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Exploration of Physical Characteristics, Mechanical Strength, and Wear Resistance of Bronze Fiber-Reinforced Brake Pads

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This research focused on the production of brake pads reinforced with bronze fibers to see the anticipated performance principles for braking systems. Three unique amalgamated formulations, labeled BRZ-I, BRZ-II, and BRZ-III, were set by varying the bronze fiber content to 5%, 10%, and 15% by weight. The tribological characteristics of these composites were systematically evaluated to determine their effectiveness. Traditional manufacturing processes were used in developing the brake pad. Various properties such as physical, chemical, mechanical and tribological possessions were assessed by means of chase test rig. Worn-superficial examination stayed carried out by using chase test rig. Base results it was evident that the 10 weight percentages of the bronze fibers showed better physical, chemical, mechanical and tribological properties. Chase test results confirmed that the composite brake pad developed with 10 weight percentages of bronze showed better results at higher pressure-speed conditions than others due to better plateau formation and less wear rate. The results obtained after performing various performances such as physical, chemical, mechanical and tribological properties concluded that the bronze fiber possessed lesser wear and stable coefficient of friction.

Keywords: Bronze, Brake Pad, Fade and Recovery, Chase Test Rig

1 Introduction

To govern the automobile at varied swiftness and compressions, the current automobile industry needs effective braking performance. Due to their superior physical, biological, and motorised properties, composite materials are taking greater positions in the industry [1-4]. These materials are being employed extensively in the automobile industry, in biomedical applications, and in the defense sector. Because of their lower density values, higher specific strengths, and ease of formability, composite materials are increasingly being used, particularly in the automotive industry. Its capacity to give automobiles an attractive appearance and resist wear and corrosion is another crucial factor driving its usage up in the current industry [5-8]. The ability to enhance the composite's characteristics by adding reinforcement fibers is one of the main aspects that increases its appeal for use in aerospace and automotive applications. Recent innovations include the use of hybrid systems, which join two or more fibers to produce a composite material with advantageous qualities [9-12]. Many parts of modern autos are currently made of thermoplastic materials. The braking system is an automobile's most crucial part. The selection of elements included in brake pad material has a major role in the vehicle coming to a desired halt [13-16]. Following the phase-out of asbestos as a brake friction material, many industries are creating their own methodologies for choosing the components of brake pads [17-20]. Sai Krishnan et al. [21] investigated on friction and wear characteristics of palm kernel brake pad by varying various weight percentages (0, 5,10 and 15 wt. %) along with phenolic resin binder, along with remaining ingredients exhibited good results in terms of wear and stable coefficient of friction. Numerous studies on the tribological characteristics of limestone in copper and asbestos-free brake friction materials have been conducted [22-26]. As a filler for the composite in this study, the author used limestone with a 30 to 40 weight percentage. The findings show that the density of the samples reduces as the limestone concentration rises. Contrarily, friction coefficient and wear rate produce closer values and reach their ideal levels [27-32].

The likelihood of manufacturing high-quality thermal, wear, and fatigue-resistant materials suited for clutch facings and brake linings is increased. Less wear, a high coefficient of friction, low fade behavior, high strength, high reliability, low cost, and the best ingredient bonding are the major criteria for an excellent brake friction material. Bronze fiber, which was taken into consideration for this investigation, has good corrosion and fatigue resistance qualities.

Various metallic fibers were also explored but brake pad with bronze fiber as a key ingredient has not been done so far. Additionally, this material has good electrical and heat conductivity qualities.

2 Materials and methods

An innovative resistance material was intended using a phenolic polymer matrix as the key binder, with barytes added to maintain compositional balance. Each ingredient was deliberately chosen for its role in improving the thermal stability of the material and its ability to endure fatigue stresses. The selection of components was pivotal in achieving superior performance attributes. Three unique composite brake pads, designated as BRZ-I, BRZ-II, and BRZ-III, were formed with variable bronze fiber fillings of 5%, 10%, and 15% by weight. The tribological behavior of these brake pads was thoroughly evaluated and assessed.

Tab. 1 *Formulation*

S.No.	Classifications	BRZ-1	BRZ-II	BRZ-III
1	Fibers with additives	19	19	19
2	Binder with additives	21	21	21
3	Bronze Fiber	5	10	15
4	Fillers (Functional, Inert)	41	41	41
5	Barites	14	19	4

A computerized density measurement device with a precision of 0.01 g/cc was employed to measure density based on the Archimedes principle. The hardness of the fabricated friction materials was assessed using the "K" Scale ball indentation method, performed on a Rockwell Testing machine with a 3.12 mm diameter scale indenter. Acetone was extracted following the Soxhlet method. Proper curing of the developed composites was ensured during the process. To determine the loss on ignition, the sample was heated to 800°C in a muffle furnace for two hours, and the resulting weight difference was recorded. This procedure complied with IS-2742-Part-3 standards from 1994. A standard method was applied to evaluate the porosity of the manufactured brake pads. The tribological performance of the developed brake pads was analyzed using the Chase test in accordance with IS 2742-4. The testing process followed the methodology described in prior literature and consisted of two fade cycles and two recovery cycles. The wear of the composite samples was determined by calculating the weight difference before and after testing.

3 Physical, chemical and mechanical properties of developed brake pads

The physical, chemical, and mechanical characteristics of the produced composites have been evaluated; the results are displayed in table 2. The density of the composites tends to decrease as more bronze fiber is included. The main causes of this are the existence of barytes and the density of bronze fibers. The addition of fiber improved the void content and porosity of friction composites, according to published study [16]. In the current study, it was also demonstrated that friction composite porosity increased as bronze fiber content added. This can be explained by the fact that more bronze fiber results in structural heterogeneities throughout the composites, which increased the levels of voids. The hardness of friction composites increases with increasing bronze fiber content. As the amount of bronze fiber increases, the composites' ash content reduces, which is connected to the decomposition of organic components at high temperatures.

Tab. 2 *Developed composites Charactersitics results*

S.No.	Properties	Unit	BRZ-1	BRZ-II	BRZ-III
1	Density	g/cc	2.014	2.286	2.214
2	Compressibility values	[μm]	248.3	269.7	257.4
3	Hardness	No unit	86	89	94
4	Acetone Extraction	%	1.47	1.39	1.23
5	Loss of Ignition	%	24.5	23.7	20
6	Cold Shear Strength	kg/cm²	40	43	47
7	Porosity	%	5.3	6.35	7.9

3.1 Tribological analysis of fade and recovery Tests

During the second fade run, the coefficient of friction (μ) exhibited a gradual increase until the temperature reached 261 °C for BR-1 composites and 233 °C for BR-3 composites. Figure 1 illustrates the variations in the coefficient of friction during both fade and recovery tests. In the initial phase of the first fade run, the frictional performance showed a slight improvement with rising temperature. For BR-1 composites, the highest value of 0.564 ± 0.004 was observed at 177 °C, while BR-2 composites achieved a peak value of 0.573 at 149 °C.Following this, all composites experienced a steady decline in frictional performance until the temperature reached 233 °C. Beyond this point, the coefficient of friction dropped sharply, reaching minimum values of 0.434 and 0.354 at 289 °C for BR-1 and BR-3 composites, respectively, by the end of the first fade run.In the second fade run, the temperature progressively rose to 261 °C for BR-1 composites and 233 °C for BR-3 composites, after which the coefficient of friction rapidly decreased until the end of the run. During this phase, BR-1 composites recorded the highest value of 0.596, while BR-2 composites dropped to a minimum value of 0.298. During the first recovery run, BR-2 composites reached their highest temperature at 205 °C, followed by a gradual decrease. The maximum friction value for BR-2 composites shifted to a lower temperature of 149 °C, after which it declined significantly.

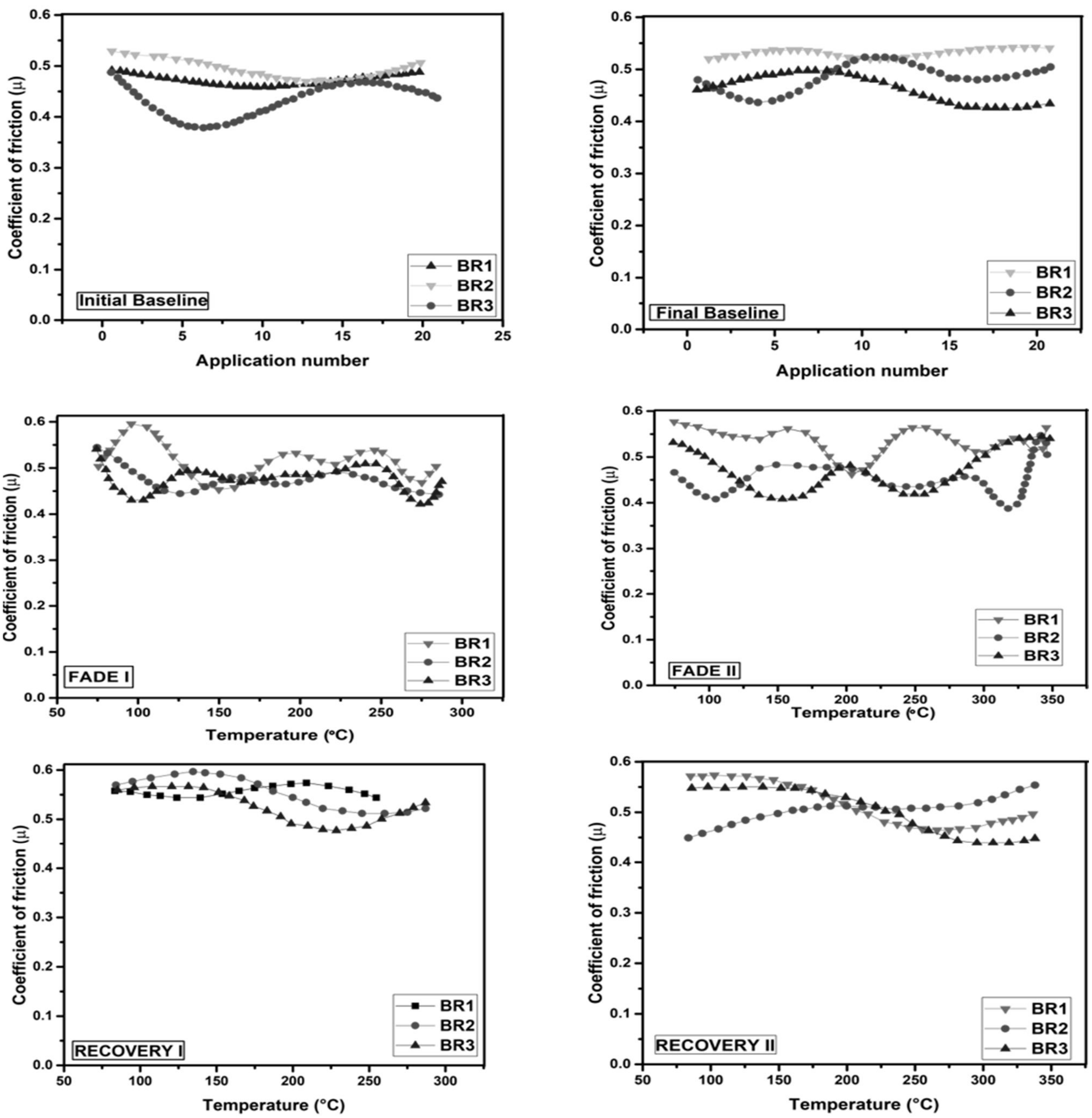

Fig. 1 *Frictional parameters assessment by using chase test rig*

Figure 1 shows the computed findings from a further study of the fade-recovery response of the examined composites in terms of recovery coefficient of friction μR, performance coefficient of friction μP, and fade coefficient of friction μF. For all composites, the magnitude of P and F is visible. For all composites, the magnitude of μP and μF is visible. For BR-1 and BR-2 composites with bronze fiber at 10 weight percentages, the observed μP 0.538 and μF 0.421 values are still much higher. The existence of a higher proportion of organic components, such as phenolic resin and bronze, may be the cause of the lower magnitude of the μP and μF performance. A friction film forms at the tribo-interface due to the thermal degradation/softening of organic constituents at higher temperatures (>250 °C), which lowers the friction performance. Additionally, the composites' performance in terms of fade and recovery was assessed and shown in figure 4. A friction composite is given a higher rating if its μF% and μR% values are lower and higher, respectively. It was discovered that the BR-1 composite still had the lowest F% (22.1%) and the highest μR-%. The μF % for the BR-2 composite was found to be 26.67%, almost identical to the μF% for the BR-1 composite. The sudden rise in F-% can be attributed to the presence of more bronze fiber with barytes.

3.2 Wear performance

The below figure depicts show bronze fiber content affects how well created composites wear under various conditions. The inclusion of bronze fibers significantly affected all the composites' wear, which continues to be lowest for BR-1 composite and greatest for BR-3 composite, which contains 15% bronze fibers. It indicates that adding fiber with a lower content increased wear resistance whereas adding fiber with a higher content was seen to reduce wear resistance. The composite wear for BR-I (with 5 wt.% fiber) is still 1.36 g, while the composite wear for BR-III composite is still the greatest (1.65 g) after additional bronze inclusion. The increase in composite wear was 16% for BR-2 at 10 weight percent and 64% at 15 weight percent. According to experimental findings, this unbalanced ingredient distribution leads to structural inhomogeneities and higher wear.

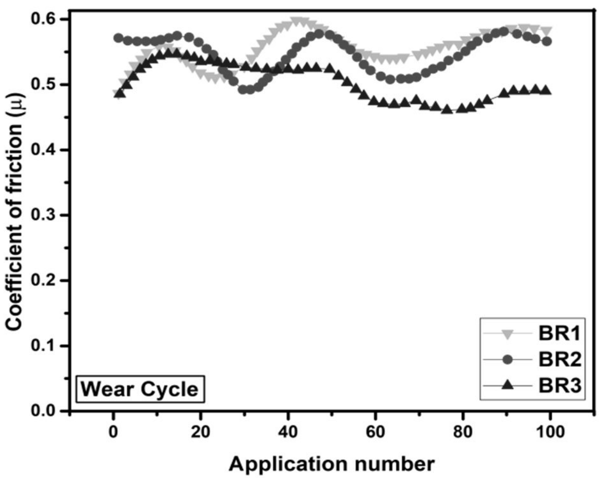

***Fig. 2** Wear cycle of the developed composites*

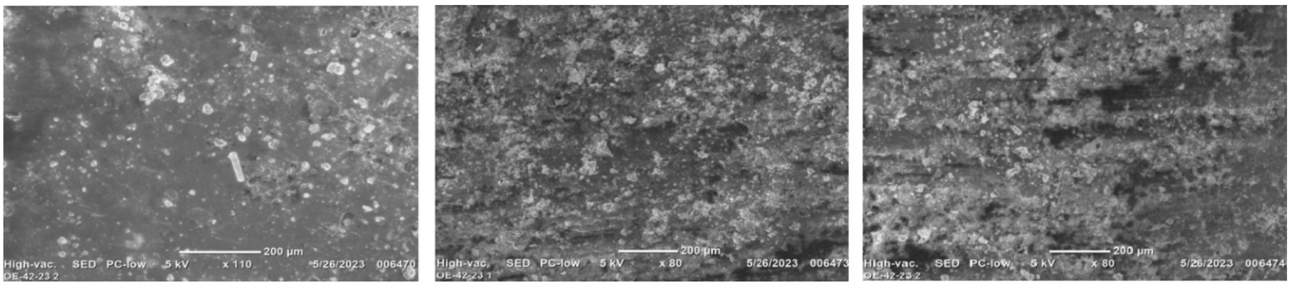

***Fig. 3** Worn surface analysis of the chase tested brake pad composites*

3.3 Worn surface study

A ZEISS-EVO scanning electron microscope can be used to look at the friction composites' worn surfaces to discover the wear mechanism, tribology performance, and undulations that occurred when the composites were produced and put to the test. As can be seen in the figure below, the composite BR-I worn surface was relatively smooth with just a few minor detached patches and spalling pits visible on the surface, which correlated to the least wear. Figures show that the composites BR-3s worn surfaces are severely degraded and coated in wear debris and microcracks. In addition, tiny cracks with diminished contact plateaus were seen. These occurrences were the cause of composites wearing out more quickly than BR-1 composite.

4 Conclusion

Bronze fiber reinforced brake pads were developed to meet the desired characteristics of brake pads with different proportions were developed and analysed.

- Brake pads with 10 % bronze fiber had superior properties. The density of the composites tends to decrease as more bronze fiber is included. The main causes of this are the existence of barytes and the density of bronze fibers.

- For BR-1 composites, the maximum values of 0.564were recorded at 177 °C. While the greatest value for BR-2 composites, 0.573, was reached at 149 °C. After that, all composites had a progressive drop in till the temperature reached 233 °C. Beyond 233 °C, suddenly declined and hit its lowest values for BR-1/BR-3 at the conclusion of the first fading run, or 289 °C, of 0.434 and 0.354 respectively.
- Figures show that the composites BR-2 and BR-3's worn surfaces are severely degraded and coated in wear debris and microcracks.

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