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Experimentation and Analysis of Three Different Compositions of Semi-Metallic Brake Pads for Wear Rate under Dry Friction Condition

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***Abstract*—This work is a part of curiosity to know actual behavior of brake pad material related to wear under the influence of parameters like velocity of sliding, sliding distance, and last but not the least normal load when the brake pad is subjected to work with dry friction. Brake pads should ensure continuous coefficient of friction, safety and durability. Brake pads in disc brake systems are made of complex composite material; such three compositions are selected for test and study, coded as material I, material II and material III. Detail composition of all three materials are obtained by EDX on scanning electron microscopy machine, experiment is designed by using Taguchi array in design expert 7 software and the test is conducted on pin-on-disc test rig, earlier mentioned parameters are set for three 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 three material are different which is shown in paper in tabulated form. The increase in percentage of carbon (in graphite form) increases the wear resistance.**

Keywords*—Wear rate; Wear analysis; Brake pads; Design Expert, Material composition

I. INTRODUCTION

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 three 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 three material compositions is made.

II. METHODOLOGY

A. Selection of parameters

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

- Normal load
- Sliding velocity
- Sliding distance

And the working condition is considered as dry sliding, Temperature is not considered as a factor because the brake pad material is made by powder metallurgy and the curing temperature for binding is about 230^{0}C, the maximum temperature reached during testing is below curing temperature.

B. Design of test runs

The 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

	Level		
	Low	*Medium*	*High*
Load (kg)	2	4	6
Disc Speed (RPM)	500	800	1100
Sliding distance (km)	1.5	2.5	3.5

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

TABLE II. LAYOUT OF L9 ORTHOGONAL ARRAY FOR EXPERIMENTATIONS

Run	Load (kg)	Disc speed (rpm)	Sliding distance (km)
1	2	500	1.5
2	2	800	2.5
3	2	1100	3.5
4	4	500	2.5
5	4	800	3.5
6	4	1100	1.5
7	6	500	3.5
8	6	800	1.5
9	6	1100	2.5

C. Selection of material

The experimentation is carried out on the pin on disc test rig. 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	Net Counts	Net Counts Error	Weight %	Atom %
C	225	+/- 26	13.63	35.13
O	1342	+/- 100	13.81	26.72
Si	2427	+/- 113	5.76	6.35
P	373	+/- 67	0.98	0.98
S	2607	+/- 251	6.91	6.67
S	0	+/- 17	---	---
Ca	342	+/- 51	1.14	0.88
Ca	0	+/- 44	---	---
Fe	492	+/- 89	4.21	2.33
Fe	382	+/- 118	---	---
Cu	1836	+/- 110	32.47	15.81
Cu	11590	+/- 172	---	---
Mo	1096	+/- 418	3.87	1.25
Mo	81	+/- 16	---	---
Ba	2309	+/- 162	17.23	3.88
Ba	0	+/- 190	---	---
Total			100.00	100.00

TABLE IV. DETAIL COMPOSITION OF MATERIAL II

Element	*Net Counts*	*Net Counts Error*	*Weight %*	*Atom %*
C	206	+/- 27	20.91	32.63
O	1968	+/- 73	45.06	52.78
Mg	272	+/- 38	1.33	1.03
Al	771	+/- 44	3.60	2.50
Si	1678	+/- 84	7.38	4.93
S	748	+/- 144	4.08	2.39
S	0	0	---	---
Ca	365	+/- 68	2.75	1.29
Ca	0	+/- 40	---	---
Fe	39	+/- 19	0.81	0.27
Fe	0	+/- 31	---	---
Cu	1	+/- 12	0.06	0.02
Cu	292	+/- 46	---	---
Mo	608	+/- 238	4.42	0.86
Mo	140	+/- 17	---	---
Ba	553	+/- 85	9.59	1.31
Ba	0	+/- 92	---	---
Total			100.00	100.00

TABLE V. DETAIL COMPOSITION OF MATERIAL III

Element	Net Counts	Net Counts Error	Weight %	Atom %
C	392	+/- 46	27.34	43.76
O	1536	+/- 94	30.69	36.88
Na	232	+/- 35	1.72	1.44
Mg	451	+/- 45	1.74	1.38
Al	864	+/- 99	3.14	2.24
Si	1411	+/- 97	4.75	3.25
S	1057	+/- 84	4.28	2.57
S	0	0	---	---
K	92	+/- 32	0.45	0.22
K	0	+/- 75	---	---
Ca	1319	+/- 88	7.30	3.50
Ca	0	+/- 52	---	---
Fe	690	+/- 66	10.63	3.66
Fe	1018	+/- 73	---	---
Ba	622	+/- 89	7.98	1.12
Ba	0	+/- 42	---	---
Total			100.00	100.00

D. Fabrication of Pins

Three pins are made respectively from brake pad materials material I, material II, and material III shown in “Fig1”.

Fig. 1. Pins for Testing

E. Test 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 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”.

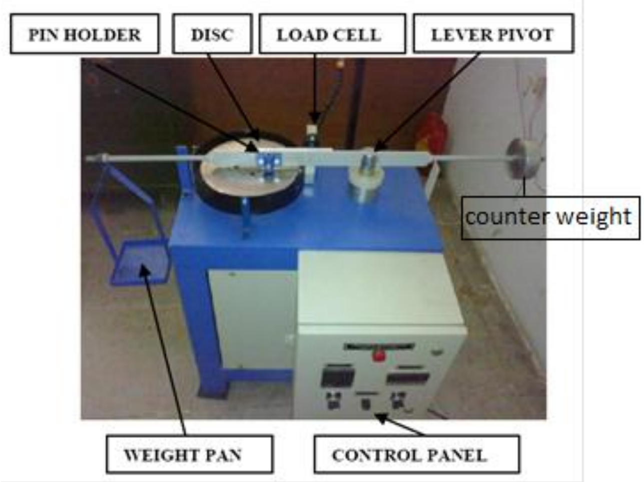

Fig. 2. Pin on disc Test-Rig

TABLE VI. FINAL TEST RUN DESIGN

Run	Load (kg)	Disc speed (rpm)	Time (min)
1	2	500	11.943
2	2	800	12.44
3	2	1100	12.666
4	4	500	19.904
5	4	800	17.416
6	4	1100	5.4285
7	6	500	27.866
8	6	800	7.4642
9	6	1100	9.0475

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

Run	Load (kg)	Sliding Velocity (m/s)	Sliding Distance (m)
1	2	2.09	1500.00
2	2	3.35	2500.00
3	2	4.61	3500.00
4	4	2.09	2500.00
5	4	3.35	3500.00
6	4	4.61	1500.00
7	6	2.09	3500.00
8	6	3.35	1500.00
9	6	4.61	2500.00

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 (FROM EFFECT LIST)

	% CONTRIBUTION		
FACTORS	*Material I*	*Material II*	*Material III*
A:Load	19.5854	49.42412	45.93967
B:Sliding Velocity	34.51224	12.24373	9.836818
C: Sliding distance	26.96055	10.20689	15.66722
AB	2.007044	22.16683	22.56058
AC	2.234055	5.391931	5.748114
BC	14.70071	0.566495	0.247606

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

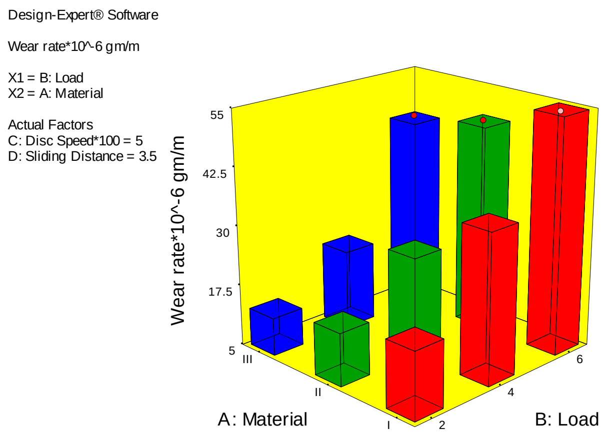

Fig. 3. Wear rate v/s Load

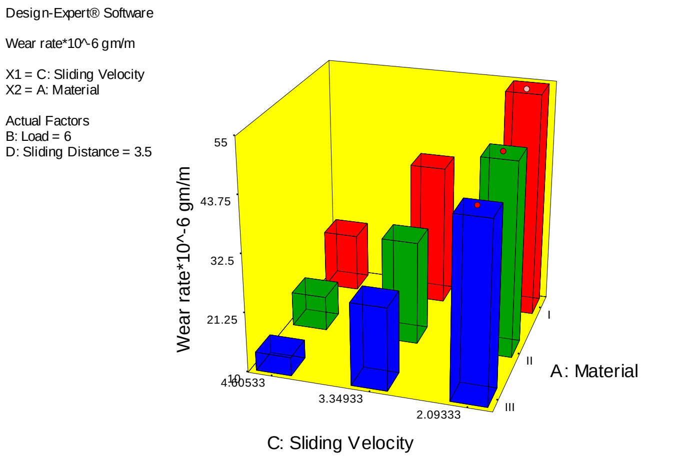

Fig. 4. Wear rate v/s Sliding velocity

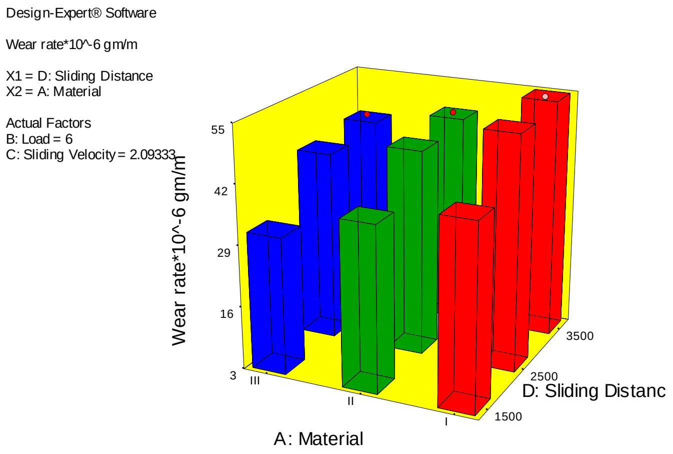

Fig. 5. Wear rate v/s Sliding Distance

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) It is observed from "Table IX" that the wear of material-III is less than material I and II and Material I which have 32.47 % of Cu by weight and 13.63 % Carbon has highest wear rate and the percentage of Carbon in Material II is 20.91% and in material III is 27.34% by weight which show lesser wear rates respectively.

TABLE IX. COMPARATIVE WEAR DATA OF ALL MATERIAL

Sr. No	Material	Total Wear rate in (gm/m)	Average Coefficient of friction (μ)
1	Material I	23.1×10^{-5}	0.290468
2	Material II	17.8×10^{-5}	0.302978
3	Material III	13.4×10^{-5}	0.329993

3) Following correlations are obtained for three materials.

- For material I

Wear rate $\times 10^{-06}$ gm. /m = - 67.91379 + 10.95469 × Load + 14.17233 × Sliding Velocity + 0.034911 × Sliding Distance -1.18074 × Load × Sliding Velocity -1.56463 × 10^{-03} × Load × Sliding Distance - 6.39107×10^{-03} × Sliding Velocity × Sliding Distance.

- For material II

Wear rate $\times 10^{-06}$ gm. /m = -26.12386 + 9.71656 × Load + 12.12859 × Sliding Velocity -8.61709 × 10^{-04} × Sliding Distance -3.18471 × Load × Sliding Velocity + 1.97279 × 10^{-03} × Load × Sliding Distance - 1.01823 × 10^{-03} × Sliding Velocity × Sliding Distance.

- For material III

Wear rate $\times 10^{-06}$ gm. /m = -33.29857 +10.09749× Load +12.43194× Sliding Velocity - 1.49658× 10^{-03} ×Sliding Distance - 3.41219× Load ×Sliding Velocity +2.16327 × 10^{-03} × Load × Sliding Distance - 7.14939× 10^{-04} × Sliding Velocity × Sliding Distance.

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.
- Carbon in brake material composite is in the graphite form and graphite acts as a solid lubricant. Increase in percentage of carbon in composition may lead to increase in wear resistance. Material I which has 13.63 % Carbon has highest wear rate amongst three. The percentage of Carbon in Material II is 20.91% and in material III is 27.34% by weight, and the wear rates decreases with increase in % of C respectively.
- 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 23.1×10^{-5} gm/m which ensure great durability.

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