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Analysis of Brake-Pad Friction Material Formulation

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Abstract—*In the technologically advanced era that we currently live in, there is a growing demand for cheaper and more durable materials for a variety of purposes. The most important safety feature of an automobile is its braking system. The ability of brakes is to provide safe and repeatable stopping, which is related to safety of automobiles and human. Automotive friction materials are multi component composites in which binder, fibers, fillers and property modifier all plays important role.*

The presented research work investigates/explore the influence of mineral fibrous reinforcement like lapinus fiber and wollastonite fiber on the physical, mechanical and wear performance of friction materials. The composites formed have common master batch of straight phenolic organic resin, barite, Kevlar and graphite. The designed formulations are fabricated as per the standard procedure and the moulding processing conditions adopted according to industrial standard. The samples are then characterized for their physical, mechanical and sliding wear properties. The physical and mechanical properties of such friction composites have been found to be well within the standard industrial norms. The specific wear rate generally increases with the increase in applied load and sliding speed for all compositions found to increase with increase in wollastonite fiber content.

I. INTRODUCTION

Most of us only think about brakes when a panic stops occur ahead in traffic and all we see are brake lights and the undersides of cars. These near emergencies illustrate how important brakes are to our safety. Most brake friction material on the market is organic. Organic friction material held together by resin binders. Contains asbestos, glass or synthetic fibers.Asbestos were widely used in drum and disk formulations for several decades until health and safety concerns triggered efforts to find suitable substitutes. Asbestos-free formulations use a fiber combination of aramid pulp, ceramic fiber, rock wool, and other fibers or whiskers.Organic matter present in them disintegrates in severe braking conditions. The asbestos fiber in organic linings can withstand high temperature, but with no binder to hold it together it has no strength. The metallic materials solve this problem. carbon-carbon friction materials are used for thermally demanding applications like aircraft and race car brakes. Typically, both pads and rotors are made of carbon composite. These friction couples have a relatively low friction level, which is insensitive to the high temperatures. Brake friction material consists of binders, fillers, fibres, friction modifiers. Continuous emphasis on the development of durable and efficient friction materials for the braking applications conforming to the stringent norms, such as, higher friction coefficient, negligible fading, faster recovery, better wear resistance, low-sensitivity towards load-speed alterations, least noise and vibration propensity for safe and reliable operation over a wider range of braking application has been the theme of automotive braking industries. The development of vehicles started with marked usage of asbestos fiber in friction material [12]. The ban on the use of asbestos by Environmental Protection Agency's (EPA) had forced the friction industry to seek alternative of asbestos. DuPont's Kevlar fibers were used as a replacement for asbestos in friction materials [13]. Kevlar fibre's properties such as high specific strength, infusibility and good wear resistance were the main advantages [14, 15]. Various fibres were reported as an alternative to asbestos fibre in friction composites [16-18]. Phenolic resin or their modified versions are the most favoured binders for friction composites [19]. The effects of various abrasives on tribological performance of friction materials were reported [20]. The roles of various solid lubricants viz. graphite, Sb_2S_3, MoS_2 etc. were also reported in literature [21]. Few interesting papers have been also reported on the use of carbon nano-tubes and other nano-materials in brake friction materials [22-24].

Against this background, the present work mainly focus on the influence of mineral fibre combinations on the physical, mechanical and wear performance of friction materials. The focus has been on fabrication of a series of friction composites filled with inorganic fibre combinations and evaluation of their physical, mechanical and wear performance.

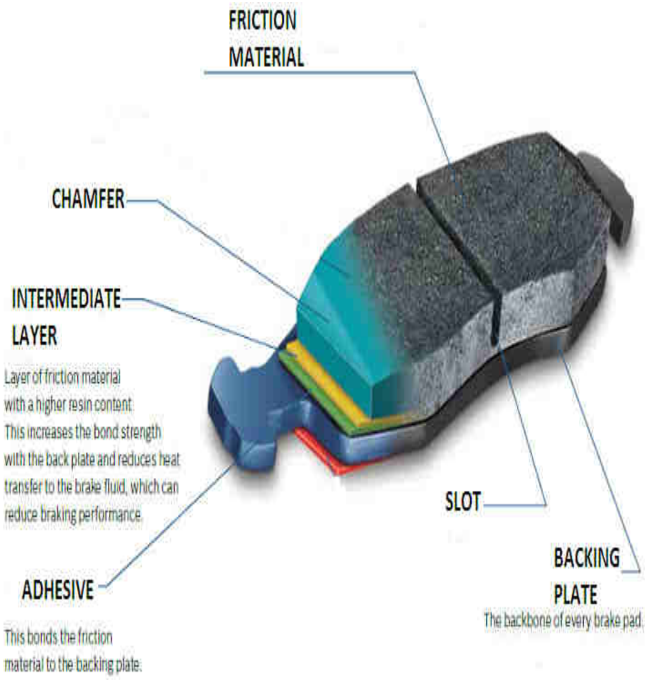

Fig 1. Brake Pad Detail View

II. LITERATURE REVIEW

Idris et al. [25] studied the influence of banana peels waste on the physical and mechanical properties of phenolic based friction composites. They concluded that water absorption decreased as the wt.-% resin increases which can eventually be attributed to the decreased pores because of the close interface packing achieved.

Mukesh and Bijwe [26] studied the influence of copper shape (particle and fibre) and amount on the physico-mechanical properties of friction materials. Mechanical properties such as tensile strength increased whereas, hardness and flexural strength deteriorated.

Arjmand and Shojaei [27] studied the physico-mechanical properties steel fibre and aramid pulp filled styrene-butadiene rubber based friction materials along with a fiber-free reference material. Overall aramid pulp added composites show higher hardness and compression modulus when compared with the other composites.

Singh et al. [28, 29] investigated the role of nanofiller and organic-inorganic fibre combinations on the physico-mechanical properties of brake friction materials. They concluded that inclusion of nanoclay and hybrid MWCNT/nanoclay contents led to increases in the density void contents and deterioration in mechanical properties.

Bijwe and Mukesh [30, 31] investigated the influence of steel and brass fibre on the physical and mechanical properties of friction composites. They concluded that that the density of composites showed increasing trend because of addition of steel and brass fibre which are heavier than the filler barite. Void contents increased slowly with increase in steel and brass fibers because of larger size of fiber as compared to barite powdery particles.

Bijwe and co-workers [32-36] investigated the influence of modified resins and their content on the physical and mechanical properties of friction materials. They show that with increase in the content of resin, density of the composites decreased.

Yi and Yan [37] studied the effect of three friction modifiers (0-25 vol.-%) calcined petroleum coke (CPC), talcum powder (TP) and hexagonal boron nitride (h-BN) on the mechanical properties of phenolic based friction composites. It is seen that the bending strength and hardness of the phenolic resin-based friction composite increased with increasing CPC content.

Kim et al. [38] studied the effect of potassium titanate and barium sulphate on the physical and mechanical properties of friction composites. They found that density and hardness remains higher for barium sulphate filled friction composites whereas void content remain maximum in potassium titanate filled friction composite.

Ho et al. [39] studied the effect of different fibers on the physico-mechanical properties of brake friction materials. The hardness of the materials has a similar trend, except for copper and brass added materials, which show similar hardness to that without fiber.

In additional study [40] they studied the effect phenolic content on the physical and mechanical properties of phenolic-copper based friction composites.

Cho et al. [41] studied the effect of sixteen ingredients viz. aramid fibre, MgO, rockwool, cashew, potassium titanate, rubber, phenolic resin, $Ca(OH)_2$, graphite, Fe_3O_4, MoS_2, Cu chip, Sb_2S_3, vermiculite, ZrSiO4, $BaSO_4$ on the physical properties of friction materials. They found that increasing phenolic, increases the hardness while decreases porosity and compressibility. Increasing aramid fibre increases the hardness, porosity and compressibility. Increasing PT and cashew, decreases the hardness and increases porosity and compressibility.

Verma et al. [42] comparatively studied the physical and mechanical properties of glass woven roving simultaneously filled with straight and modified phenolic resin. They observed that modification enhances the tensile strength/modulus and impact energy characteristics of the composites by making the matrix more ductile.

Mutlu et al. [43] studied effect of boric acid modification in phenolic friction composites. They show that hardness increases whereas density decreases due to modification. **Kim et al.** [44] studied performance of friction composite based on phenolic resin, potassium titanate and cashew nut-shell liquid (CNSL). They suggested that the friction composites having a low hardness, high porosity and compressibility tended to reduce noise propensity.

Kim et al. [45] have investigated the synergistic effect of aramid pulp and potassium titanate ($K_2O.6TiO_2$) on the physical properties of friction materials. They show that a composite having potassium titanate exhibit high porosity and less hardness as compared composites having Kevlar or both the fibers.

According to **Patnaik et al.** [46] the specific gravity of the composites remained inappreciably affected by the compositional changes.

According to **Nandan et al.** [47, 48] the void content and the ash content increased with the increase in the flyash content in the composites.

2.1. RESEARCH GAPS

The extensive literature survey exposed that though much work had been described on various characteristics of friction materials. The literature survey presented above reveals the following knowledge gap that helped to set the objectives of this research work:

1. There are too many constituents in the friction materials to make their behavior predictable.
2. There are fewer research reports regarding influence of phenolic resin and its variants or other grades of resin.
3. Inadequate efforts towards the understanding of the influence of addition of mineral fiber combinations in friction formulations.

Against this background, the present work mainly focus on the influence of inorganic fibre combinations on the physical and mechanical properties of friction materials. The focus has been on fabrication of a series of friction composites filled with inorganic fibre combinations and evaluate their mechanical , physical ,and wear behaviour.

2.2.OBJECTIVES

The extensive literature survey exposed that much work had been done on tribological characteristics of friction materials of brakes. The literature survey reveals the following knowledge gap that helped to set the objectives of this research work:

1. Fabrication of a series of friction composites using mineral fibre combinations.
2. Characterization of physical properties such as density, ash-content, void- content, heat- swelling, water-swelling etc.
3. Characterization of mechanical properties of friction composites such as tensile-strength, hardness, tensile-strength,flexural-strength,shear-strength, of the friction composites.
4. Evaluation of sliding wear performance using Pin-on-Disc test rig.

2.3Fabrication of friction materials

The formulation design of the friction composite materials was carried out on the basis of four classes of frictional materials i.e fillers ,binders,reinforcing fibers and property modifiers with fixed percentages by weight. The various compositions and the designations of frictional composites are given in Table 3.2. PF Resin and $BaSO_4$ mix together for 5 min in the high speed chopper mixing machine. After that this mixture is mix with wollastonite, lapinus, Kevlar and graphite for 5 min in the high speed chopper making machine. Finally, the pads are stress relieved in muffle furnace and thus residual resin is cured. The composite brake pads so obtained are subjected to surface polishing. Then the samples are characterized for various physical and mechanical properties.

Table 3.2.*Designation and composition of composites.*

S. No.	Sample	Composition					
		Phenolic	$BaSO_4$	Graphite	Kevlar	Lapinus	Wollastonite
		wt.-%	wt.-%	wt.-%	wt.-%	wt.-%	wt.-%
1.	LW-0	15	50	5	5	25	0
2.	LW-1	15	50	5	5	20	5
3.	LW-2	15	50	5	5	15	10
4.	LW-3	15	50	5	5	10	15

III. CHARACTERIZATION OF THE FRICTION COMPOSITES

The fabricated friction composites were characterized for the physical, chemical and mechanical properties as follows.

3.3. 3.1. Density

The density (ρ_{ce}) of the frictional composites was evaluated by water displacement method.

3.3. 3.2. Void content

The void content gives an idea of porosity of the samples. Void-content of the sample is evaluated by the following relation:

$$\% \text{ void contents} = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \quad \text{……….(3.1)}$$

where, ρ_{ce} is the experimental density of the friction composites and ρ_{ct} is the theoretical density of friction composite materials calculated as;

$$\rho_{ct} = \frac{1}{\frac{w_{Barium}}{\rho_{Barium}} + \frac{w_P}{\rho_P} + \frac{w_K}{\rho_K} + \frac{w_L}{\rho_L} + \frac{w_G}{\rho_G} + \frac{w_{Wl}}{\rho_{Wl}}} \quad \text{……….(3.2)}$$

where, w_{Barium}, w_P, w_K, w_L, w_G, w_{Wl} are the weight ratios of $BaSO_4$, phenolic resin, Kevlar, lapinus , graphite and wollastonite whereas ρ_{Barium}, ρ_P, ρ_K, ρ_L, ρ_G, ρ_{Wl} are their densities respectively.

3.3. 3.3. Ash content

To determine ash-content the sample in powdered form is roasted up to 800 ^{o}C in a muffle furnace

The ash-content percentage can be calculated as:

$$\% \text{ ash content} = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{…………(3.3)}$$

Where, W_1 = Weight of the sample before heating to 800^{o}c,
W_2 = Weight of the sample after heating to 800^{o}c

3.3. 3.4. Water absorption

The friction composite materials deteriorate the braking performance while come in contact with water. To avoid this problem the brake pads should be highly resistant to water. Water absorption test was carried out according to ASTM 570-98. The specimen cut into 25 mm × 25 mm × 5 mm and weighing done. For 24 hours the samples are kept dipping in water. The percent of water absorbed was calculated from the following relation:

$$\% \text{ Water absorption} = \frac{W_f - W_i}{W_i} \times 100 \quad \text{(3.4)}$$

Where, W_i = weight of the sample before keeping in water, W_f = weight of the samples after keeping in water

3.3. 3.5. Heat swelling

Heat produced when brake applied can make brake to swell and can cause performance deterioration related problems. The ideal material should withstand the high temperature with minimal swelling and hence without appreciable loss in the brake pad shape and performance. Heat swelling of the samples was carried according to SAE J160 JNU80 slander. The sample is cut into 10 mm × 10 mm × 4 mm size and thickness was measured accurately at six different places. After this the sample was heated at 200 ^{0}C ± 5 ^{0}C in muffle furnace for two hours. The thickness was measured of the heated sample.

$$\% \text{ Heat swelling} = \frac{T_f - T_i}{T_i} \times 100$$

Where, T_i = Thickness of the sample before heating, T_f = Thickness of the sample after heating.

3.3. 3.6. Hardness

Hardness as a measure of resistance to indentation under loads was measured on a digital hardness tester (Figure 3.9) on Rockwell-R and L scales with a minor load of 10 kg and a major load of 60 kg. The indenter used was in the form of a steel ball with 12.7 mm diameter for HRR and 6.35 mm diameter for HRL. The mean hardness value form 12 points was reported.

3.3. 3.7. Tensile strength

The tensile strength reflects the integrity of the composites under axial stress. The tensile strength was evaluated on a Zwick tensile tester (Figure 3.10) following ASTM D3039-76 standard. The gauge length was fixed at 70 mm.

3.3. 3.8. Flexural strength

The flexural strength of the composite represents the resistance of the composite to deformation under radial stresses. The flexural strength characterization (3-point bending) was carried out as per as the ASTM D2344-84 method-I on the Zwick universal testing machine (Figure 3.10). The gauge length was fixed at 70 mm and the strain rate was 2.5 mm/min.

3.3. 3.9. Compressibility

The compressibility of the fabricated friction composites was evaluated following ISO 6310. The compressibility test was conducted on compressibility machine

***Table 3.3** Machine Specifications.*

Parameter	Specification
Pin Size	3 to 12 mm diagonal
Disc Size	160 mm dia * 8 mm thick
Wear Track diameter (mean)	10 mm to 120 mm
Sliding Speed	0.05 m/sec to 10 m/sec
Disc Rotation Speed	100-2000 RPM
Normal Load	200 N maximum
Frictional Force	0-200 N
Wear measurement Range	± 2mm
Temperature (4 Channels)	Ambient – 200°C
Power (Input)	415V, 15 Amps, 3 phase, 50 Hz
Pump Power	230V, 200VA, 1 Phase, 50 Hz
Capacity of Storage Tank	3 litters

3.3.3.10. Shear strength

Shear strength was measured on universal testing machine from fuel instruments and engineering pvt. Ltd.

3.3.4. Wear Characterization

3.3.4.1. Wear monitor apparatus

A pin-on-disc type wear monitoring test rig (supplied by DUCOM) as per ASTM G 99 used for the wear performance evaluation of the fabricated friction composites under dry sliding condition. The schematic diagram of the test rig is shown in the Figure 3.13-3.14. This is a sturdy versatile machine which facilitates study of friction and wear characteristics in sliding contacts.The specifications of the machine are given in Table 3.3. Sliding occurs between stationary pin and a rotating disc normal load; rotational speed and wear track diameter can be varied to suit the test conditions. Tangential force and wear are monitored with electronic sensors and record stored. The wear and friction monitor machine consists of:

Wear and Friction monitor-Machine

The major constituents of the machine are mechanical parts assembled, AC driving-motor, loaded pulley and pan for weighing purposes. The track- radius and load for the test are set on machine side.

Wear and Friction monitor-Controller

Test parameters such as speed of disc, duration of test, revolutions can be set with the front panel setting on the controller. The wear and frictional force are continuously displayed. Temperature, wear and frictional force data is processed and serially transmitted through data acquisition cable.

- Data acquisition system

Data acquisition system includes data acquisition cable and one CD containing WINDUCOM2002 Software

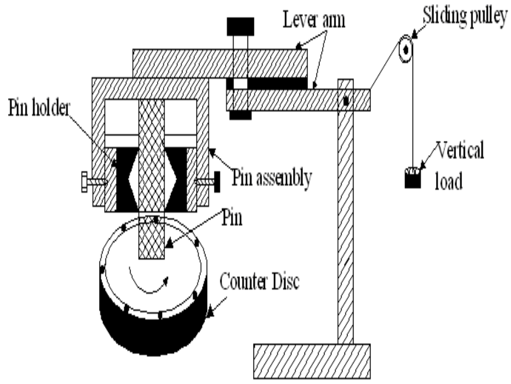

Figure 3.14. The schematic diagram of Pin-on-Disc set-up.

3.3.4.2. Operation of machine

The controls for the operation are given in Table 3.4.

Table 3.4 Machine operational mode and their

Mode	Implication
Wear	To be preset to zero before start of operation.
Frictional force	To be preset to zero before start of operation.
Speed	Speed of the disc- variable in the range of 100-2000.
Timer/Counter	To control the duration or revolutions of the disc.
Start/Stop	To start/stop the system operation.

implications Switched on the MCB on the machine side panel and specimen 10×10 mm was clamped by placing it between the jaws adjusting the height of the pin with respect to the wear disc using height adjustment block ensuring that the loading arm is parallel to the plane of the wear disc. Track radius of 100mm was set by adjusting the traverse of the scale-slider assembly. Now switched on the controller "POWER" switch and loosened LVDT lock screw observing the Wear digit display within range of ±50 µm and locked it by tightening the lock screw. Time duration of

20 minutes for the test using SET, RESET and ENTER push buttons was entered. Load of 5kgf had been used for dry sliding wear and friction check. Set WEAR and FRICTIONAL FORCE displays to zero by actuating corresponding ZERO push buttons and setting RPM for various samples of varying composition by rotating the SET RPM in clockwise direction. Measured RPM is displayed on the SPEED display of the controller front panel. Now WINDUCOM2002 software was run and respective data were introduced, actuating START push button on the controller front panel to commence the test. The test stops automatically after the elapse of preset time. The experiment was performed at room temperature.

3.3.4.3. Calculation of specific wear rate

A pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99 used for the performance evaluation of tribological performance of these friction composites under dry sliding condition at room temperature. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 μ Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of test are conducted with four sliding velocities of 1, 2, 3 and 4 m/sec under three different normal loading of 40N, 80N and 120N at a constant sliding distance of 3000 m. The surface of the disc was cleaned with acetone before the start of every new experiment. The material loss from the composite surface is measured using a precision electronic balance with accuracy $\pm$ 0.1 mg and the specific wear rate (mm^3/N-m) is then expressed as:

$$W_s = \Delta m/\rho t\ V_s.F_n \qquad (3.6)$$

where Δm is the mass loss in the test duration (g), ρ is the density of the composite (g/mm^3), t is the test duration (sec), V_s is the sliding velocity (m/sec) and F_N is the average normal load (N).

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