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Development of Non-asbestos Composite Material for Disc Brake Pad

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ABSTRACT

Automobile car disc brakes are safety critical components whose performance depends strongly on contact conditions at the pad to disc interface. During braking both brake pad and disc surfaces worn, affecting the useful life of brake as well as its behaviour. From literature, it is found that asbestos is widely used in automobile disc brake pads. But it is found that it may cause cancer to human being because of its carcinogenic nature. Therefore the aim of this study is to analyze the effect of different material composition on friction & wear of brake pad. The effect of steel wool fiber content varying from 4 to 12 % and barites varying from 24 to 32 % on the wear behaviour of asbestos free brake pad has been investigated. The formulation was produced by substituting asbestos with steel wool fiber reinforcement, phenolic resin & Nitrile butadiene Rubber (NBR) as binder. The phenolic resin is also added as a necessary ingredient to hold all the components together. NBR is a good toughened rubber for the organic binder and has a positive effect to improve wear. Barites, vermiculite were selected as fillers to enhance friction in the formulations. Synthetic graphite, Zirconium silicate were used as friction modifier because of their good wear resistant capability. The wear test was performed using pin on disk machine by varying the sliding speed, applied load and temperatures. Full factorial design of three factor-three levels and analysis of variance were used in the study of the wear test. The results shown that wear rate increases with increasing the sliding speed, load, temperatures. The co-efficient of friction obtained is within 0.3-0.4 which is within the recommended standard for automobile brake pad. The 12% fiber content composite gave the better wear resistance as compared to other. The results of this study indicate that steel wool composite can be effectively used as a replacement to manufacture brake pads.

***Keywords*— Coefficient of friction, composite material, pin on disc machine, steel wool, wear rate**.

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I. INTRODUCTION

Commercially available automotive brake pads are roughly categorized as semi-metallic (SM), low-metallic (LM), or non- asbestos organic (NAO) materials. They are all considered to be organic friction materials since the matrix of these complex composites is formed by one or more polymers. The friction materials usually contain four classes of ingredients: binders, reinforcements, friction modifiers, and fillers. Developing a successful friction material is to find the best balance among many factors yielding acceptable performance, costs, and environmental friendliness. Considering the high cost of aramid fibers and environ- mental concerns related to the use of copper and asbestos, natural fibers become increasingly attractive material candidates due to their high specific mechanical properties, low cost, and low environmental impact [1].

Amaren asserts that volume percent is the correct unit of measure for friction material composition. While the exact compositions of commercial friction materials are almost never published in the open literature, the constituent of the brake pad material are normally made known. One of the most used constituents over the years is asbestos. Medical research has proved that asbestos fibers can lodge in the lungs and induce adverse respiratory conditions. As a consequent of this, the USA Environmental Protection Agency 1986 announced a proposed ban on asbestos. This action opened a wide door to the development of asbestos – free brake pads through different researchers [2].

Yun et al. [1] developed three eco-friendly brake samples were prepared by replacing a portion or all of the metals, aramid pulp, and antimony trisulfide with a natural fiber and a flaky titanate in a model brake lining formulation to study wear and brake effectiveness.

Aku et al. [2] studied the characterization of periwinkle shell as asbestos-free brake pad material. They found out that periwinkle shell is an agricultural waste. They studied the effect of this fiber on friction & wear of brake pad.

Saffar and Shojaei [3] studied deeply the role of rubber component on the tribological characteristics of composite friction materials. They prepared a series of friction materials with various amounts of rubber component, ranging from completely pure resin-based material, i.e. with no rubber component, to completely rubber-based material, i.e. with no resin binder. Then the influence of rubber component on the mechanical, physical, frictional, wear and fade characteristics was explored. The wear resistance of resin-based materials is higher than that of rubber-based composites.

D. Gultekin et al. [4] studied the friction behavior and wear characteristics of sintered copper matrix composite brake pads, reinforced with different amount of graphite against cast Al–Si/SiCp brake disc and the effects of applied load on the coefficient of friction have been investigated. Applied normal load was the most important parameter on wear performance and friction coefficient varied with the applied normal load in a manner that when the applied load is increased, the friction coefficient values are decreased.

Therefore, the aim of this study is to analyze the effect of different material composition on friction and wear of brake pad. The formulation was produced by substituting asbestos with steel wool fiber reinforcement, phenolic resin & Nitrile butadiene Rubber (NBR) as binder. The phenolic resin is also added as a necessary ingredient to hold all the components together. NBR is a good toughened rubber for the organic binder and has a positive effect to improve wear. Barites, vermiculite were selected as fillers to enhance friction in the formulations. Synthetic graphite, Zirconium silicate were used as friction modifier because of their good wear resistant capability. The pin on disc machine was used to evaluate the friction and wear of the developed composite material.

II. SAMPLE PREPARATION

Designed formulations of friction samples are listed in Table 1. The fabrication of composites containing seven ingredients was based on keeping parent composition of 5 ingredients (around 64wt. %) constant and varying two ingredients, namely steel wool and barite (around 36wt. %) in complementary manner as shown in Table 1 based on a systematic increase in steel wool (4, 8, and 12 wt. %).

TABLE I
FORMULATIONS OF DEVELOPED FRICTION MATERIALS (CONTENT IN VOL%)

Sr. No.	Raw Materials	Samples		
		S1	S2	S3
1	Steel wool∗	4	8	12
2	Phenolic Resin	36.5	36.5	36.5
3	NBR rubber	8.5	8.5	8.5
4	Synthetic graphite	10	10	10
5	Zirconium silicate	2	2	2
6	Synthetic barites∗	32	28	24
7	Vermiculite	7	7	7
	Total	100	100	100

The friction materials were manufactured by dry-mixing, pre-forming, hot press molding, post-curing and heat treatment. All the brake pad materials were cut into specimen size of 8 mm diameter and 32 mm length as shown in Fig. 1.

Fig.1 Samples of developed composite after wear

III. EXPERIMENTAL PROCEDURE

Factorial design and linear regression techniques have been widely used in engineering analysis. These techniques consist of plan of experiments with an objective of acquiring data in a controlled way, executing these experiments in order to obtain information about the behavior of a given process. Representing the wear rate value by W, the response function can be expressed by the equation below:

$$W= f(A, B, C) \quad \ldots..(1)$$

Where, A= load, B= sliding speed, C=temperature

The process factors, their designation and three levels selected are given in Table 2.

TABLE II
VARIABLE FACTORS AND THEIR LEVELS

Factors	Levels	Level 1	Level 2	Level 3

A) Load (N)	15	50	100
B) Speed (rpm)	191	477	955
C) Temperature (°c)	150	200	250

Therefore, the objective of the present work was to investigate the effect of factors that is (A) load (N), (B) speed (rpm) and (C) temperature (°c) for the friction & wear of the disc brake pad for the different compositions S1-S3. The Full factorial design was selected for the experimentation. All the factors selected three levels were being taken, so the degree of freedom associated with one variable was 2 (No. of levels – 1). During experimentation all the trials were repeated three times, so for the 3^3 factorial total number of experiments performed were 27. The experiment consists of 27 tests and the columns were assigned with parameters. The first column in table 3 was assigned to load, second column was assigned to speed and third column was assigned to temperature remaining columns were assigned to their interactions. For lower is the better performance objective, the response to be studied. ANOVA is performed to determine significant parameter and at last confirmation test is conducted to verify the optimal process parameter.

The 27 experiments were conducted on the friction & wear monitor test rig as shown in fig. 2 for each samples. The tests were carried out at the elevated temperature under dry operating conditions. The sliding wear of the composite was studied as a function of the applied load, temperature and the speed.

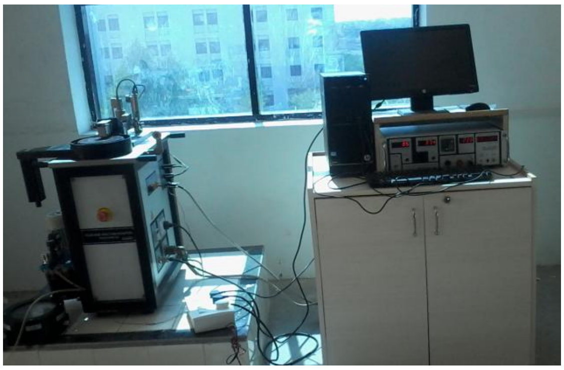

Fig.2 Friction & Wear monitor

IV. RESULTS & DISCUSSION

A. Friction & wear-

The tests were conducted with the aim of relating the influence of load, speed, temperature with dry sliding wear of composite for constant sliding distance of 1000m. On conducting the experiments as per design, the wear results for all the combinations of parameters were obtained.

The wear (W) measured using pin on disc test rig was in micrometers. The worn volume (W_v) of the pin was determined using equation given by

$W_v = A*W$ ……. (2)

Where, W_v= worn volume (mm^3)

A= cross-sectional area of the pin (mm^2)

W= wear (mm)

The wear rate (WR) was determined using equation given by

$WR = W_v/L$ …….. (3)

Where, WR = Wear rate (mm^3/m)

W_v =worn volume (mm^3)

L = sliding distance (mm)

The results of the wear rate after analysis are plotted in the form of graphs for various variations of speed, load and temperature.

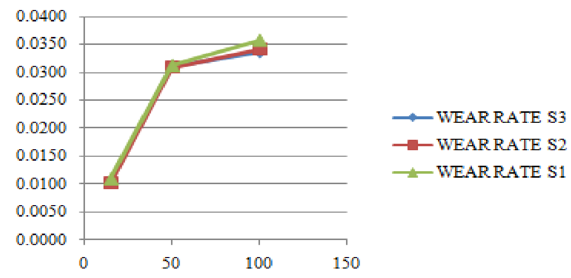

Fig.3 Wear rate at varying load, at constant speed 477 rpm and at temp. 150 °c

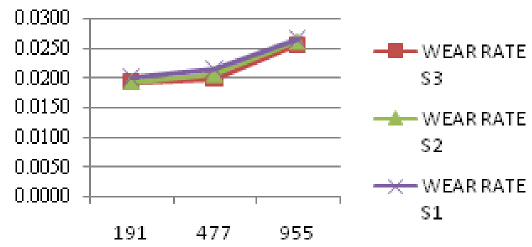

Fig.4 Wear rate at varying speed, at constant load of 50N and at temp. 200°c

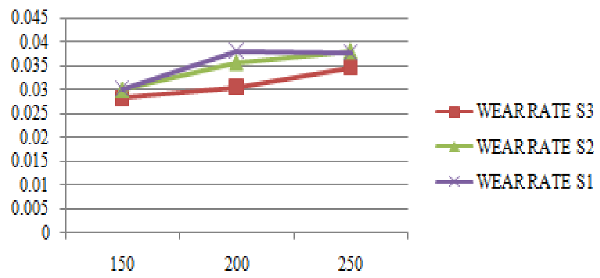

Fig.5 Wear rate at varying temperature, at constant load of 100N and at speed of 955 rpm.

The result shows that the wear rate of the samples increases with increase in sliding speed, load and temperatures (fig. 3-5). The S1 sample exhibited the highest wear than the other samples at the same conditions of sliding speed, load, and temperatures. As the sliding speed and temperature increased the wear rate of the brake pad sample increased. Heavy noise and vibration was observed. Also the transfer of the pin material to the disc was observed during the process. Also fig. 3 shows that the wear rate has direct relationship with the load. The effect of fiber content on the brake pad composite wear resistance was better for low loads. At high temperatures plastic deformation occurs with consequence of very high wear.

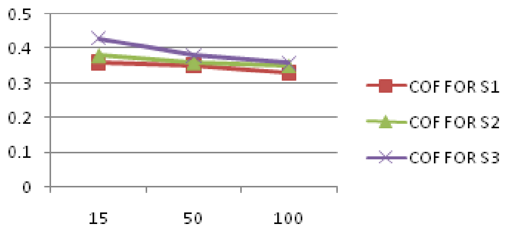

Fig.6 COF at varying load, at constant speed 477 rpm and at temp. 150 ^{o}c

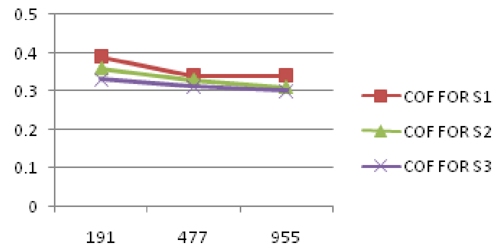

Fig.7 COF at varying speed, at constant load of 50N and at temp. 200^{o}c

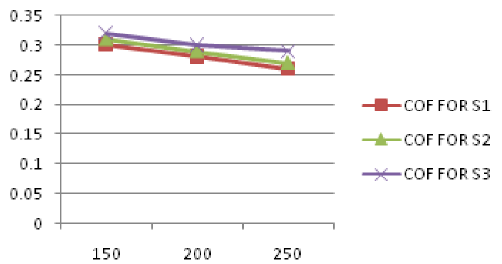

Fig.8 COF at varying temperature, at constant load of 100N and at speed of 955 rpm.

On the other hand wear rate decreases with increase in fiber content of the composite material. It was found that the wear resistance was better for S3 having 12% fiber content material as compared to S1 and S2. The decrease in wear rate of the composite brake pad may also be attributed to higher load bearing capacity of hard material and better interfacial bond between the particle and the resin reducing the possibility of particle pull out which may result in higher wear. The friction coefficient decreases when the applied loads, sliding speed and temperatures increased (fig. 6-8). The amplitude of the friction fluctuations was seen at all the stages. Due to sliding surface irregularities, the temperatures, speed and applied load cause a typical stick–slip oscillation as observed in the frictional profiles. This decrease could be explained by the appearance of significant plastic deformation of the pin surface.

B. Analysis of Variance

The adequacy of the models is tested using the analysis of variance (ANOVA) technique. It is a statistical tool for testing null hypothesis for designed experimentation, where a number of different variables are being studied simultaneously. ANOVA issued to quickly analyze the variances present in the experiment with the help of fisher test (F test). This analysis was carried out for a level of significance of 5%, i.e. the level of confidence 95%.

From the friction and wear test it was found that the wear rate was minimum for composite S3 as compared to other composites of brake pad. Therefore, the ANOVA analysis was carried out for composite S3. For ANOVA analysis wear data used was in terms of micrometers. The results for composite S3 are as shown in table 3. ANOVA results are shown in table 4.

One can observe from the ANOVA analysis that the value of P is less than 0.05 for first two parametric sources. Therefore it is clear that load and speed has the influence on the wear of composite. The last column in table 4 shows the percentage contribution of each factor on total variation including their degree of influence on the result. One can observe from the ANOVA table that the Load (51.63%), speed (33.67%) and temperature (10.28%) has great influence on the wear. The temperature is influencing comparatively less (10.28%), which indicates that there is no appreciable increase in wear by increasing the temperature from 150 to 250 ^{o}c.

The graph shows the Main Effect plot for S/N ratio. The level for a factor with the highest S/N ratio was the optimum level for response measured. From the plot, it is observed that the minimum wear was at the higher S/N values in the response graph. The optimal wear parameters were 15N Load (level 1), 191 rpm (level 1) and 150^{o}c temperature (level 1). From S/N ratio graph, it is observed that for dry sliding wear, the Load and Sliding speed has the greatest influence on the wear. Figure 9 and 10 show graphically the effect of control factors on wear. Process parameter settings with highest ratio always give the optimum quality with minimum variance. The graph show the change of ratio when setting of the control factor was changed from one level to another.

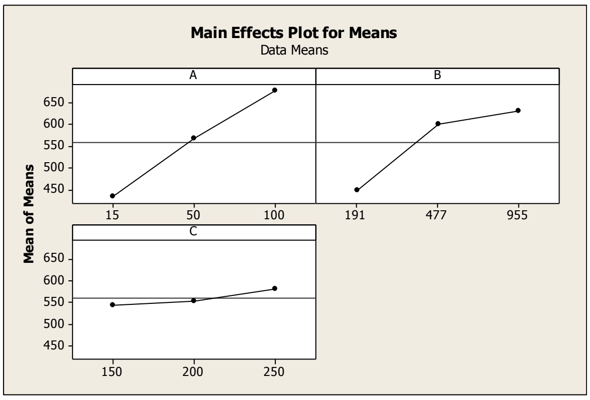

Fig.9 Main effects plot for means

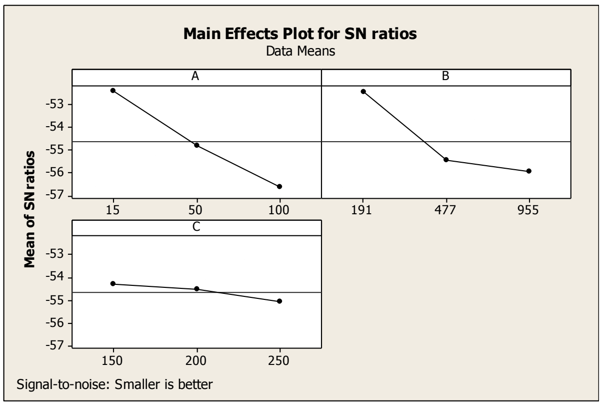

Fig.10 Main effects plot for SN ratios

C. Multiple Linear Regression Model

To establish the correlation between the wear parameters 1) load 2) speed 3) temperature and dry sliding wear loss the wear multiple regression model was obtained using statistical software 'MINITAB 16'. The terms that are statistically significant are included in the model. Final Equation obtained is as follows,

WEAR = 208.028 + 2.8204 LOAD + 0.222082 SPEED +
0.3811 TEMPERATURE …….. (4)

Substituting the recorded values of the variables for the above equation (4) the sliding wear of the material can be calculated. The positive value of the coefficient suggests that the sliding wear of material increases with their associated variables. Whereas the negative value of the coefficient suggest that the sliding wear of the material will decreases with the increase in associated variables. The magnitude of the variables indicates the weightage of each of these factors. It is observed from the Equation (4) that the Load has the more effect on wear of the composites, which is followed by Sliding speed, and temperature for the tested range of variables. The important factor affecting the sliding wear is the load and coefficient associated with it is positive (2.8204). This suggests that the Load increases the penetration ability of the fractured particles, will increase and remove the material on the pin surface. The coefficient of Sliding speed is positive (0.222) which indicates that increase in wear weight loss with increasing the Sliding speed. The coefficient of temperature is also positive (0.3811) which indicates that Sliding wear increases with increasing rpm for the tested range.

V. CONCLUSIONS

Full factorial design of three factor-three levels and analysis of variance were successfully used in the study of the wear test. The results shown that wear rate increases with increasing the sliding speed, load, temperatures. The co-efficient of friction obtained is within 0.3-0.4 which is within the recommended standard for automobile brake pad. The 12% fiber content composite gave the better wear resistance as compared to other. The ANOVA analysis has shown that the variable load is most significant factor affecting wear followed by speed and temperature. The results of this study indicate that steel wool composite can be effectively used as a replacement to manufacture brake pads.

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