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EXPERIMENTAL AND NUMERICAL ANALYSIS OF WEAR BEHAVIOR OF BRAKE PAD FOR LMV USING DIFFERENT COMPOSITIONS

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Abstract: - *In this work, the wear behavior of brake pad material under the influence of parameters like sliding velocity, sliding distance, and normal load under Dry Friction Condition is studied. Brake pad is made up of complex composite material so such three compositions suitable for Light Motor Vehicles are selected for test and named as material I, material II and material III. The tribological behavior of composites was investigated by pin on disc apparatus. 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. Graphical representation is used to interpret the 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 three material are different which is shown in paper in tabulated form. The increase in percentage of carbon increases the wear resistance.*

Keywords*: Brake Pads, Wear Rate, Compositions, etc. complex compositions*

I. INTRODUCTION

A **brake** is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction. Most brakes commonly use friction between two surfaces pressed together to convert the kinetic energy of the moving object into heat, though other methods of energy conversion may be employed. For example, regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, fin, or rail, which is converted into heat. Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel.

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.

The Disc against which a brake pad slides can be Ferrous or Nonferrous, two have different effects of wear rate of brake pads. 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 three Material compositions are made and tested by designing an experiment using Taguchi array.Many resins and composites are used now days to meet the requirements of brake pad materials To have better wear resistance characteristics Aluminium based metal composites are used they shows better tribological properties.

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 three material compositions is made.

II. METHODOLOGY

2.1 Selection of parameters

For the three composite materials to be compared on the basis of wear behavior on pin-on-disc apparatus three parameters are selected for the experiment, these three have direct effect on wear.

- Normal load
- Sliding velocity
- Sliding distance

2.2 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.

Table I. FACTORS AND THEIR LEVELS

	Low	Medium	High
Load (Kg)	2	4	6
Disc Speed (RPM)	500	750	1000
Sliding Distance(Km)	1	2	3

The parameter given in "Table I" are put in Design expert software so it will generate a following Run sheet of parameters for pin-on-disc apparatus as shown in "Table II" which can be further utilized as Observation table to note wear rate as response.

Test Run.	Load (Kg)	Disc Speed (R.P.M)	Sliding Distance (Km)
1	2	500	1
2	2	750	2
3	2	1000	3
4	4	500	2
5	4	750	3
6	4	1000	1
7	6	500	3
8	6	750	1
9	6	1000	2

2.2 Selection of material

The experimentation is carried out on the pin on disc apparatus. To start the experimental work first three different materials are selected and coded as Material I, Material II, and Material III. The detail composition of these three materials are given in tabulated form in "Table III to TableV", the composition is tested by EDX on SEM machine

TABLE III. DETAIL COMPOSITION OF MATERIAL I

Element	Weight %
C	1.2
Si	8.34
Mn	5.27
Ni	7.33
Al	2.05
Cu	0.957
Fe	40.32
Co	2.06
Ti	1.07
V	4.45
W	7.47
Pb	0.306
Cr	14.32
Mo	0.567

TABLE IV. DETAIL COMPOSITION OF MATERIAL II

Element	Weight %
C	5.22
Si	10.23
Mn	4.28
Ni	7.56
Al	3.36
Cu	0.383
Mg	0.276
Fe	58.8
Co	1.9
Ti	0.29
V	0.568
W	3.55
Pb	0.455
S	0.432

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TABLE V. DETAIL COMPOSITION OF MATERIAL III

Element	Weight %
C	4.35
Si	19.5
Mn	2.22
Ni	2.27
Al	2.8
Cu	0.234
Mg	0.23
Fe	65.5
Ti	1.33
V	0.106
S	0.36
N	0.358

2.4 Fabrication of Pins

All three pins are made respectively from brake pad materials material I, material II, and material III as shown in "Fig1"

Fig. 1 Fabricated Pins

2.5 Test Setup

Standard pin on disc test apparatus is used for the experiment on the specially made pins. The photo of test setup is shown on "Fig 2". Layout of L9 orthogonal array for experimentation is shown in "Table II", the arrangement to set sliding distance is not provided on test setup instead the time of run can be calculated and can be monitored using stopwatch, the final test run and parameter combination is shown in "Table VI"

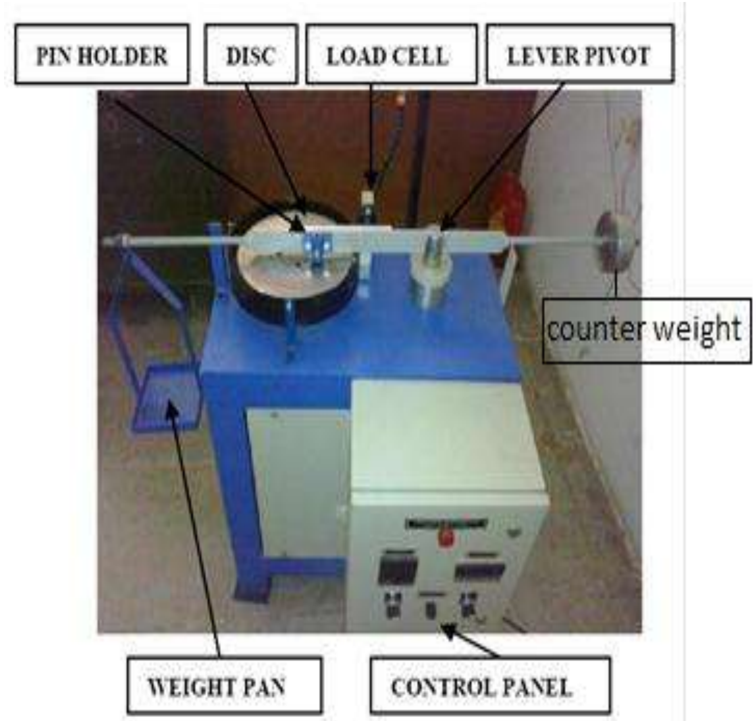

Fig. 2. Pin on disc Test-Rig

TABLE VI. FINAL TEST RUN DESIGN

Test Run.	Load (Kg)	Disc Speed (R.P.M)	Time (min)
1	2	500	7.9618
2	2	750	10.616
3	2	1000	11.943
4	4	500	15.924
5	4	750	15.924
6	4	1000	3.9809
7	6	500	23.885
8	6	750	5.3079
9	6	1000	7.9618

III. TESTING

Experiments are conducted as per the design matrix "Table IV" and response is recorded in terms of wear by weight loss method. Weight of pin before run and weight of pin after run is noted and calculated to obtain wear rate. Weighing scale with minimum capacity of 10 mg is used for the same. Response parameters are different for each material composition under study. The value of wear rate and the parameter matrix of "Table II" are put in design expert software for further analysis. For the analysis and to find correlation all factors should be in same unit therefore while filing the data in software Disc speed and Run time is converted in Sliding Velocity (m/s) and Sliding Distance (Km) as shown in "Table VII"

TABLE VII. FINAL TEST RUN DATA FOR SOFTWARE

Serial No.	Load (Kg)	Speed (m/s)	Sliding Distance (m)
1	2	2.09333	1000
2	2	3.14	2000
3	2	4.18667	3000
4	4	2.09333	2000
5	4	3.14	3000
6	4	4.18	1000
7	6	2.09333	3000
8	6	3.14	1000
9	6	4.18667	2000

IV. RESULTS AND DISCUSSION

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 "Fig VIII".

TABLE VIII. % CONTRIBUTION OF THREE FACTORS AND THEIR INTERACTIONS, FOR WEAR RATE

	% CONTRIBUTION		
FACTORS	***Material I***	***Material II***	***Material III***
A:Load	27.61906	51.16755	56.02654
B:Sliding Velocity	45.04934	12.83169	13.9408
C: Sliding distance	5.6693572	10.1617	1.578763
AB	13.505889	22.6763	24.97715
AC	0.9523866	2.513579	2.789864
BC	7.2039758	0.649197	0.686887

Result graphs are obtained after wear rate analysis in Design -Expert software

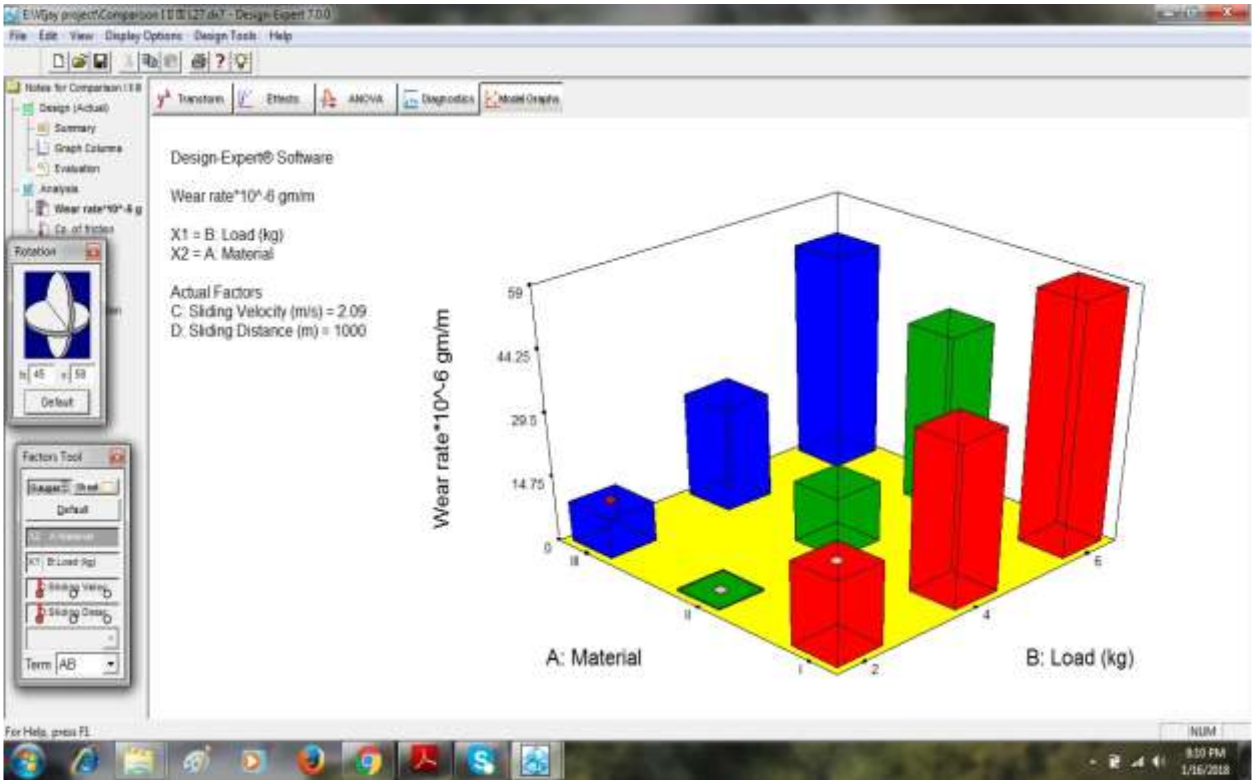

Fig. 3. Wear rate v/s Load

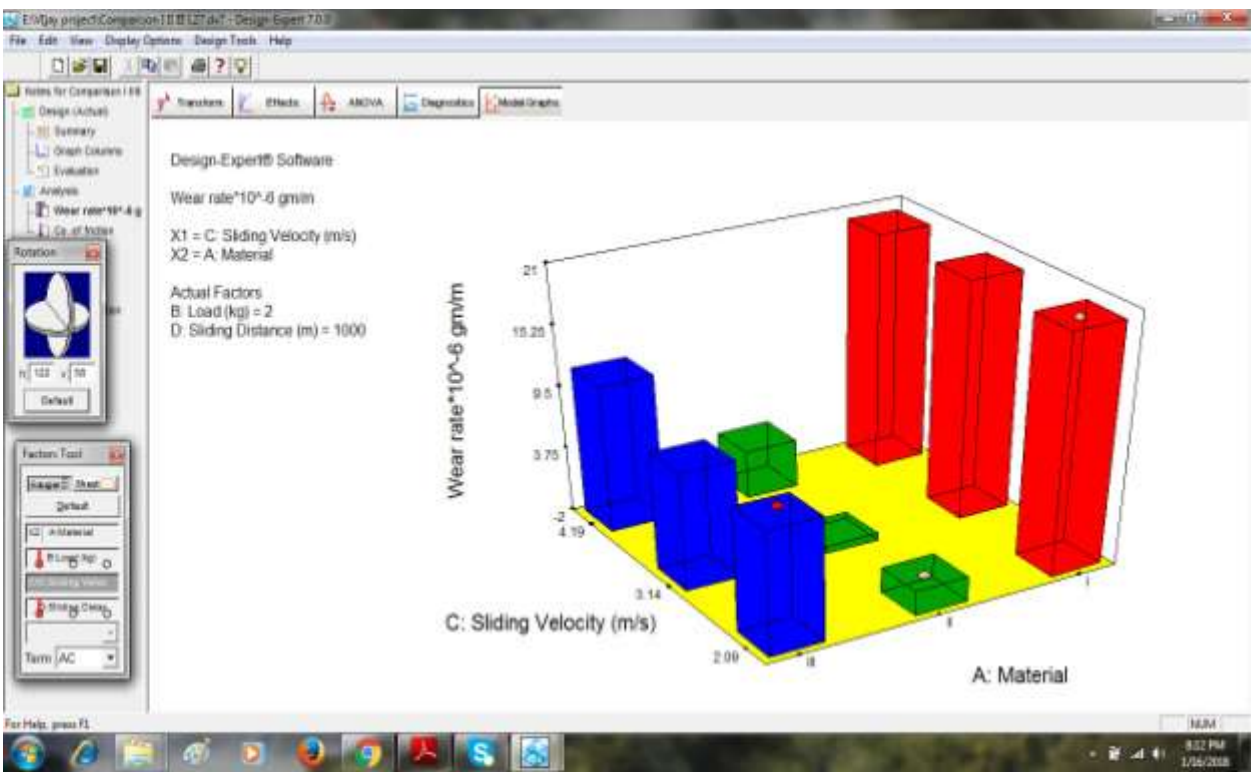

Fig. 4. Wear rate v/s Sliding velocity

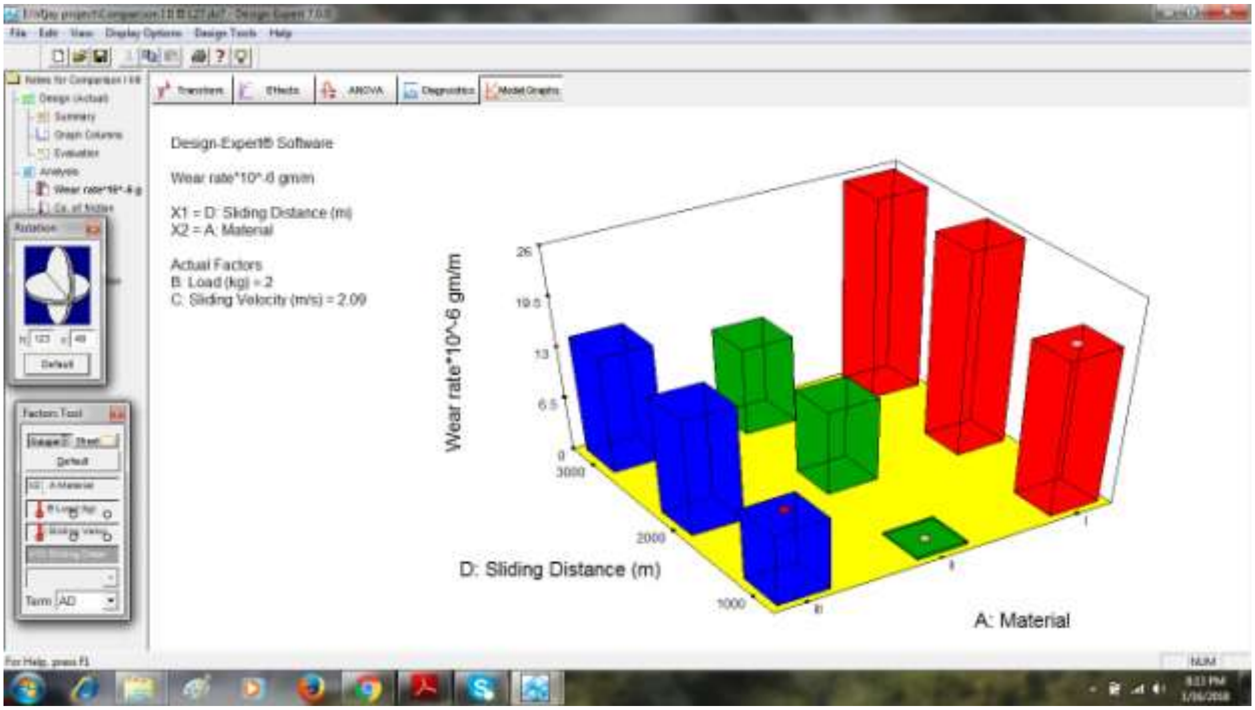

Fig. 5. Wear rate v/s Sliding Distance

TABLE IX. COMPARATIVE WEAR DATA OF ALL MATERIAL

Sr. no	Material	Total Wear Rate in gm/m	Avg. Coefficient of Friction
1	I	$31.5\text{x } 10^{\wedge -5}$	0.233824
2	II	$16.7\text{x } 10^{\wedge -5}$	0.306335
3	III	$22.5\text{x}10^{\wedge -5}$	0.333349

1) It is clearly seen from “Fig. 3 to Fig. 5”, that as load and sliding distance increases wear rate of all three brake pad materials also increases whereas velocity of sliding increases wear of all three brake pad materials decreases.

2) Following correlations are obtained for three materials

For material I

Wear rate x $10^{\wedge -6}$ gm/m = -40.48396+ 16.02821* load(Kg) + 15.29699* sliding velocity(m/s)

+ 0.022547* sliding distance (m)

-3.41144* load (Kg)* sliding velocity(m/s)

-9.5055*$10^{\wedge -004}$ *load (Kg) * sliding distance (m)

-4.98302*$10^{\wedge -003}$ * sliding velocity (m/s) * sliding distance (m)

For material II

Wear rate x 10^{-6} gm/m = -51.9443+16.611006* laod(Kg) + 17.46652* sliding velocity(m/s)

+ 2.860278 *10^{-003}* sliding distance (m)

– 4.75550* load(Kg)* sliding velocity(m/s)

+1.66131*10^{-003} *load (Kg) * sliding distance (m)

-1.60927*10^{-003} * sliding velocity (m/s) * sliding distance (m)

For material III

Wear rate x 10^{-6} gm/m = -39.95647+16.65375* laod(Kg) + 17.50997* sliding velocity(m/s)

-4.45306* 10^{-005}* sliding distance (m)

– 4.77591* load (Kg)* sliding velocity (m/s)

+1.67483*10^{-003} *load (Kg) * sliding distance (m)

-1.58401*10^{-003} * sliding velocity (m/s) * sliding distance (m)

3) Percentage deviation between actual and predicted wear rate:

The percentage deviation between actual and predicted wear rate obtained during the test. The equations developed by 2FI model are used for all three materials.

TABLE X Percentage Deviation of Wear rate of Material-I

SR.No.	**Wear rate of Material 'I'**		
	Actual Value * 10^-6 gm/m	Predicted Value* 10^-6 gm/m	% deviation
1	20	19.21439283	4.006728706
2	25	27.87889744	-10.888644
3	26.7	26.07906424	2.352962356
4	45	43.43980626	3.528261316
5	40	37.80700939	5.637000123
6	30	28.11310898	6.493856729
7	63.3	63.8630077	-0.88548974
8	40	40.34295491	-0.85372739
9	25	25.64502546	-2.54724113

TABLE XI Percentage Deviation of Wear rate of Material-II

Wear rate ofMaterial 'II'		
Actual Value * 10^-6 gm/m	Predicted Value* 10^-6 gm/m	% deviation
0	0	0
10	8.51559837	16.03406599
13.3	12.92948576	2.825173469
25	23.52912695	6.061815398
20	22.96880889	-13.818437
10	10.74102079	-7.14546116
53.3	52.98123373	0.599854283
20	20.74220398	-3.64341594
15	13.51794906	10.39381152

TABLE XII Percentage Deviation of Wear rate of Material-III

Wear rate of Material 'III'		
Actual Value * 10^-6 gm/m	Predicted Value* 10^-6 gm/m	% deviation
10	9.978119502	0.219044624
15	15.00230803	-0.015385666
16.7	16.70007975	-0.000477563
30	30.01616503	-0.053868922
26.7	26.69738519	0.00979379
20	19.9988489	0.005755657
56.7	56.75351456	-0.09433742
30	29.9998455	0.000514986
20	20.00130569	-0.006528238

4) Confirmation test:

To test the accuracy of the model the confirmation tests were performed by selecting the set of parameters as shown in table XIII. The wear value for materials calculated from the mathematical model developed by 2FI Approach were compared with values obtained experimentally as shown in table XIV.

Table XIII: Parameters used in the confirmation test

Material	Test	Disc speed in (RPM)	Velocity of Sliding	Load	Sliding distance (L)
		RPM	m/s	Kg	m
I	1	600	2.512	3	1500
	2	900	3.768	5	2500
II	3	600	2.512	3	1500
	4	900	3.768	5	2500
III	5	600	2.512	3	1500
	6	900	3.768	5	2500

Table XIV: Confirmation test of all selected material for wear rate

Material	**Velocity of sliding**	**Load**	**Sliding Distance**	**Actual Wear**	**Predicted wear**	**avg**	**% Deviation**
	m/s	Kg	m	(gm/m) X 10^{-6}	(gm/m)X 10^{-6}		
I	2.512	3	1500	33.33	30.78456968	32.05728484	7.940255504
	3.768	5	2500	32	30.26927566	31.13463783	5.558838827
II	2.512	3	1500	13.33	11.62677533	12.47838767	13.64939696
	3.768	5	2500	20	20.08381968	20.04190984	-0.41822201
III	2.512	3	1500	20	19.49995855	19.74997928	2.531858093
	3.768	5	2500	24	25.2143607	24.60718035	-4.93498515

V. CONCLUSION

- Wear rate of brake pads increase with the increase in normal load
- Wear rate of brake pads decreases with increase in sliding velocity
- Wear rate of brake pads increases with increase in the sliding distance.
- Increase in percentage of carbon in composition may increase in wear resistance. Material I which has 1.2 % Carbon has highest wear rate amongst three. The percentage of Carbon in Material II is 5.22% has lowest Wear rate, percentage of Carbon in material III is 4.35% by weight, and the wear rates decreases with increase in % of C respectively.

• In order to satisfy all the requirements of brake pad materials. Brake pad is made of complex composition to have minimum wear rate amongst family of materials. Since the highest total wear rate amongst three is 31.5×10^{-5} gm/m which ensure great durability.

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