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Wear behavior of Aluminium Metal Matrix Composite with Silicon Carbide used for Brake Pads under Dry Friction Condition

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Abstract: In this paper, the wear behavior of Aluminium Metal Matrix Composite with Silicon Carbide used for Brake Pads under Dry Friction Condition is to be studied. The percentage of silicon carbide is varies from 4 to 13 in four steps. The tribological behavior of composites was investigated by pin on disc apparatus. Percentage reinforcement, load, sliding speed and sliding distance were taken as the process variable. The parameters are set for different levels and in optimum possible combination by Taguchi experimentation design array. Wear rate is obtained as a response of experimentation and then further analyzed in design expert software. Parametric relation is developed in the form of equation for each material composition. At the end all three materials are compared on the basis of wear rate and coefficient of friction. As graphical representation is the most user friendly way of interpretation of statistical data, three-dimensional graphs comparing wear rate of all three materials simultaneously under the influence of individual parameters namely load, sliding distance and sliding velocity are given in results. Conclusions of the present work are, as load and sliding distance increases wear rate also increase, and as the velocity of sliding increases wear rate slightly decrease. Material composition is the major factor influencing the wear rate of brake pad, as the wear rate of all four material are different which is shown in paper in tabulated form. The increase in percentage of silicon carbide increases the wear resistance.

Keywords: wear rate, aluminium metal matrix, SiC, pin on disc apparatus, and design expert software.

I. INTRODUCTION

Metal matrix composites are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, etc. Aluminium and its alloys have attracted most attention as base metal in metal matrix composites.

Aluminium & its alloys are widely used in industries especially in automobile & aerospace industry due to its good mechanical properties like low density, corrosion resistance as compared to conventional metal & alloys. Among the materials of tribological importance, Aluminium metal matrix composites have received extensive attention for practical as well as fundamental reasons. Aluminium alloys and aluminum-based metal matrix composites have found applications in the manufacture of various automotive engine components. Weight reducing in rapid moving parts of automobile engines such as Crankshaft, connect rod, rotor disc brake to a reduction of the weight and wear.

A brake can stop or slow down a moving vehicle by converting kinetic energy into friction heat. A Disc brake is sliding friction couple made of rotor (disc) connected to the wheel and a stator on which the friction material (say brake pad) is mounted. The friction causes wear of Brake pads.

The brake pad is characterized by the frictional behavior brake pads are always subjected to wear. The result can be dangerous if the brake fails. Therefore, the material used for brake pad is very important part of a braking system. Brake pad material should have (1) High Coefficient of friction (2) Good thermal conductivity (3) minimum wear rate (4) Good wear resistance when subjected to heavy loads and high speeds [1].

The Disc against which a brake pad slides can be Ferrous or Nonferrous, two have different effects of wear rate of brake pads [2]. To find the wear rate characteristics of different compositions of brake pad materials sliding against the same disc, a pin-on-disc setup is ideal. Pins of all four material compositions are made and tested by designing an experiment using Taguchi array [3] .Many resins and composites are used now days to meet the requirements of brake pad materials [5]. To have better wear resistance characteristics Aluminium based metal composites are used they shows better tribological properties [6].

The following work in this paper concentrates more on the material composition for brake pad and there wear rates. Pin on disc setup is used for performing experimental work to obtain wear rate, the result is analyzed using design expert 7 software, and the relation between various tests parameters are found in terms of a mathematical equation. the basic trend of effects of parameter like Normal load, Velocity of sliding and Sliding Distance on wear rate is interpreted in graphical form finally a comparison between four material compositions is made.

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1.1 Parameters in Wear Testing:

 Load: Load is important factor when we consider friction & wear. As we know, friction & wear is proportional to the applied load.

 Sliding Velocity: When it's deal with friction and wear testing machine, it is very necessary to consider the sliding velocity of the specimen.

 Sliding Distance: As we know, Sliding distance is directly proportional to wear rate.

1.2 Parameters to study:

 Coefficient Of Friction: The coefficient of friction is generally depends on the Load, sliding speed. Material should possess low coefficient of friction.

 Wear rate: Wear is the removal of material from either or both of the contacting surfaces. Material should have improved wear resistance under load and permanent deformation.

II. EXPERIMENTAL TOOLS AND TECHNIQUES

A. DESIGN OF EXPERIMENT

It is methodology based on statistics and other discipline for arriving at an efficient and effective planning of experiments with a view to obtain valid conclusion from the analysis of experimental data. Design of experiments determines the pattern of observations to be made with a minimum of experimental efforts. More specifically, the use of orthogonal Arrays (OA) for DOE provides an efficient and effective method for determining the most significant factors and interactions in a given design problem.

B. TAGUCHI METHOD

As the number of factors considered at multi-levels increases, it becomes increasingly difficult to conduct the experiment with all treatment combinations. To reduce the number of experiments to practical level, only a small set from all the possibilities is selected. The method of selecting a limited number of experiments, which produces the most information, is known as a practical fractional experiment, but there are no general guidelines for fractional experiments that cover many applications. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments, which could give the full information of all the factors that affect the performance parameter. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. A full factorial design will identify all possible combinations for a given set of factors. If an experiment consist of m number of factors & each factor at levels X, then Number of trails possible is given by (Treatment Combination) = X^m .

C. A TYPICAL ORTHOGONAL ARRAY (OA)

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. Standard notation for orthogonal Arrays is, Ln (Xm) Where,
n=Number of experiments to be conducted
X=Number of levels
m= Number of factors

III.EXPERIMENTAL DESIGN PROCEDURE

A. Statement of experimental problem:

Analysis using Pin-on-Disc wear and friction testing machine as shown in Fig.1 considering the following point.

●Study of friction behavior of Aluminium metal matrix with Silicon carbide.

●Study of wear rate of Aluminium metal matrix with Silicon carbide material under different varying condition.

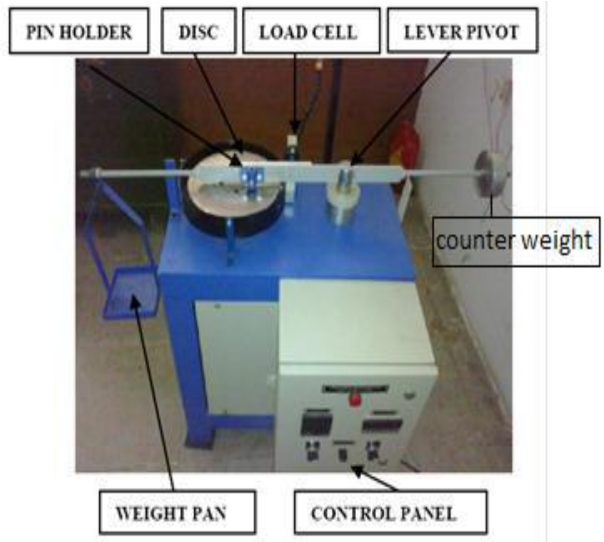

Fig.1. Pin on disc Test-Rig

B. Design of test runs:

To ensure the optimum interaction of all the parameters L9 (3^4) Method of Taguchi Orthogonal array is used which have nine test runs, 3 levels of factors, and maximum 4 factors, we identified 3 factors. The assignments of levels to the different independent factors used in investigation and its coding and designations of materials are shown in Table I-III.

Table I: Assigning of Levels to the variable as Applicable to Pin on-Disc machine

Level→	**Low**	**Medium**	**High**
Load (Kg) A	2	3	4
Speed (RPM)B	500	800	1100
Sliding distance (m) C	2000	3000	4000
Code	-1	0	+1

Table II: Designation for aluminium metal matrix materials

Material	**Composition in Wt.%**
I	4.71% of SiC with Al MMT
II	7.82% of SiC with Al MMT
III	10.13% of SiC with Al MMT

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Table III: Assigning of Levels to the Variable as Applicable Practically

Level→	Low	Medium	High
Load (kg) (A)	1	2	3
Velocity of Sliding (m/s) (B)	2.62	3.66	4.71
Sliding distance (m) (C)	1500	3000	4500
Code	-1	0	+1

C. Selection of DOE:
Design of experiments (DOE) offers a systematic approach to study the effects of multiple variables or factors on products or process performance by providing a structural set of analysis in a design matrix.

D. Performing the experiments:
Conducting the experiments as per the design matrix and recording the response parameters as shown in Table IV.

E. Data analysis:

F. Analysis of results and conclusions:

G. Confirmation test:

To test the accuracy of the model the confirmation tests were performed.
The comparison of wear results from the mathematical model equation developed in the present work.

Table IV: Layout of L9 (34) Orthogonal Array for Experimentations

Trial No.	Load (Kg)	Velocity (m/s)	SD (m)
1	1.5	2.62	2500
2	1.5	4.19	3500
3	1.5	5.76	4500
4	2.5	2.62	3500
5	2.5	4.19	4500
6	2.5	5.76	2500
7	3.5	2.62	4500
8	3.5	4.19	2500
9	3.5	5.76	3500

.

Table V: Final test run Design

Run	Load (kg)	Disc Speed (RPM)	Time (min)
1	1.5	500	12.73
2	1.5	800	11.93
3	1.5	1100	11.57
4	2.5	500	19.09
5	2.5	800	15.92
6	2.5	1100	5.78
7	3.5	500	25.46
8	3.5	800	7.95
9	3.5	1100	9.69

Table VI. Final Test Run Data for Design Expert Software

Run	Load (kg)	Sliding velocity (m/s)	Sliding distance (m)
1	1.5	2.62	2500
2	1.5	4.19	3500
3	1.5	5.76	4500
4	2.5	2.62	3500
5	2.5	4.19	4500
6	2.5	5.76	2500
7	3.5	2.62	4500
8	3.5	4.19	2500
9	3.5	5.76	3500

Table VII: Mathematical Correlations

Material	Wear equation
I	Wear rate × 10^{-05} gm /m = 25.94082 - 4.11927 × Load + 3.36786 × Sliding Velocity -0.013767 × Sliding Distance - 1.92730 × Load × Sliding Velocity +3.90295 ×10^{-03} × Load × Sliding Distance +6.17590×10^{-04} × Sliding Velocity × Sliding Distance
II	Wear rate × 10^{-05} gm/m = +11.6444691-2.5834 × Load+ 2.0762 × Sliding Velocity -0.0054094 × Sliding Distance -0.9775123 × Load × Sliding Velocity +0.00190386× Load × Sliding Distance + 0.00010283× Sliding Velocity × Sliding Distance
III	Wear rate × 10^{-05} gm/m = -1.55764 +1.589723 × Load+ 1.094404 × Sliding Velocity -0.00096 × Sliding Distance - 0.52168 × Load × Sliding Velocity +0.000283× Load × Sliding Distance – 1.79 ×10^{-05} × Sliding Velocity × Sliding Distance

Table VIII: Confirmation Test

Material	L	Vr.	SD	Actual wear	Predicted wear	Variation
	kg	m/s	Km	(gm/m) X 10-5	(gm/m) X 10-5	%
I	2	3.5	3	5.0103	4.873291	2.81142
	3	5.0	4	5.5814	6.023476	-7.1732
II	2	3.5	3	3.7263	3.658968	1.84019
	3	5.0	4	5.7124	5.645526	1.18454
III	2	3.5	3	2.7035	2.771105	-2.43964
	3	5.0	4	3.2486	3.262391	-0.42273

IV. RESULTS AND DISCUSSION

1) One can observe from Fig. 2-4 , that as load and sliding distance increases wear of all material goes on increasing where as velocity of sliding increases wear of all material goes on decreasing.
2) It is observed from Table IX, that the wear of material III is less than material I and II and as percentage of SiC in

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aluminium MMT increases, wear rate decreases.

3) Analysis of Variance (ANOVA) for Wear Rate is done for all three Material compositions and checked if the model is significant or not, when all models were significant the following list of effects showing percentage contribution of various parameters is shown in Table IX.

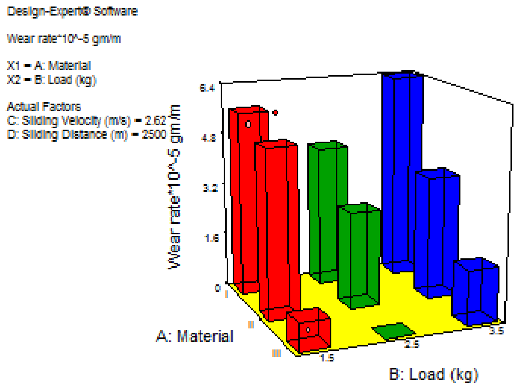

Fig 2: Wear v/s Load

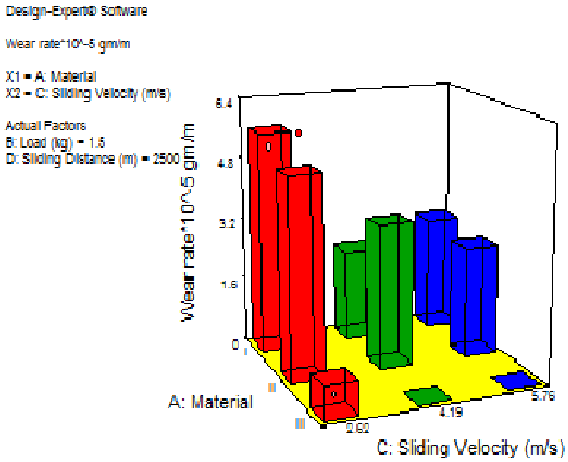

Fig 3: Wear v/s Velocity of sliding

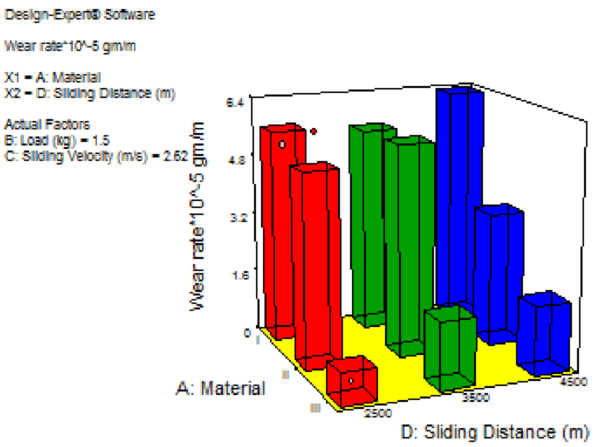

Fig 4: Wear v/s Sliding distance

Table IX: Comparative wear data of all material

Material	**Total Wear rate (I) in (gm/m)**	**Average Coefficient of friction (µ)**
I	41.32x 10-5	0.2831
II	25.92x 10-5	0.2914
III	8.17x 10-5	0.3327

V. CONCLUSION

- Wear rate of material increase with the increase in normal load.
- Wear rate of material decreases with increase in sliding velocity.
- Wear rate of material increases with increase in the sliding distance.
- Increase in percentage of SiC in composition may lead to increase in wear resistance. Material I which has 4.71 % Carbon has highest wear rate amongst three. The percentage of Carbon in Material II is 7.82% and in material III is 10.13% by weight, and the wear rates decreases with increase in % of SiC respectively.
- From Confirmation test it is observed that the percentage of Variation is for wear is between 0.42 to 2.81% which tells that the mathematical model developed for all three materials is significant.

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Nomenclature	
MMT	Metal matrix
SD	Sliding Distance
DOE	Design of Experiment
OA	Orthogonal Array
Vr	Velocity of Sliding (m/s)
I	Wear Rate (gm/m)
µ	Coefficient of Friction
µ	Coefficient of Friction

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