Tribological Study of Aluminum Based Composite Material for Automotive Brake Material

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Abstract: ***Automobile braking system is one of the most important mechanical devices. It is used for slowing or stopping the rotation of the wheel. The main aim of the braking system is to control the speed of the vehicle for which there is need of maximum coefficient of friction which can be obtained by studying the tribological study of automobile brake and brake pad material. So for braking action coefficient of friction & frictional force should be optimum. But there is limitation because inordinate braking causes hot spot formation and wear of the brake pad material. Composite strong lightweight materials are used for the industrial application because of their good mechanical properties compared with the conventional alloys and materials. According to ASTM G99 standard pin on disc apparatus is used to determine the relative wear. Taguchi approach with the L9 array is employed to conduct experimentations and extraneous array, signal to noise ratio and ANOVA for investigating wear behavior of composite brake pad.***

Index Terms - Metal Matrix Composites, Orthogonal Array, Stir Casting, Taguchi Method, Wear behavior.

I. INTRODUCTION

Brake pads as a friction material are used in vehicles for braking action so as to stop the vehicle and the force applied can be hydraulic, mechanical, pneumatic or electromagnetic to the both sides of the brake disc. The disc brake and wheel of vehicle are stopped or slowed due to the force of friction created. Disc brake can be cooled readily also their recovery time is less as compared to the drum brakes. Braking performance of the vehicle is increased by the usage of the disc brakes with respect to drum brakes. Because of the above mentioned characteristics the disc brakes are now being very widely used in light weight vehicles such as cars and motor bikes. Because of generation of high temperatures due to braking action the surface of the brake rotor has formation of cracks and also the rotor can get plastically deformed.

The wear of brake pad is caused because of high stopping force, because of the wear and tear the micro particles of the brake pad get framed in the middle of the rotor disc and the brake pads. The metal matrix composites have good resistance capabilities against wear and tear as compared with conventional grey cast iron for sliding action against the vehicles friction material which makes them superior and ultimately are used as an alternative to the cast iron. The most important physical phenomena related to braking is friction. The resistive force acting on a body prevents or slows the slipping of the body relative to a second body or surface. This relative motion can be expressed as a combination of sliding, rolling and spin. The force is acting tangent to the surface at points of contact and is directed to opposite to relative motion. There are several types of friction, but this study will focus on dry friction which is sometimes adverted to as Coulomb friction. The resistance of relative motion between two solid surfaces in contact at rest or in motion can be termed as dry friction.

II. LITERATURE REVIEW

S. Vijayarangan, N. Natarajan, & I. Rajendran [1] looked into wear behavior of A356-25SiC_p aluminum metallic matrix composite versus delineating material & compared with mainstream grey cast iron. A uniform reduction of coefficient of friction with respect to increase in load is observed for both Al MMC materials & cast iron. The wear and tear of the delineating material had increased more when sliding against MMC disc because of the plugging of the delineating stuff by the silicon carbide subatomic particles.

A. Douad, M.T Abou El-Khair [2], studied the wear and tear behavior of sand cast brake rotor made of A359-20%vol SiC particle composite sliding against automotive friction material. The load and speed are kept in the range of 30–100N and 3–12m/s on the wear and friction behavior of sand cast brake rotor constructed of A359-20 volume % SiC particle composites slewing against automobile friction material was investigated.

R.K. Uyyuru, M.K. Surappa & S. Brusethaug[3] investigated tribological behavior of stir-cast Al–Si/SiCp composites against automobile brake pad material was studied using Pin-on-Disc Tribotester. The Al-metal matrix composite (Al-MMC) material was used as disc, whereas the brake pad material forms the pin. It has been found that both wear rate and friction coefficient vary with both applied normal load and sliding speed. With increase in the applied normal load, the wear rate was observed to increase whereas the friction coefficient decreases. However, both the wear rate and friction coefficients were observed to vary proportionally with the sliding speed. During the wear tests, formation of a tribo-layer was observed, presence of which can affect the wear behavior, apart from acting as a source of wear debris. Tribo-layer formed over the worn disc surfaces was found to be heterogeneous in nature.

V.D. Londhe, Prof. M.S. Mhaske, Prof. R.A. Kapgate[4] experimented that for semi-metallic lining material there is the transfer of material on disc & leads to the formation of the transfer layer, but at higher load & sliding, there is generation of high temperature & destruction of transfer layer which leads to increase in wear. The coefficient of friction for semi-metallic lining material is high but wear is also maximum. For LM13 cast Al alloy the wear & frictional force increases with increase in load & sliding velocities. For LM13-10SiC composite material wear is negative & the coefficient of friction is high at lower load as compared to semi-metallic lining material.

"Dry Sliding Wear Behavior of aluminum /Be3Al2(SiO3)6 Composite Using Taguchi Method" H. B. Bhaskar and Abdul Sharief [5] shown investigation relating to the influence of wear parameters like sliding speed, applied load and sliding distance on the dry sliding wear of aluminum metal matrix composites.

In "Frictional and Wear Characteristics of Stir-Cast Hybrid Composite aluminum Al6061 reinforced with SiC Particulates". Experimental investigation & analysis of wear parameters on Al/SiC/Gr- Metal matrix hybrid composite by Taguchi method by Rachit Marwaha, Mr.

Rahul Dev Gupta, Dr. Vivek Jain [6] depicts Metal matrix hybrid composites (MMHCs) are now gaining their usage in aerospace, automotive and other industries because of their inherent properties like high strength to weight ratio, hardness and wear resistance, good creep behavior, light weight, design flexibility and low wear rate.

III. PROBLEM DEFINATION

The continuous braking leads to break and causes severe wear and tear of brake pad. Heavy braking leads to establishment of grooves on brake pads, hot spots on brake disc and excessive wear leading to failure of brake system. In order to optimize the existing semi metallic material used in passenger car the study of tribological behavior of LM9 composite under various load and sliding velocity is performed.

3.1Objective

The prime objectives of the experiment are as follows

1. To design the performance characteristics for L9 orthogonal array by Taguchi method.
2. To seek the deportment of the material subject to wear and friction point of view and study the effect at different sliding speeds, loads, sliding distance and material.
3. Usage of the ANOVA technique to identify the significant control factors contribution.

IV. MATERIAL

According to classical theory of dry friction/ adhesive wears depends upon applied load, reinforcement fracture toughness wearing surface hardness, and morphology the precarious condition of wear. The aluminum alloy LM9 selected as base material for composite as these are chosen where sliding contacts (coulombs friction/ adhesive wear) are expected. And selected reinforcing element is Titanium Carbide.

4.1Pin Material (Brake Pad)

The pin samples are made of composites of LM9 Al alloy and semi metallic brake pad delineating of the passenger car. The pins are of diameter 12 mm and 32 mm and length 32mm. The semi metallic pin is having square cross-section of dimension 8 x 8 and length 30 mm. Square cross-section is selected for semi metallic pins are because the circular section are tedious to manufacture. A 320 emery paper is used for cleaning the coat of pin samples. The pin specimen for Al alloy and composite are shown in fig.1

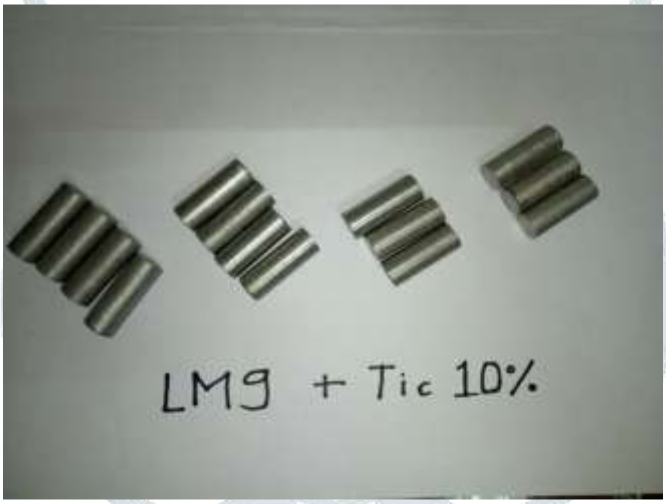

Fig.1 Al Alloy Composite Pin Samples

4.1.1 Chemical Composition

Table below shows the chemical composition for the pin material LM9+10%TiC

Table 4.1.1 Chemical Composition for LM9+10% TiC

Sr. No	Substance	% Composition
1	Silicon (Si)	9.20
2	Copper (Cu)	0.10
3	Magnesium (Mg)	0.60
4	Nickel (Ni)	2.40
5	Zinc (Zn)	0.06

4.2 Disc Material

The disc has similar chemical makeup as the brake disc used in passenger vehicles for testing, which is of grey cast iron manufactured at Bhagwati Casters Pvt, Ltd,Nasik. The dimension of the disc is diameter of 165 mm & 8 mm thickness having surface disorderliness value (Ra) of 1.57 similar to actual brakes.

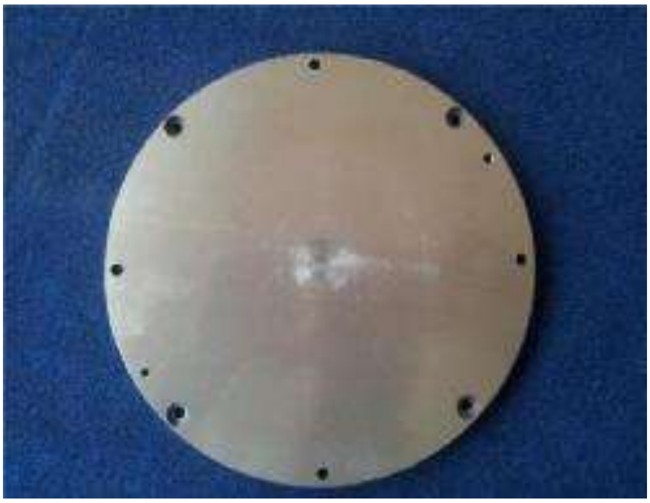

Fig.2 Grey Cast Iron

V. DEVELOPMENT OF LM9 AL/TIC METAL MATRIX COMPPOSITES

The composite matrix is made by reinforcing the LM9 cast Al alloy with Titanium Carbide subatomic particles of size 25 (10% by weight). The LM9 Al alloy in actual is the combination of aluminum-silicon alloy widely used for high temperature application where the main focus is on low coefficient of thermic expansion & good acquitting properties. For manufacturing the composite the method of stir casting is used. For oxidizing the surface of the titanium carbide particles they are preheated till 9000 C in a muffle furnace for 3hrs. Electric furnace is used to melt Aluminum Alloy(LM9) at a temperature 600-7000 C, and this molten slurry is stirred for 3-5mins in clockwise as well as anticlockwise direction at 400rpm so as to create the vortex. Nitrogen gas is used to prevent the happening of blow holes by using the technique of degassing for the molten slurry. After this the preheated TiC particles are added simultaneously while stirring. The TiC particles are well dispersed in Al matrix due to the negative pressure at center because of the formation of vortex. The molten metal is inserted in the sand mould after stirring for about 20mins.

VI. OVERVIEW OF TAGUCHI METHOD

Taguchi method has certain assumptions considered the method is used for designing engineering systems such as a machine to do require work, function or manufacturing product or item. For designing the system in first place, some understanding of prime processes is too considered inherent in the system. The same knowledge is used for making the experiments more efficient. It is eminent that we skip extra effort which might have gone in to investigating interactions that does not exit. By not considering much of details, it has already been known that the level of efforts can be decreased by ten or twenty times or maybe more in some cases. Other main aspect of Taguchi method is the appreciation that some variables can be controlled and some cannot be. In Taguchi terms such are called as Control Factors and Noise Factors respectively. Taguchi is employed in four numbers of steps

1. Conceptualize the quality characteristics and design parameters important to the product/processes.
2. Plan, conceptualize and conduct the experiment.
3. Study the results to ascertain the optimum conditions of Al-TiC composite. Experiments will be conducted with the factor level as given in table 1

6.1 Design of Taguchi

As per Taguchi approach the test conducted depends on the number of parameters and no. levels, the proper L9 orthogonal array is selected.

Table 6.1.a Parameter and there Level for Wear Test

Controllable Factor	Load, L (N)	Sliding Speed, S(m/s)	Sliding Distance, D (m)
Level 1	10	3.04	2000
Level 2	13	3.85	3000
Level 3	15	4.13	4000

Table 6.1.b Orthogonal Array Condition

Load L (N)	Sliding Speed V (m/s)	Sliding Distance D (m)
10	3.04	2000
10	3.85	3000
10	4.13	4000
13	3.04	2000
13	3.85	3000

13	4.13	4000
15	3.04	2000
15	3.85	3000
15	4.13	4000

6.2 Design of Experiment

The knowledge of process/products which are to be investigated is of prime importance before designing experiment so as to identify the factors likely to influence the outcome. The focus of the analysis is to find the answers for optimum condition, factors contributing to seek the result and the expected result at the optimum condition.

Fig. 3 Experimental Setup

In Tribometer, counter surface of known material is to be fixed. Pin on stiff lever having frictionless force transducer. The deflection of the highly stiff elastic arm, without parasitic friction, insures a nearly fixed contact point and thus a stable position on the friction track. The friction coefficient is determined during the test by measuring the deflection of the elastic arm. Wear coefficients for the pin and disc material are calculated from the volume of the material lost during the test. The simple method facilitates the study of friction and wears behaviors of almost every solid state material combination with or without lubricant. 6Furthermore, the control of the test parameters such as speed, contact pressure and varying time allow a close reproduction to the real life conditions of practical wear situations.

6.3 Specification of Tribometer

Table 6.3 Specification of Tribometer

Sr. No	Parameter	Value
1	Wear Disc Size	165mm Dia. 8mm Thick
2	Specimen Pin Size	3,6,8,10,12 mm dia 25-30mm long
3	Disc Rotation	Mean 200rpm Max 2000rpm
4	Sliding Speed	0.5-10m/s
5	Wear Track Diameter	Mean 50mm, Max 200mm
6	Load Range	Mean 5N, Max 200N
7	Frictional Force	Mean 0N, Max 200N
8	Wear	Mean 2000micro m, Max 2000micro m
9	Temperature	Mean ambient, Max 400 C

VII. EXPERIMENTAL PROCEDURE

The experiments were conducted on the pin on disc apparatus Tribo Tester (W.O. No. 1153 and SI. No 419) at ambient and elevated (average) temperature according to the L9 array. The material of the disc is grey cast iron having similar chemical composition like the brake disc application in passenger vehicles. The chemical analysis of the disc has been carried out at Bhagvati Casters Laboratory at Nashik, whereas the chemical analysis for composite has been carried out at FAN Laboratories in Nashik. The disc is placed with the help of dial indicator within minimum run out. The surfaces of the pins are polished by 320 Emery paper before starting the experiment. Precaution has to be taken that the pin makes contact with the disc and on the display zero should be shown which is adjusted with the help of screw adjustment for wear and tear in control system. Also the frictional force is directly measured on system.

VIII. EXPERIMANTAL RESULTS

Table 8.a Design Parameters and Responses for Coefficient of Friction

Design Parameters				Coefficient of Friction		
Sr. No.	Load L (N)	Sliding Speed V (m/s)	Sliding Distance D (m)	Semi-metallic	LM 9	LM9+10% TiC
1	10	3.04	2000	0.201	0.4936	0.4713
2	10	3.85	3000	0.29	0.5112	0.4621
3	10	4.13	4000	0.43	0.513	0.4589
4	13	3.04	2000	0.31	0.6142	0.58
5	13	3.85	3000	0.493	0.4942	0.55
6	13	4.13	4000	0.513	0.4968	0.4519
7	15	3.04	2000	0.4	0.428	0.4916
8	15	3.85	3000	0.3941	0.4218	0.4146
9	15	4.13	4000	0.3912	0.45	0.4713

Table 8.b Design Parameters and Responses for Wear Rate

Design Parameters				Wear Rate(mm/sec^3)		
Sr. No.	Load L (N)	Sliding Speed V (m/s)	Sliding Distance D (m)	Semi-metallic	LM 9	LM9+10% TiC
1	10	3.04	2000	0.00203	0.002571	0.00231
2	10	3.85	3000	0.006301	0.00516	0.004306
3	10	4.13	4000	0.004817	0.00386	0.003418
4	13	3.04	2000	0.0213	0.002316	0.01408
5	13	3.85	3000	0.00396	0.003213	0.01408
6	13	4.13	4000	0.004053	0.00351	0.003746
7	15	3.04	2000	0.00521	0.00361	0.003236
8	15	3.85	3000	0.007612	0.00614	0.005813
9	15	4.13	4000	0.001854	0.00204	0.001042

8.1 Analysis of Variance

Analysis of variance (ANOVA) is nothing but accumulation of statistical models which are further used to analyze the deviations among group means and their related procedures. Parameters like sliding speed, skidding distance and load can also be analyzed for the effect of wear by the ANOVA technique. Relative significance of factors in terms of their percentage contribution to the response also can be established.

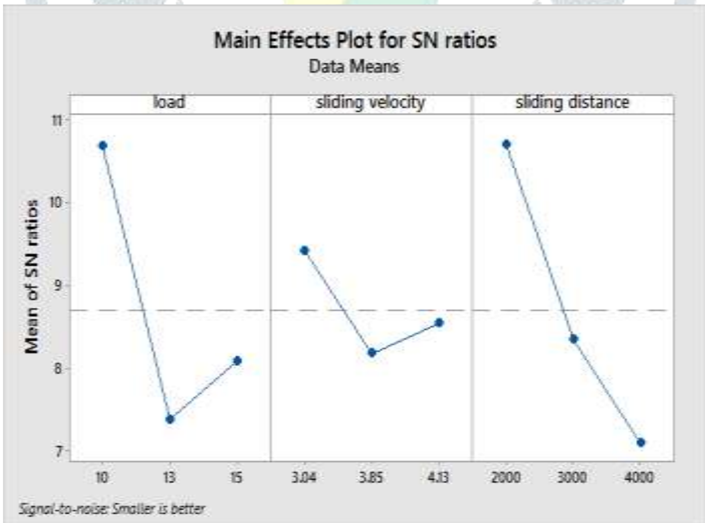

Fig 4 S/N Ratio of Semi-Metallic Material COF

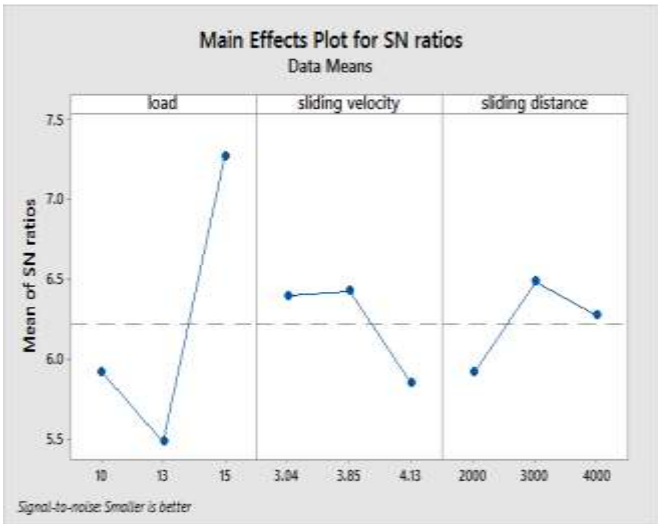

Fig 5 S/N ratio of LM9 alloy-COF

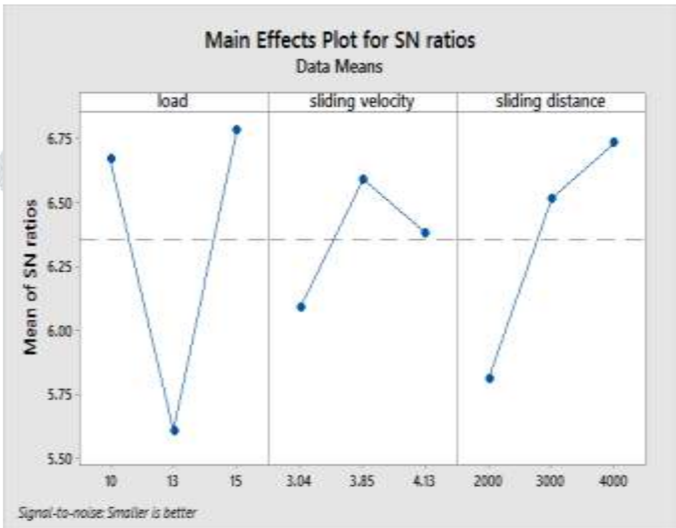

Fig 6 S/N ratio of LM9+10% TiC-COF

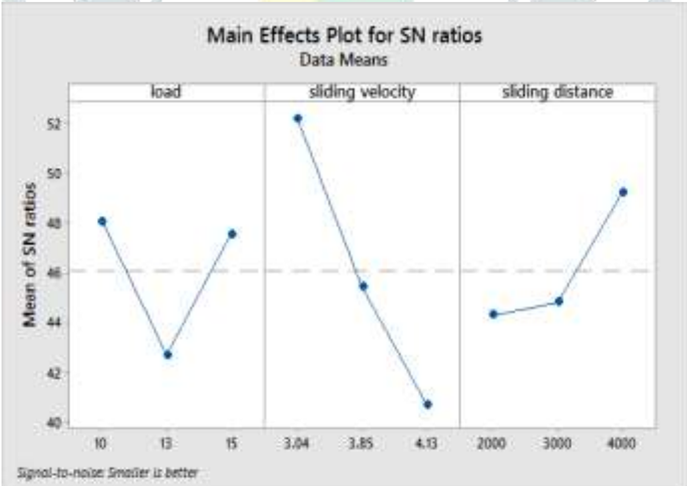

Fig 7 S/N ratio of Semi Metallic Material-Wear

Fig. 8 S/N ratio of LM9 alloy-Wear

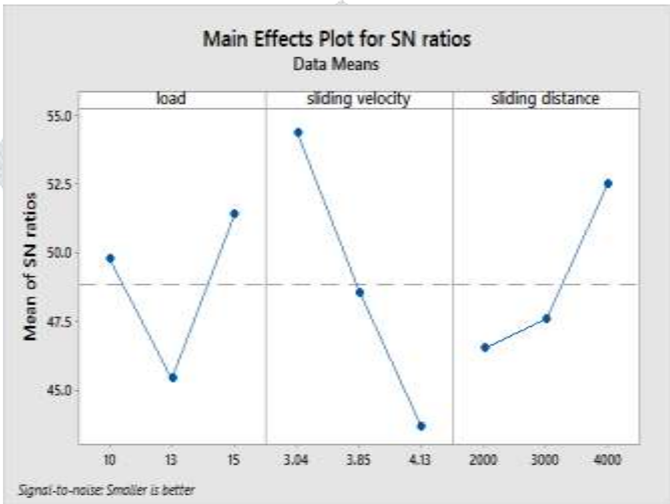

Fig. 9 S/N ratio of LM9+10% TiC-Wear

Table 8.1.a. Analysis Of Variance Results for SN Ratio for Lm9+10%Tic

Sources of Variation	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contribution
Regression	3	0.000061	0.00002	1.86	0.254	
Load	1	0.00001	0.00001	0.03	0.863	4.81
Sliding Velocity	1	0.000039	0.000039	3.56	0.118	33.67
Sliding Distance	1	0.00022	0.00022	1.98	0.219	18.72
Error	5	0.000055	0.00011			
Total	8					

Table 8.1.b Analysis Of Variance Results - S/N Ratio for Semi-Metallic and Lm9 Alloy

		Percentage Contribution	
Sr. No	Parameters	Semi Metallic	Lm9
1	Load	5.92	13.46
2	Sliding Velocity	33.89	33.46
3	Sliding Distance	19.26	18.97

From the above table (Table 6) of ANOVA analysis it is known that the sliding speed, load and skidding distance have an effect on wear and tear of composite material. Percentage contribution of each factor is indicated by the last column on the result. It can be observed from ANOVA (Table 6) that the load (4.81%) and sliding distance (18.72%) has a great effect on the wear of the aluminum matrix material. The Table 7 shows ANOVA analytics of semi-metallic and LM9 alloy material. From the result it is found that sliding velocity (33.67%) and sliding distance (18.72%) which also has great effect on the wear of such composite material.

8.2 Multiple Linear Regression Model

A multiple linear regression analysis attempts to model the relationship between two or more predictor variable and a response variable by fitting a linear equation to the observed data.
The regression equation for LM9+10%TiC

1) COF=0.618+0.00075load-0.0173 sliding velocity-0.000027sliding distance.
2) Wear = -0.0075+0.000097load+0.00451sliding velocity-0.00002sliding distance

8.3 Conformation Test Results

To validate the results obtained from the analysis, conformation experiment was conducted and comparison was made between the experimental values and computed values developed from regression analysis, the table and show the conformation experiment and its results.

Table 8.3.a Conformation Test Parameters for Lm9+10%tic

Test Material	Load	Speed	Sliding Distance
Lm9+ 10% TiC	10	3.85	3000
	15	3.85	3000
	13	4.13	4000

Table 8.3.b Conformation Test Results

Sr. No	Experimental Wear Rate	Regression Model Wear Rate	Error %
1	0.004306	0.0048335	1
2	0.005813	0.0053185	9
3	0.003746	0.004187	10

Based on the conformation experiment, it was observed that the error associated with experimental values and computed values was minimal and hence this regression model obtained from the L9 array can be used effectively to predict the wear rate of the composite with good accuracy.

IX. CONCLUSION

From the above analytics the following conclusions are drawn from this present study.

1) The DOE technique was satisfactorily applied to the brake pad materials so as to study there parameters
2) The analysis of variance shows that the Sliding Velocity (33.67%) and Skidding Distance (18.72%) have significant regulation on wear of LM9+TiC.
3) From the analysis of the variance it can be seen that the Sliding Velocity (33.89) and Skidding Distance (19.26) have significant influence on wear of Semi-Metallic stuff.
4) Variance analysis shows that the Sliding Velocity (33.46) and Sliding Distance (18.97) have significant influence on wear and tear of LM9 alloy.
5) Coefficient of friction obtained increased in the LM9+TiC alloy as compared with the Semi-Metallic material also the Wear rate was reduced with significant value for LM9+TiC with respect to Semi-Metallic material.
6) The regression equation gives the beat results for various parameters. This means a considerable saving in cost and time, which would benefit the industry to build more general and particular databases of material properties.

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