Tribological Performance of inorganic-metallic fiber reinforced automotive brake friction materials

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Abstract - ***Automotive brake friction materials comprising of varying proportions of inorganic (lapinus) fibre and metallic (brass) fibre are designed, fabricated and evaluated for tribological performance. Comprehensively, it is found that incorporation of higher brass fibre in composition enhances the overall frictional response. It is found that coefficient of friction, fade and recovery follow a consistent increase with increase in the brass fibre content, whereas friction stability and variability have been observed to increase with increase in lapinus fibre content. It was concluded that the composition with 10 wt.% of lapinus fibre and 5 wt.% of brass fibre content was observed the best fade performance, highest wear resistance and lowest frictional fluctuations.***

Key Words: *Brake friction materials, Brass, Lapinus, Fade and Recovery, Wear*

1. Introduction

In the beginning of 18th century, the industrial revolution changed the way the mankind lives. Since then mankind actively engaged in developing stylish machineries for the production of quality goods and better means of transportation with the objective of making the life easy. In such machines, friction materials were extensively used in various machinery parts and its usage was exponently increased with the booming of automotive industries. Generally, friction materials are multi-phased composites consisting more than 20 ingredients, primarily of five classes viz. binder, fillers, fibers, abrasives and lubricants [1, 2]. The widespread investigations concerning the role of binders, fibres, fillers, lubricants, abrasive and other special fillers on one hand and various optimization techniques were amply reported in literature [3-15].

For performance enhancement different kinds of fibers, e.g., organic [16], inorganic [17], natural [18], ceramic [19], metallic [4] and their combinations [20] have been reported as reinforcement for friction materials. Among them, inorganic and metallic fibers have attracted much attention because of its better thermo-physical properties. The inclusion of metallic and inorganic fillers enhances the physical and mechanical properties as well as also influences the braking performance of the disc brake pad friction materials. They also stand important because of their high thermal stability and abrasiveness which helps in maintaining brake effectiveness. Various inorganic and metallic ingredients such as: lapinus fibre [21], basalt fibre [21], wollastonite fibre [17], steel fibre [22], brass fibres [23], copper [24], iron powder [25], aluminium [26] etc. are extensively utilized in friction materials.

For development of brake friction materials with good and stable tribological performance, fibre inclusion is imperative. The role of inorganic and metallic fibres has been reported to improve the tribological performances to a wide range of braking conditions. Hence, their combination may potentially enhance the tribological performance of a brake friction material. Therefore, this paper deals with utilization of lapinus and brass fibres in varying proportions to study possible synergistic effect of their combination on the tribological performance of brake friction materials.

2. Experimental details

2.1. Materials and fabrication

The friction composite materials based on straight phenol-formaldehyde (PF) resin, Kevlar fibre, lapinus fibre, alumina, graphite, barites, vermiculite and brass fibre together were fabricated. The compositional variations and nomenclature of the fabricated composites are presented in Table 1. The ingredients were mixed sequentially in a plough type shear mixer, where mixing of powdery ingredients was followed by fibrous ingredients to ensure the proper distribution of ingredients before moulding. The mixture is preformed to the shape of brake pads and then heat cured in a compression-moulding machine at temperature of 150^{o}C under 15MPa of pressure for 10 min. Four intermittent breathings were applied during molding to expel volatiles evolved during curing. To relieve residual stresses developed during moulding cycles the specimens were post-cured in an oven at 170^{o}C for 4h. The friction materials in the form of brake pads are ejected out of the mold and the friction surfaces were then lightly ground to gently wipe-off the resinous skin via a mild bruising. Thereafter, the composites are used for tribological characterizations.

Table -1: Brake friction material composition and designation.

Composition (wt.%)	Designation			
	FM-0	FM-1	FM-2	FM-3
PF Resin	15	15	15	15
Graphite	5	5	5	5
Kevlar Fibre	5	5	5	5
Vermiculite	5	5	5	5
Alumina	5	5	5	5
$BaSO_4$	50	50	50	50
Lapinus Fibre	15	10	5	0
Brass Fibre	0	5	10	15

2.2. Tribological performance evaluation methodology

The tribological assessment tests were conducted on a Krauss machine in conformance to regulations laid by Economic commission of Europe (ECE R-90), details of which are mentioned elsewhere [27-30]. The Krauss machine is fully computer-controlled having data acquisition capabilities. In brief, a pair of brake pad was pressed against the rotor for undergoing cold, fade and recovery cycles.

3. Results and Discussion

3.1. Braking performance response

The frictional response and the rise in disc temperature in relation to braking instances are presented in Fig. 1. In general, it is clear that all the composites have responded to three regimes of friction evolution i.e. friction-build up, friction-peaking and friction-decay irrespective of compositions and testing cycles. The plot systematically accounts 70-braking instances of testing cycles according to the test procedure. Fig. 1 shows that all the investigated frictional composites FM-0, shows steady friction response in the cold cycle but in FM-1, FM-2 and FM-3 shows unsteady friction response in the cold cycle as it firstly increase then reduce in coefficient of friction. In FM-0 (Fig. 1a) plateaus are flatter but there is no frictional peaking and coefficient of friction in fading is low as compare to FM-1 (Fig. 2b). In which there is high coefficient of friction in fade cycle and good recovery. In all fade cycles the first curve show abrupt rise in coefficient of friction with good recovery. In friction composite FM-2 (Fig. 1c) the μ performance remained wildly fluctuating and as a follow-up response abrupt friction peaking accompanied with steep friction-decay within the first four braking instances were observed in the first two fade cycles. However, from third fade run onwards the friction response is showed signs of stability followed by a nominal trend of friction-decay as compared to earlier fade cycles. FM-3 shows slow friction rise in first fade cycle there is stable frictional performance in next two cycle after that there is abrupt rise in the friction in fourth fade cycle. Last fade cycle shows stable frictional performance. However in recovery run there is initial increase in recovery in increasing order FM-0<FM-1<FM-2<FM-3.

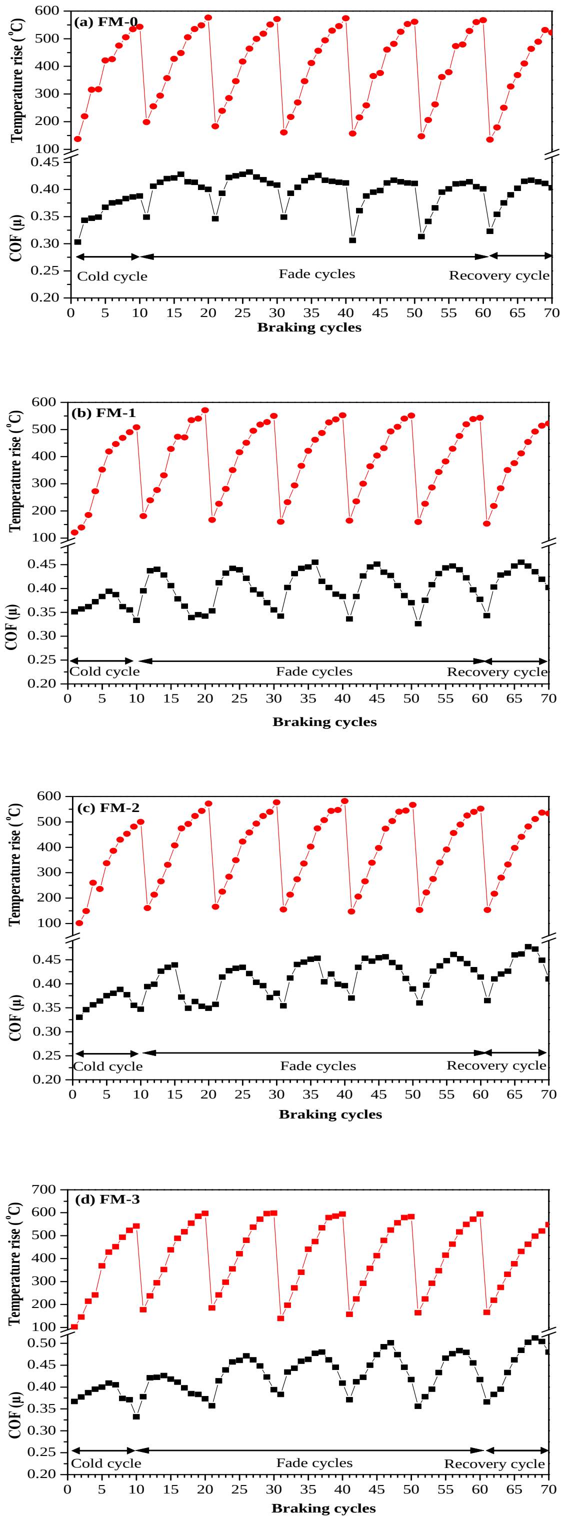

Fig -1: Frictional response of the brake friction materials (a) FM-0 (b) FM-1 (c) FM-2 (d) FM-3.

3.2. Tribological properties of brake friction materials

3.2.1. μ-performance (μ_P), μ-fade (μ_F), μ-recovery (μ_R), friction fluctuations (μ_{max}-μ_{min}) response

The tribological performance parameters such as performance coefficient of friction (μ_p), fade coefficient of friction (μ_F) and recovery coefficient of friction (μ_R) as obtained by tribological performance evaluation in Krauss machine following ECE R-90 norms are depicted in Fig. 2. It can be clearly seen from the Fig. 2 that an increased in brass content as compared to lapinus in the composition results with the increase of μP and μR along with a slight increase in the μF. However, in case of FM-1/FM-2/FM-3, the higher magnitude of friction coefficients may be attributed to the presence of hard brass fibre that enhances the abrasive component.

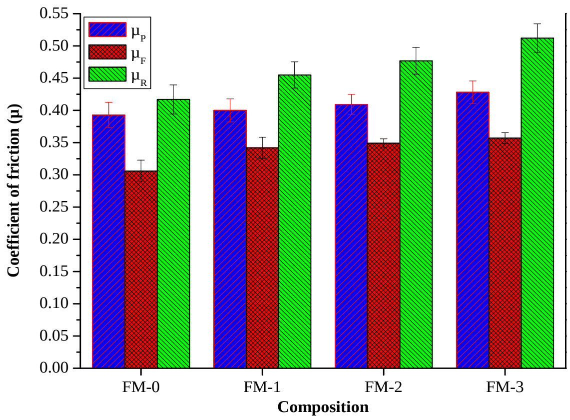

Fig -2: Friction performance of the brake friction materials: μ_p, μ_F and μ_R

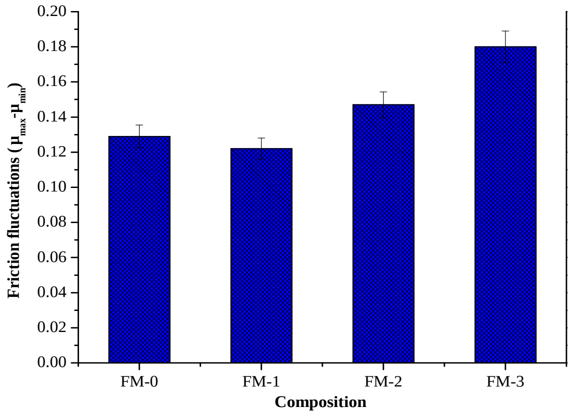

Fig -3: Frictional fluctuations of brake friction materials.

Fig. 3 shows the friction-fluctuations of the brake friction materials. High fluctuation are reported in FM-3 which have 15 wt.% of brass fibre, whereas it remains lower for composition having 10:5 wt.% of lapinus: brass content i.e. FM-1. Friction material FM-3 is likely to have higher susceptibility to vibration, noise, judder etc. that should be as low as possible. The composition having 10:5 wt.% of lapinus: brass content i.e. FM-1 with least friction fluctuations (0.122) proved effective in the absorption of vibrations which generated during the braking operation and minimizing the unwanted phenomenon like judder, noise to a larger extent as compared to other compositions.

3.2.2. Fade and recovery performance

Fig. 4 shows the plot between %-fade and %-recovery for the various brake friction materials studied in this work. It is clearly seen from Fig. 4 that, fade was maximum for the FM-0 (22.14%). For FM-1 it is minimum (14.50) and for FM-3/FM-2 it is moderate (~14.58±0.09). Recovery is in increasing order with contents of brass fibre (FM-0<FM-1<FM-2<FM3) and remains well within the range of 90-140% recommended by IS-2742 standard for brake friction materials.

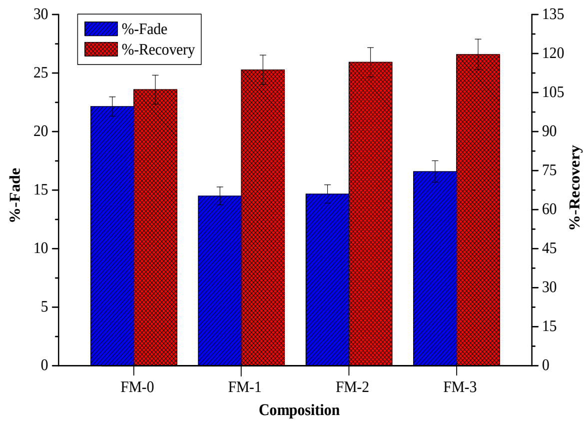

Fig -4: %-fade and %-recovery performance.

3.2.3. Friction stability and variability

Fig. 5 shows the stability and variability aspect of frictional response in terms of stability coefficient (ratio of μ_P to μ_{max}) and variability coefficient (ratio of μ_{min} to μ_{max}). It is observed that FM-0 shows highest stability coefficient and FM-3 shows least stability coefficient whereas FM-1 shows highest variable coefficient and FM-3 shows least variable coefficient. It is required that stability and variability coefficient should be as high as possible for the efficient frictional response while braking. Thus, composition of FM-0 proved effective from stability point of view whereas, FM-1 composition shows highest variability for efficient braking performance.

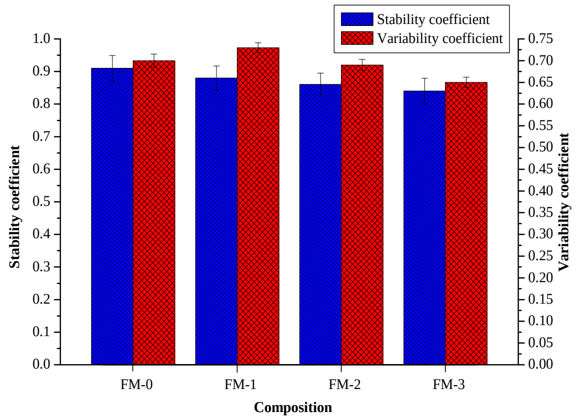

Fig -5: Stability and variability coefficients.

3.2.4. Temperature rise of the disc

The maximum disc temperature rise of brake friction materials is shown in Fig. 6. The temperature rise of the disc has been observed to be highest in case of FM-3 (698 ºC) followed by FM-0/FM-2 (679±3 ºC). The same remained lower for the composite FW-1 with the lowest amount of brass and the amount of lapinus is 10 wt.%. Such observations clearly reveal that higher amount of brass content contributes to enhanced temperature rise of the disc, whereas the lowest amount of brass in combination with 10 wt.% lapinus fibre contribute to minimum disc temperature rise.

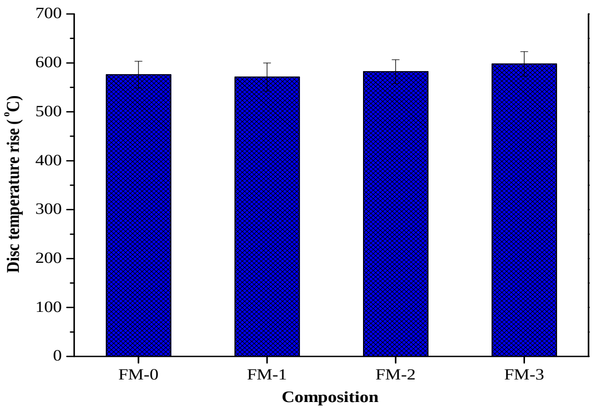

Fig. 6: Temperature rise of the disc.

3.2.5. Wear performance

Wear performance of the brake friction materials is measured in terms of weight loss (in grams) before and after tribological characterization and depicted in Fig. 7. It is found that the wear performance of the friction materials first increased and then decreased with the increase in brass fibre with corresponding decrease in lapinus fibre. Higher content of lapinus and brass get agglomerated to form bundles and thereby introduce structural discontinuities on the operating friction film resulted in enhanced wear. From Fig. 7, it is clearly seen that lapinus to brass content in the ratio of 10:5 wt.% resulted in increased in wear resistance, which indicating synergism between lapinus and brass fibres.

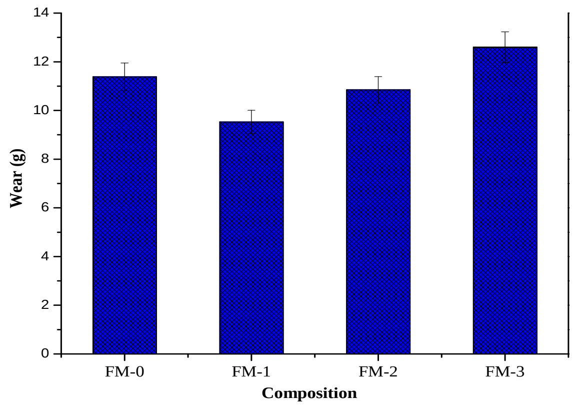

Fig -7: Wear of the brake friction materials.

4. Conclusions

Tribological properties of composite friction materials based on lapinus and brass fibre have been evaluated on a Krauss friction testing machine by using a standard test protocol conforming to ECE R-90 regulation. The following conclusions were drawn from the study:

- The performance coefficient of friction has been observed to be highest in the composite with highest amount of brass fibre and decreasing consistently with the decreased in the brass fibre.
- The frictional fluctuations have been observed to be lowest in the composite with lowest amount of brass fibre and found to be increasing consistently with the increased in brass fibre.
- The fade performance remained highest in the composite with lowest amount of brass fibre and consistently decreasing with the increased in the brass fibre, whereas recovery performance remained highest in the composite with highest amount of brass fibre and consistently decreasing with decrease in the brass fibre.
- The composite with lower amount of brass fibre shows lowest temperature rise of the disc, good stability, highest variability and highest wear resistance.

It was finally concluded that the friction compositions with brass fibre content ≤5 wt.% proved best from fade performance and wear performance point of view, whereas compositions with brass fibre content ≥10 wt.% proved best from coefficient of friction and recovery performance point of view.

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