to be lifted and poured into the mould.

Fig. 3.1 Stir casting

The LM24 aluminium alloy is introduced to the melt furnace and it is melted at 650 °C. 5% of graphite reinforcement is preheated at 300 °C for 30 minutes. Then the preheated reinforcement mix is added with the molten matrix materials. The stirring speed is set at 500 rpm and stirrer is moved down to mix the matrix material and the reinforcement material for 5 minutes. After sufficient mixing was done, the complete slurry was poured into the die using a switch which opens the gate.

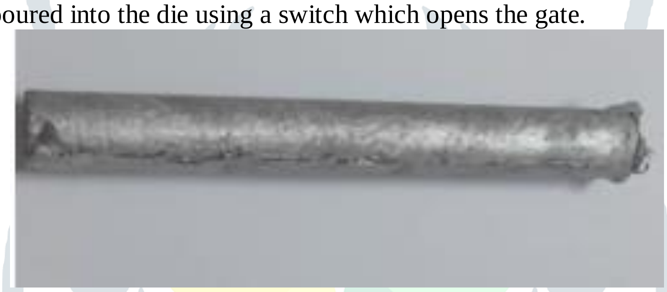


Fig 3.2 Fabricated samples

3.1 TESTING OF SAMPLES

In order to create specimens for various tests and investigate the attributes of these manufactured samples, the samples were cast in accordance with the experimental design.

Fig 3.3 Testing samples

IV. RESULTS AND DISCUSSION

The wear apparatus yielded results for dry wear, and the values are displayed in the table.

Sl NO	LOAD(N)	SLIDING VELOCITY (m/s)	SLIDING DISTANCE (m)	WEAR (micron meter)
1	10	2	1000	52
2	20	1	1000	35
3	20	2	1500	38
4	10	2	2000	46
5	20	1	2000	45

6	10	1	1500	30
7	20	2	1500	56
8	30	2	1000	70
9	20	3	2000	245
10	30	3	1500	165
11	20	3	1000	40
12	30	1	1500	74
13	30	2	2000	275
14	20	2	1500	58
15	10	3	1500	485

It was shown that samples 6 and 2 had the lowest wear rates of 30 m with a load of 10 and 20 N, 1 m/s sliding speed, and 1500 and 1000 m sliding distance, respectively. In sample 15 with a 10 N load, 3 m/s sliding speed, and 1500 m sliding distance, the highest wear rate of 485 m occurred.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	182136	20237.3	2.06	0.023
Linear	3	92030	30676.6	3.13	0.05
Load (N)	1	105	105.1	0.01	0.04
Sliding Velocity	1	70500	70500.1	7.19	0.024
Sliding Distance	1	21424	21424.5	2.19	0.154
Square	3	36346	12115.3	1.24	0.084
Load (N)*Load (N)	1	22850	22849.6	2.33	0.019
Sliding Velocity*Sliding Velocity	1	12926	12925.6	1.32	0.143
Sliding Distance*Sliding Distance	1	1275	1275.1	0.13	0.044
2-Way Interaction	3	53760	17920.2	1.83	0.19
Load (N)*Sliding Velocity	1	33124	33124.0	3.38	0.038
Load (N)*Sliding Distance	1	11130	11130.3	1.14	0.023
Sliding Velocity*Sliding Distance	1	9506	9506.3	0.97	0.05
Error	5	49001	9800.2		
Lack-of-Fit	3	48758	16252.8	133.95	0.007
Pure Error	2	243	121.3		
Total	14	231137			

To identify the design factors significantly affecting wear, an ANOVA analysis was performed. A 95% confidence level, or a significance level of 0.05, was used to assess this analysis. The load, sliding distance, and sliding velocity are determined to have p values that are less than 0.005. These criteria are important as a result. The distance is the most important component, followed by sliding velocity and weight, according to the table's f value. The R sq value is greater than 95% for it.

4.1 R-sq value:

S	R-sq	R-sq (adj)
0.459	**99.45%**	**98.23%**

Wear = 344 - 29.5 Load (N) - 107 Sliding Velocity - 0.080 Sliding Distance+ 0.787 Load (N)*Load (N) + 59.2 Sliding Velocity*Sliding Velocity- 0.000074 Sliding Distance*Sliding Distance - 9.10 Load (N)*Sliding Velocity + 0.01055 Load (N)*Sliding Distance + 0.0975 Sliding Velocity*Sliding Distance

4.2 3D SURFACE PLOT FOR DRY WEAR

Figures 4.1 to 4.3 show surface plots that link process variables such load, sliding distance, and sliding velocity to the investigation of response dry wear rate. The sample 4 with a 25 N load and a 1000 mm sliding distance saw the lowest wear rate of 33 m, as shown by the surface plot in Fig. 4.1. The maximum wear rate was observed in sample 3 with a 30 N load and a 2000 m sliding distance, which was 193 m.

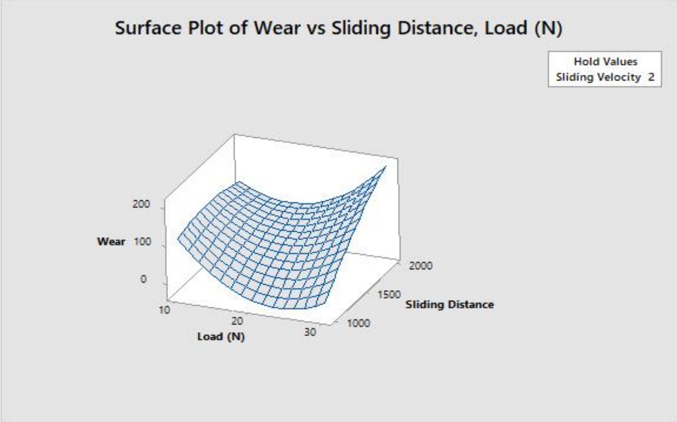


Figure 4.1 Wear vs sliding distance, Load

From the fig 4.2 the surface plot shows that sample 5 had the lowest wear rate of value 30 m at 1000 m sliding distance and 1 m/s sliding velocity. For sample 2 with 3 m/s sliding velocity and 1000 m sliding distance, the highest wear rate of value 287 m occurred.

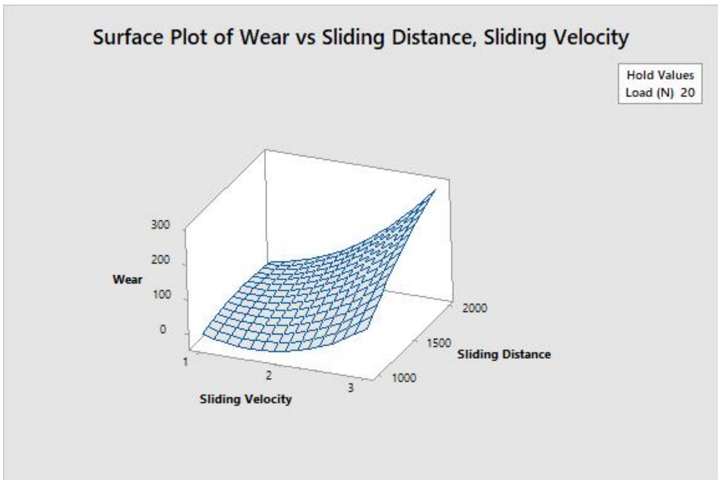


Figure 4.2 Wear vs sliding distance, sliding velocity

From the fig 4.3 the surface plot shows that sample 5 with a load of 10 N and a sliding velocity of 1 m/s saw the lowest wear rate of 44 m. Sample 6 saw the highest wear rate of 390 m with a load of 10 N and a sliding speed of 3 m/s, respectively.

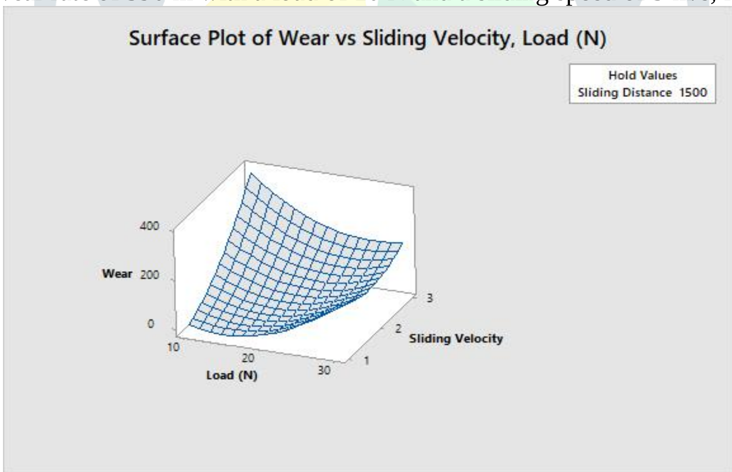
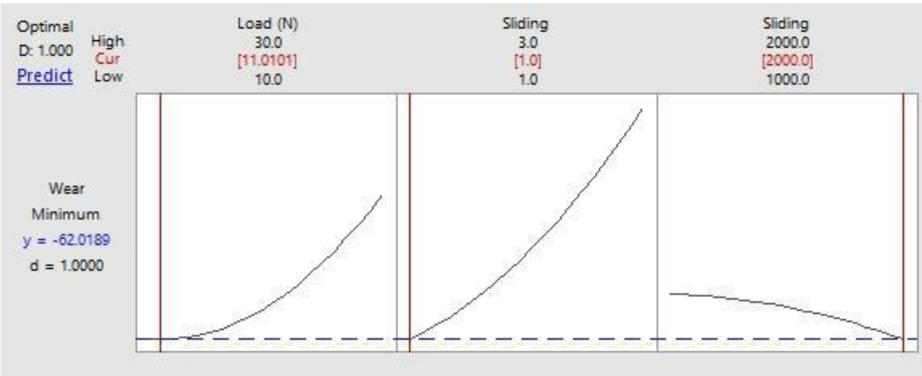


Figure 4.3 Wear vs sliding velocity, load

4.3 OPTIMIZATION DRY WEAR GRAPH

The surface figure shows that for 11 N load, 1 m/s sliding velocity, and a sliding distance of 2000 m, respectively, the minimal wear rate of 16 m happened.



V CONCLUSION

By using the stir casting process, the aluminium hybrid composites were effectively created. The samples were also examined for their tribological characteristics, and the findings were as follows**:**

The composite's wear performance was enhanced by the addition of graphite.

- With 10 N load, 1 m/s sliding speed, and 1500 m sliding distance, the minimal dry wear rate for the dry wear test of 30 microns occurred
- R2 scores show that the model terms are important.
- The model terms are significant in the Anova table when the P values are less than 0.05.
- The surface plot shows that 11 N load, 1 m/s sliding speed, and 2000 m sliding distance are the best process parameters for dry wear rate.

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