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Experimentation and Analysis of Aluminum Metal Matrix Composite with Silicon Carbide Used for Brake Pad Applications under Wet Friction Condition

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Abstract: The excellent mechanical properties & relatively low cost make alluminium alloys very attractive for variety of applications in scientific & technological point of view. The main aim of designing metal matrix composite is to combine the desirable properties of metals & ceramics. In this present study, we focused on the study of alluminium metal matrix composite with silicon carbide. Different percentage of reinforcement of silicon carbide is used for study.

In this paper, the wear behavior of Aluminium Metal Matrix Composite with Silicon Carbide used for Brake Pads under Wet Friction Condition is to be studied. The percentage of silicon carbide is varies in three steps. The experimentation is carried out 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. 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. 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 three material are different which is shown in paper in tabulated form. The increase in percentage of silicon carbide increases the wear resistance.

Keywords: Alluminium, metal matrix, composites, silicon carbide, disc brake system, design expert, wet condition.

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.

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.

A. *Parameters in Wear Testing*

1) *Load:* Load is important factor when we consider friction & wear. As we know, friction & wear is proportional to the applied load.
2) *Sliding Velocity:* When it's deal with friction and wear testing machine, it is very necessary to consider the sliding velocity of the specimen.
3) *Sliding Distance:* As we know, Sliding distance is directly proportional to wear rate.

B. *Parameters to study*

1) *Coefficient Of Friction:* The coefficient of friction is generally depends on the Load, sliding speed. Material should possess low coefficient of friction.
2) *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.

C. Purpose of Present Study

1) To study the friction &wear behaviour of carbon & bronze fillers in PTFE and the effect of various parameters like load, sliding velocity and sliding distance on friction & wear rate in wet conditions.
2) To study comparative effect of all parameters under wet condition.

II. LITERATURE SURVEY:

Harshal Deshmukh, Navneet Patil [1] has studied three different composites of semi-metallic brake pads for wear rate under dry conditions. Conclusions of the work are, as load and sliding distance increases wear rate also increase, and as the velocity of sliding increases wear rate slightly decrease.

Deepak Bagle [2] has studied the tribological behavior of polytetrafluoroethylene and its composites with filler materials as carbon and bronze under dry conditions. He found that addition of filler materials such as bronze and carbon to PTFE causes an increase in hardness and wear resistance, while the coefficient of friction is slightly increased. From the results the highest wear resistance was found for PTFE with carbon filler followed by PTFE with bronze filler and pure PTFE.

M. Ramesh, T. Karthikeyan, R. Arun, C. Kumaari, P. Krishnakumar and M. Mohankumar, [8] had study effects of applied pressure on the wear behavior of brake lining sliding against ferrous and nonferrous disc, In this paper they developed an indigenous pin on disc wear test setup to study the wear behavior of truck brake lining material sliding against low carbon steel and aluminium disc.

Mohammad. Asif (Dec. 2012) [12] reviews about Al- Based metal matrix composites used for automobile brake pad applications are fabricated through P/M route using 'Preform powder forging' technology. Dry sliding wear behavior of Al-MMC based brake pads against cast iron disc is studied as per ECR R-90 regulation on Krauss machine tribo-tester. It was observed that the Al- based brake pads posses lower wear rate, same order of Coefficient of friction as in resin bonded brake pads.

The following work in this paper concentrates more on the material composition and their wear rates under wet conditions. Pin on disc setup is used for performing experimental work to obtain wear rate. The result is analyzed using design expert software, and the relation between various tests parameters are found in terms of a mathematical equation. Finally a comparison between three material compositions is made under wet conditions.

III. METHODOLOGY

A. Design of Experiment

Design of experiments determines the pattern of observations to be made with a minimum of experimental efforts. To be specific Design of experiments (DOE) offers a systematic approach to study the effects of multiple variables / factors on products / process performance by providing a structural set of analysis in a design matrix. 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 [3].

B. Introduction to Design Expert

Design-Expert software is a powerful and easy-to-use program for design of experiments (DOE). With it you can quickly set-up an experiment, analyze your data, and graphically display the results. This intuitive software is a must for anyone wanting to improve a process or a product offers features for ease of use, functionality and power that you won't find in general statistical packages. Add, delete or duplicate runs in any design with the handy design editor. Rotatable 3-D color plots make response visualization easy [3].

C. 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 .

D. 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

IV. EXPERIMENTAL WORK

A. Specimen Preparation

Table I: Designation for aluminium metal matrix materials

Material	Composition in Wt.%
I	4.82% of SiC with Al MMT
II	7.63% of SiC with Al MMT
III	9.86% of SiC with Al MMT

B. Experimental Setup

Standard pin on disc test set up is used for the experiment on the specially made pins. The photo of test setup is shown on "Fig 1".

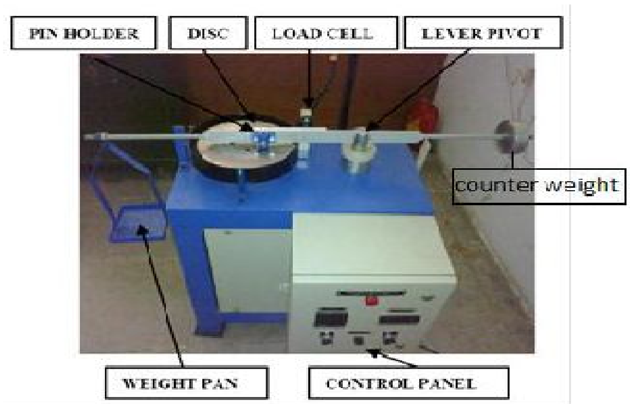

Fig.1. Pin on disc Test-Rig

C. 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 II: Assigning of Levels to the variable as Applicable to Pin on-Disc machine

Level→	Low	Medium	High
Load (Kg) A	1.5	2.5	3.5
Speed (RPM)B	500	800	1100
Sliding distance (m) C	2500	3500	4500
Code	-1	0	+1

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

Level→	Low	Medium	High
Load (kg) (A)	1.5	2.5	3.5
Velocity of Sliding (m/s) (B)	2.62	3.66	4.71
Sliding distance (m) (C)	2500	3500	4500
Code	-1	0	+1

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D. 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.

E. Performing the experiments

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

F. Data analysis

G. Analysis of results and conclusions:

H. 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

V. RESULTS AND DISCUSSION:

A. Analysis for Wear Rate

Analysis of Variance (ANOVA) for Wear Rate is done for all three Material compositions. Result graphs are obtained after wear rate analysis in Design -Expert software.

1) Comparative Study of Materials: We can observe from the Figure 2-4 that, as load increases, wear of all material goes on increasing (Fig 2), as velocity of sliding increases, wear of all material goes on decreasing (Fig 3),as sliding distance has great influence on the wear for of all the tested specimens. Wear rate increases with increasing sliding distance (Fig 4). It is observed that the wear of specimen “I” is less than specimen “II” & slightly less than specimen “III” i.e. specimen “II” has higher wear rate.

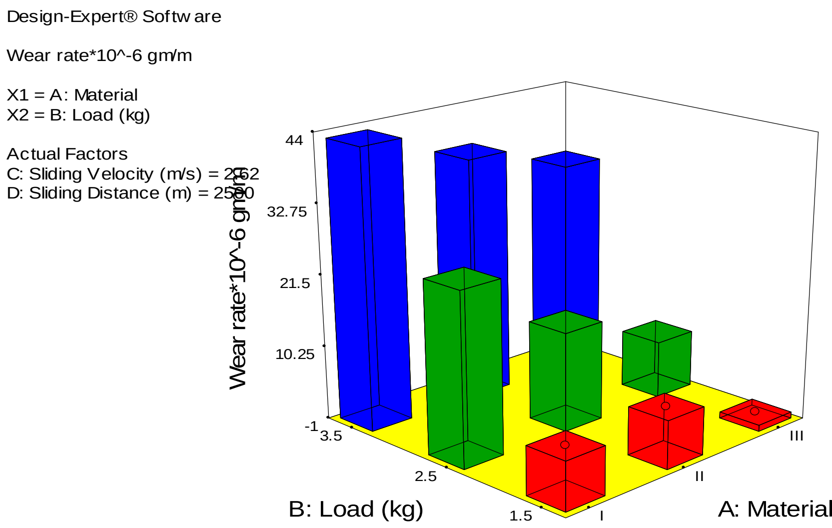

Figure 2: Wear Rate v/s Load

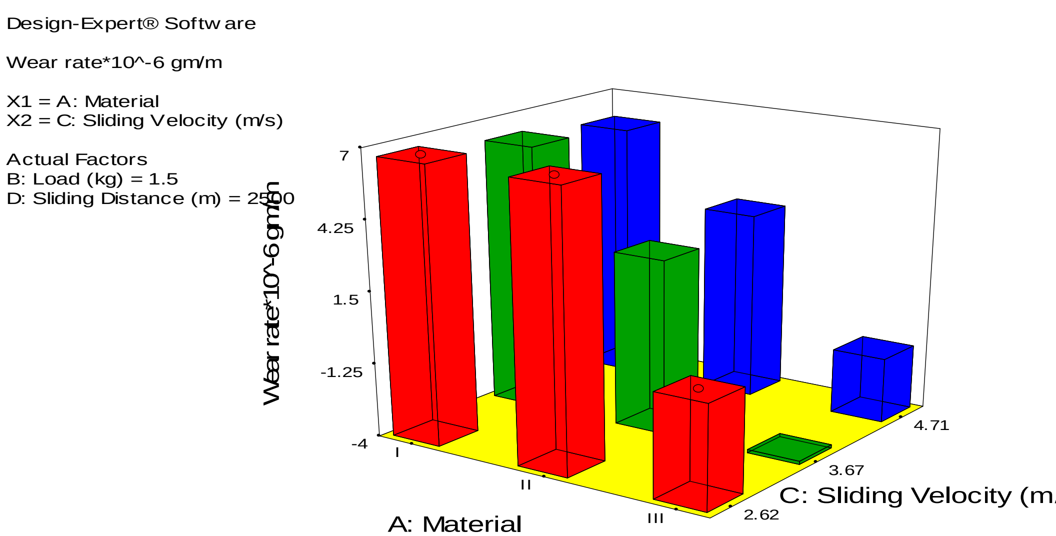

Figure 3: Wear Rate Vs Velocity of Sliding

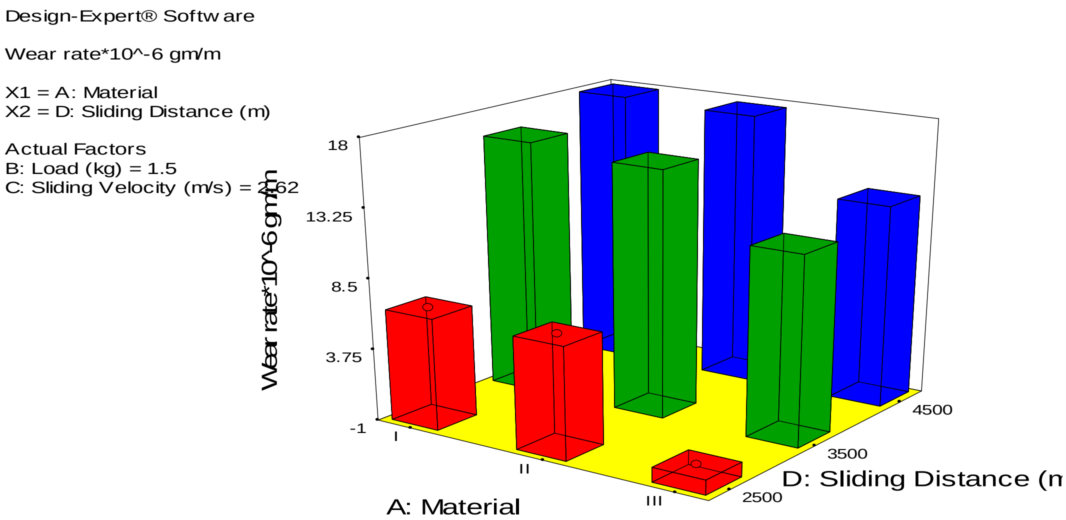

Figure 4: Wear Rate Vs Sliding Distance

2) *Table-VII: Mathematical Correlations for wear:*

MATERIAL	WEAR EQUATION
I	Wear rate × 10^-6 gm/m = -67.9137 +10.95469* Load (kg) +14.17233 *Sliding Velocity (m/s) +0.034911 * Sliding Distance (m) -1.18074 * Load (kg) * Sliding Velocity (m/s) -1.56463*10^{-3} * Load (kg) * Sliding Distance (m) -6.39107*10^{-4} * Sliding Velocity (m/s) * Sliding Distance (m)
II	Wear rate × 10^-5 gm/m = -26.14286 -3.85714 * Load (kg) +1.34213 * Sliding Velocity (m/s) -0.013310 * Sliding Distance (m) -1.20564 * Load (kg) * Sliding Velocity (m/s) +3.10714*10^{-3} * Load (kg) * Sliding Distance (m) +7.96178*10^{-4} * Sliding Velocity (m/s) * Sliding Distance (m)
III	Wear rate × 10^-6 gm/m = -33.29857 +10.09749 * Load (kg) +12.43194 * Sliding Velocity (m/s) -1.49658*10^{-3} * Sliding Distance (m) -3.41219 * Load (kg) * Sliding Velocity (m/s) +2.16327*10^{-3} * Load (kg) * Sliding Distance (m) -7.14939*10^{-4} * Sliding Velocity (m/s) * Sliding Distance (m)

3) *Confirmation test of all selected material:*

Table –VIII: Confirmation test of all selected material for wear rate

Material	Test	Velocity of Sliding (Vr)	Load	Sliding dist. (L)	Actual wear	Predicted wear	Variation
		m/s	Kg	Km	(gm/m) X 10-5	(gm/m) X 10-5	%
I	1	2.0	2	3	5.2183	4.574271	2.75142
	2	4.0	3	4	5.6894	6.728476	-6.8732
II	3	2.0	2	3	3.9243	3.258928	1.64019
	4	4.0	3	4	5.5624	5.842576	1.38454
III	5	2.0	2	3	2.7835	2.871105	-2.49964
	6	4.0	3	4	3.2986	3.462391	-0.52273

From the above analysis, we can observe that the calculated error varies from -0.52 % to 2.75 % for wear. Therefore the multiple regression equation derived above correlate the evaluation of wear.

B. Analysis for Friction

Analysis of Variance (ANOVA) for Friction is done for all three Material compositions.
Result graphs are obtained after Friction analysis in Design -Expert software.

1) Comparative Study of Materials

We can observe from the Figure 5-7 that, as load increases, coefficient of friction of all material goes on increasing (Fig 5), as velocity of sliding increases, coefficient of friction of all material goes on decreasing (Fig 6), also coefficient of friction increases with increasing sliding distance (Fig 7). It is observed that the coefficient of friction of specimen “III” is less than specimen “II” & the coefficient of friction of specimen “II” is less than specimen “I”.

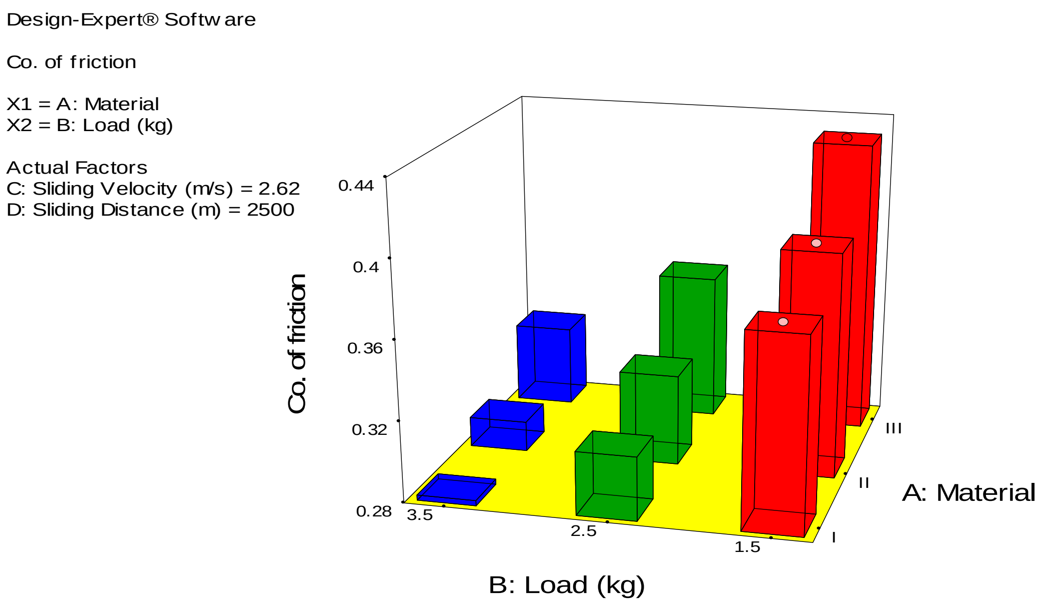

Figure 5: Coefficient of friction v/s Load

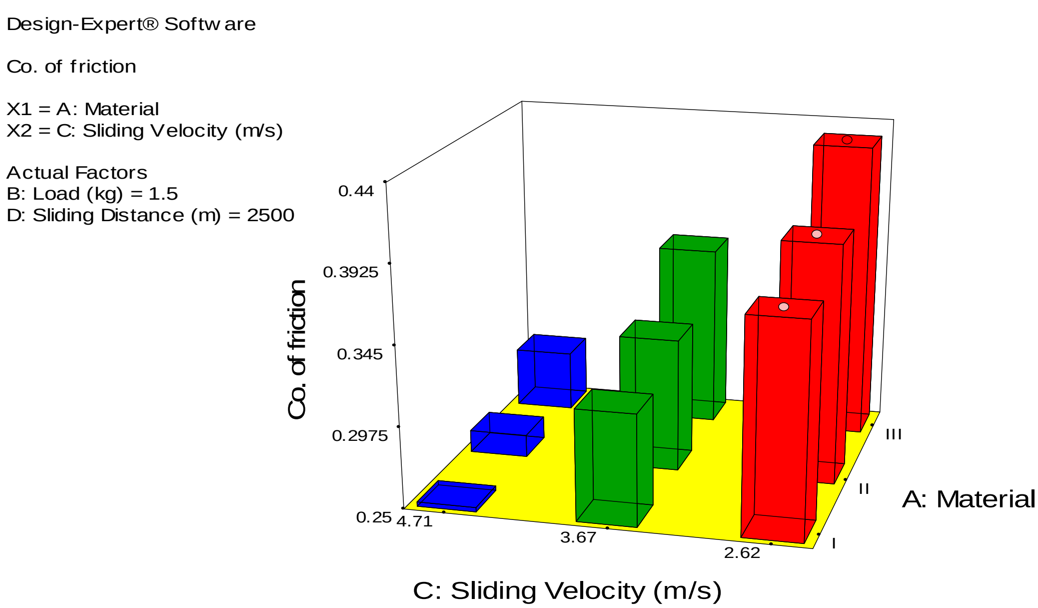

Figure 6: Coefficient of friction v/s Sliding Velocity

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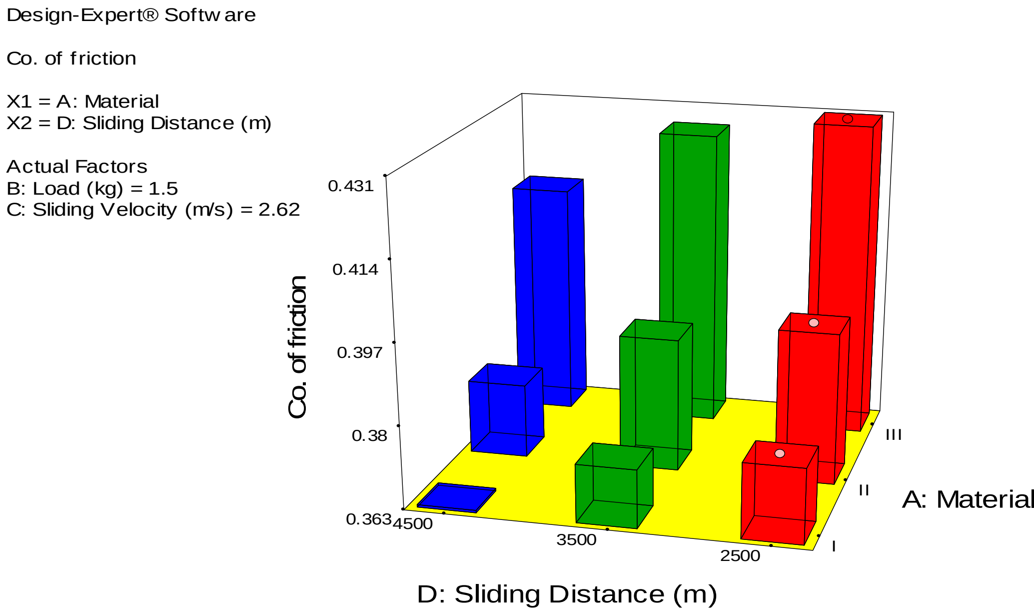

Figure 7: Coefficient of friction v/s Sliding distance

2) *Table –IX: Mathematical Correlations for Coefficient of Friction*

MATERIAL	EQUATION FOR COEFFICIENT OF FRICTION
I	Co.of Friction = +0.48591 -0.014158 * Load (kg) -0.022812* Sliding Velocity (m/s) -2.49600*10^{-5}* Sliding Distance (m) -8.46015 * Load (kg) * Sliding Velocity (m/s) +3.01544*10^{-8} * Load (kg) * Sliding Distance (m) +1.97892 * Sliding Velocity (m/s) * Sliding Distance (m)
II	Co.of Friction = +0.21610 +0.013818 * Load (kg) +0.017320 * Sliding Velocity (m/s) -1.26151*10^{-5} * Sliding Distance (m) -6.78015 * Load (kg) * Sliding Velocity (m/s) +2.61544*10^{-8} * Load (kg) * Sliding Distance (m) +2.29892 * Sliding Velocity (m/s) * Sliding Distance (m)
III	Co.of Friction = +0.55252 -0.016050 * Load (kg) -0.026043 * Sliding Velocity (m/s) -2.84386*10^{-5}* Sliding Distance (m) -9.28235* Load (kg) * Sliding Velocity (m/s) +3.85424*10^{-8}* Load (kg) * Sliding Distance (m) +2.527392 * Sliding Velocity (m/s) * Sliding Distance (m)

Table –X: Confirmation test of all selected material for coefficient of friction:

Material	Test	Velocity of Sliding (Vr) m/s	Load kg	Sliding dist. (L) Km	Actual coefficient of friction	Predicted coefficient of friction	Variation %
I	1	3.5	2	3	0.2753	0.281746	0.20611
	2	5.0	3	4	0.2684	0.268797	0.21391
II	3	3.5	2	3	0.2889	0.285105	0.19733
	4	5.0	3	4	0.2771	0.281042	1.07454
III	5	3.5	2	3	0.34435	0.33717	0.06495
	6	5.0	3	4	0.31172	0.30949	0.39773

From the above analysis, we can observe that the calculated error varies from 0.06 % to 1.07 % for coefficient of friction. Therefore the multiple regression equation derived above correlate the evaluation of coefficient of friction.

Table –XI: Comparative Wear data of all Material

Sr. No	Material	Total Loss of Weight (gm)	Average Wear Rate × (10^-5) (gm/m)	Average Coefficient of friction (μ)
1	Material-I	1.67	4.8962×10^{-5}	0.2781
2	Material-II	0.86	2.9877×10^{-5}	0.2854
3	Material-III	0.32	9.1264×10^{-6}	0.3647

VI. CONCLUSION

A. Wear rate of material increase with the increase in normal load.

B. Wear rate of material decreases with increase in sliding velocity.

C. Wear rate of material increases with increase in the sliding distance.

D. Increase in percentage of SiC in composition may lead to increase in wear resistance. Material I which has 4.82 % SiC has highest wear rate amongst three. The percentage of SiC in Material II is 7.63% and in material III is 9.86% by weight, and the wear rates decreases with increase in % of SiC respectively.

E. From Confirmation test it is observed that the percentage of Variation is for wear is between -0.52 to 2.75% which tells that the mathematical model developed for all three materials is significant.

F. With increase in Percentage of Sic the surface morphology of material becomes rough and provides maximum coefficient of friction. Material-III with more percentage of SiC which shows maximum coefficient of friction during tests.

VII. ACKNOWLEDGMENT

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)
M	Coefficient of Friction

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