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Fabrication and Performance Analysis of Automobile Brake Pad, using Recycled and Eco-Friendly Materials

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ABSTRACT

The pursuit of sustainable automobile solutions has led to development of eco-friendly brake pads using a hybrid composite of coconut shell, rice husk, steel fiber, Al powder, brass powder, SiO_2 and epoxy resin. Three samples of brake pad were tested across seven performance parameters, including frictional coefficient, density, water absorption, porosity, flexural strength, compressive strength and mechanical stability. Sample 01 exhibited a static friction coefficient 0f 0.42 at a slide angle of 23.26°, while sample 2 showed 0.42 at 22.95°, both outperforming (0.39 at 21.30°). Density measurement ranged from 2.02-2.30 g/cm^3, with minimal variation across samples. Water absorption and apparent porosity were within 6.55-7.81% and 14.36-22.24 respectively, indicating controlled fluid uptake. Flexural and compressive strengths for the top performing samples reached 39 MPa and 207.25MPa respectively, demonstrating reliability comparable to conventional brake pads. But the dynamic friction test was unable to be perform because of unavailability of experimental equipment. Overall sample 1 and 2 consistently achieved superior performance, suggesting optimized material composition. These findings quantitatively validate that eco-friendly brake pads can meet industry standards while reducing environmental impact, highlighting their potential for sustainable automobile applications. Further optimization and test are recommended to enhance performance consistency for commercial-scale production.

Keywords: Sustainable, Automobile brake pad, Eco-Friendly materials, Recycled material, Fabrication.

1. Introduction

Friction materials for automobile brake systems play a vital role in ensuring vehicle safety, performance, and environmental compliance[1] . But many traditional brake pads are made of hazardous and harmful constituents like asbestos and heavy metals, which can pose serious health risks and pollute the environment [2], [3]. Similarly other research investigates the formation of vehicle brake pads utilizing regional materials like coconut, cashew shells and palm kernel shells as basic components. The study evaluates the ability of these natural substances to alternate traditional components, highlighting sustainability and effectiveness of brake pads[4]. Further research has examined the development and tribological behavior of bio-composites for brake pads, showing natural fiber and other sustainable materials can improve friction stability, wear, density, hardness were evaluated [5]. Other investigations on incorporating recycled ceramics into automobile brake pad, assessing the physical, mechanical and tribological properties. Recent studies have also examined the recycled ceramics composite in automobile brake pad to enhance the stability[6]. Other research has examined advancements in innovative friction materials for automobile brake pads to address health and environmental concerns by reducing dependency on harmful substances[7], [8]. This research addresses the gap by developing a hybrid composite brake pad using recycled eco-friendly materials-steel fiber, coconut shell and rice husk to enhance strength, durability and sustainability. Investigating the both raw and chemically processed Sansevieria ehrenbergii fibers in brake pads. The research evaluates how fiber treatment affects tribological, mechanical characteristics of brake pads compositions [9]. Furthermore, recent studies inquire the processing and characterization of composites that include sepiolite clay for application in eco-friendly brake pads [10]. Several studies have transitioned from asbestos material to eco-friendly alternatives, demonstrating various manufacturing techniques and their effects on material properties [11]. Recent research has pursued the use of innovative binder in automobile brake pad production, assessing their mechanical, physical and tribological properties in comparison to traditional binders. The study evaluates key parameters such as friction coefficient, thermal endurance, and wear resistance under various conditions, highlighting the critical role of material selection and composition in enhancing brake pad performance [12], [13]. Several studies also inquire into the improvement and tribological performance of sustainable and eco-friendly hybrid nanocomposites intended for brake pad applications [14]. A recent scoping review was carried out on the composition of (NAO) friction materials used in brake pads, emphasizing the use of natural fillers, fibers, binders, and friction materials as eco-friendly alternatives to asbestos [15]. Other studies have researched the development and evaluation of asbestos free epoxy-based brake pads reinforced with carbon fiber. These works highlight the role of carbon fiber enhancing the performance [16].

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2. Materials and Experimental Method

The selection of suitable materials for brake pad performance is a critical step in assuring optimal performance, durability, mechanical strength, and environmental sustainability. In this research, a hybrid composite brake pad was developed utilizing a combination of natural, metallic and synthetic materials. Each & every constituent was selected based on its specific functional role-whether as an abrasive filler reinforcement or binder.

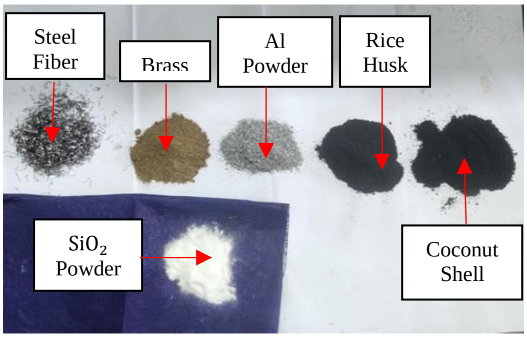

Fig. 1 Materials Used in Fabrication

In order to validate prescriptions was started from a mixture of raw materials, including rice husk, steel fiber Al, silicon powder, brass powder, coconut shell and epoxy resin. Their selection was made in accordance with the properties required for brake pads in vehicle operation[17].

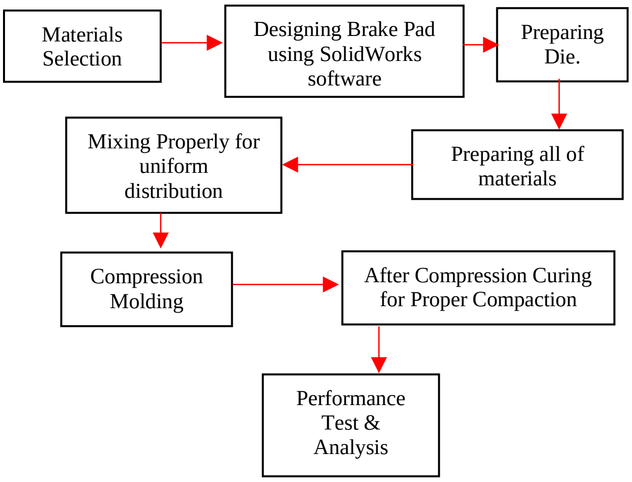

Fig. 2 Methodology of Brake Pad Fabrication

3. Formulation and Fabrication Process

An overview of the typical material composition used in automobile brake pads. The formulation generally includes friction modifiers (10-20%), binders such as resin (10-15%), abrasives (15-25%), fillers (20-30%), and reinforcing fibers (5-10%). Each component is selected to balance braking efficiency, heat resistance, noise reduction, and wear life [18].

The die cavity replicates the brake pad profile from CAD model, with curved edges (R165.29 and R 242.12) and chamfers ensuring accurate disc alignment. Tight dimensional tolerances (139 mm length) maintain pad thickness of 10mm, width 61 mm and fit with the braking system. A polished surface finish reduces demolding friction and improves the pad's quality[19] .

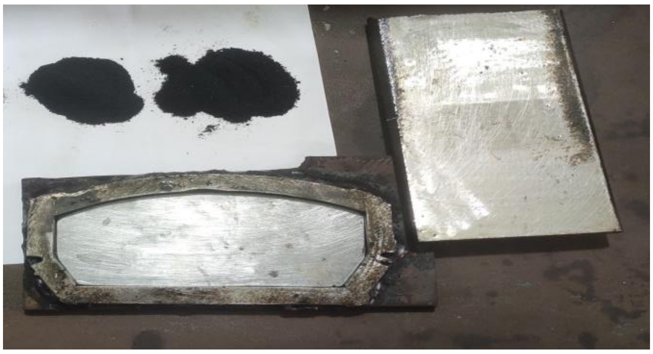

Fig. 3 Die for Fabrication

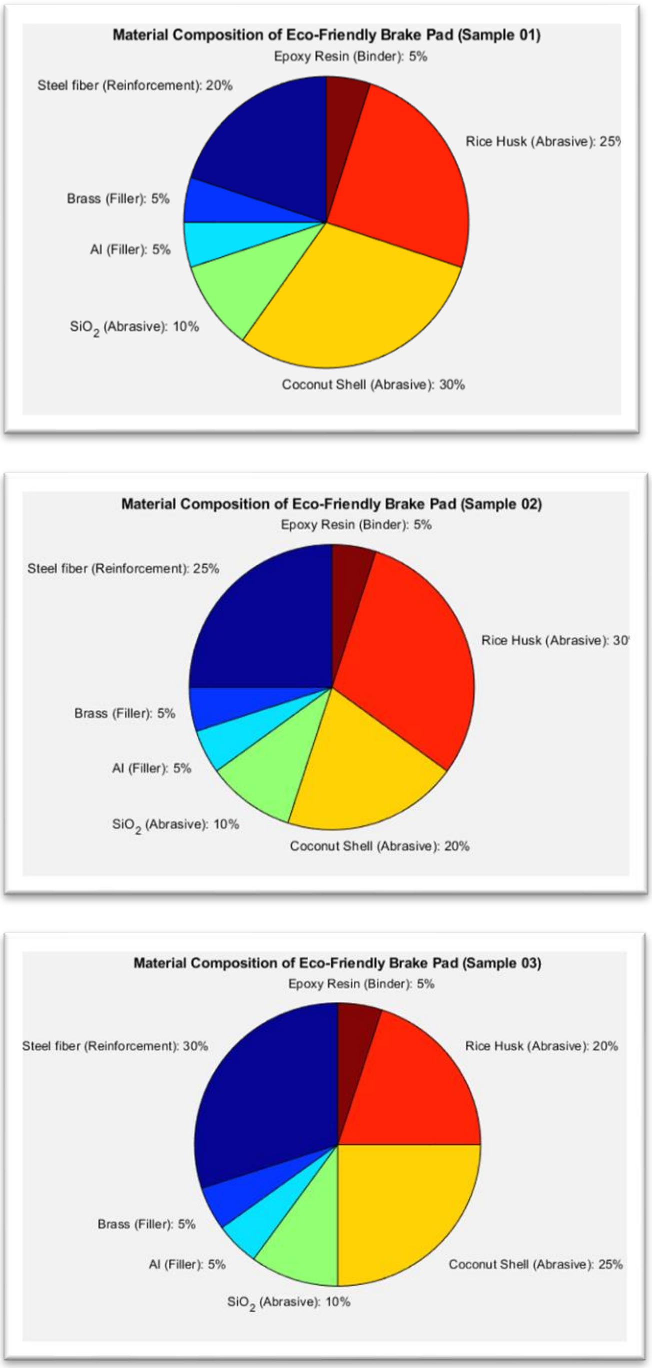

Fig. 4 Weight Percentages of Materials for All Materials Compositions

Table 1 shows weight percentage of materials for fabrication of brake pad samples.

Table 1 Formulation of Brake Pad Samples

No. of Sample	Steel Fiber	Al	Brass	SiO_2	Coconut Shell	Rice Husk	Epoxy Resin
01	20%	5%	5%	10%	30%	25%	5%
02	25%	5%	5%	10%	20%	30%	5%
03	30%	5%	5%	10%	25%	20%	5%

Fig 5. Fabrication Process

After that as a key step in brake pad manufacturing, where heat is applied (typically 150-250°C) for 45 min to harden the resin binder. This process enhances the pad's strength, heat resistance, and durability. Proper curing prevents defects like incomplete bonding or thermal failure during braking[20].

Fig. 6 Fabricated Brake Pad Sample

5. Performance Analysis

A friction material for brake pads from rice husk and its by-products, intending to produce a sustainable alternative for traditional materials. The research examines the mechanical, tribological, and thermal properties of the material, emphasizing the importance of rice husk as a feasible eco-friendly component. Through relentless testing, the study discloses how the composition of materials affects the performance metrics of brake pads[21]. Table 2 shows the performance test of brake pad sample.

6. Results and Discussion

This chapter represents the methodology and outcome of data collection and analysis conducted to assess the performance of the fabricated automobile brake pads. The preliminary objective of this phase is to evaluate how various material compositions specifically steel fiber, coconut shell charcoal, rice husk coal, Al powder, Brass powder, silicon dioxide (SiO_2) and epoxy resins affect the mechanical, physical, and frictional characteristics of the fabricated brake pads.

Table 2 Performance Analysis

Test Name	Tests
Mechanical Strength	Hardness Test Flexural Strength Compression Strength Impact Strength
Tribological Test	Frictional Test
Physical Test	Density Test Porosity Test

6.1 Hardness Test (Rockwell)

This test is performed by following the standard of ASTM D695 or ISO 604.

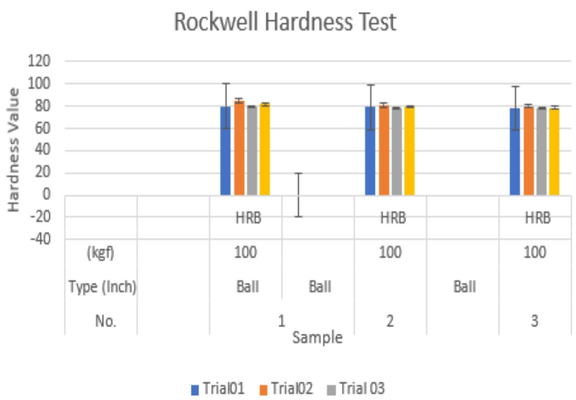

Fig. 7 Average Hardness Test Value

Figure 07 illustrates the hardness of 3 samples compare with commercial brake pads. The Rockwell hardness (HRB), closely matching the commercial brake pad value of 81.67 HRB. Specimen no.3 at 76.67 HRB. In this experiment eco-composite pads, using fillers like bagasse or date palm fiber, often achieve hardness levels of overall 75-89 HRB**[22]**.

6.2 Flexural Strength Test

Following test is performed by following the standard of ASTM D790 or ISO 178.

Figure 08 represents flexural strength vs filler composition. All of brake pad samples achieved flexural strength values of 32.18 MPa, 39 MPa, 32.50 MPa respectively. These results fall within the typical commercial range for organic brake pads, which is approximately 25-45 MPa. Sample 02 showed the highest flexural strength (39MPa), the Commercial brake pads typically exhibit flexural strength values in the range of 10-40 MPa[23].Overall the results suggested that all of 3 samples are in range.

This test is performed by following the standard of ASTM D695 or ISO 604. Figure 09 represents the compression strength vs filler composition. Comparing with overall commercial value of compression strength. Sample 01 exhibited the highest compressive strength at 207.25 MPa. Ige et al., 2022 Commercial asbestos-based brake pads exhibit compressive strengths around 100-110 MPa indicating superior load-bearing capacity[23]. Sample 02 and 03 has recorded lower strengths of 191.30 MPa and 190.30 MPa, also exceeded the commercial target.

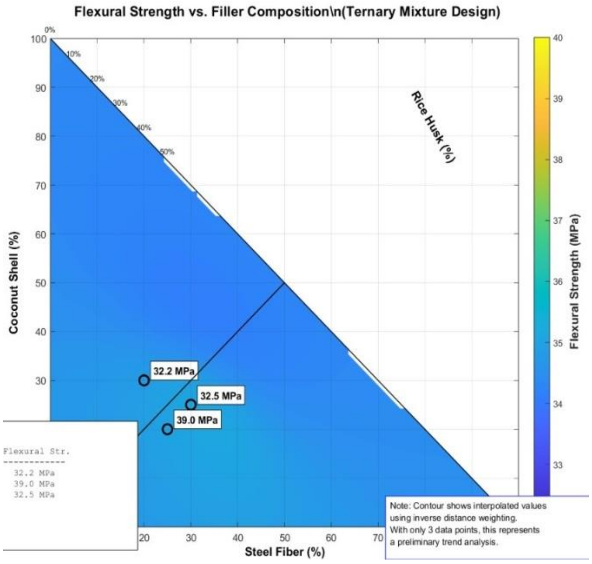

Fig. 8 Flexural Strength vs Filler Composition

6.3 Compression Strength Test

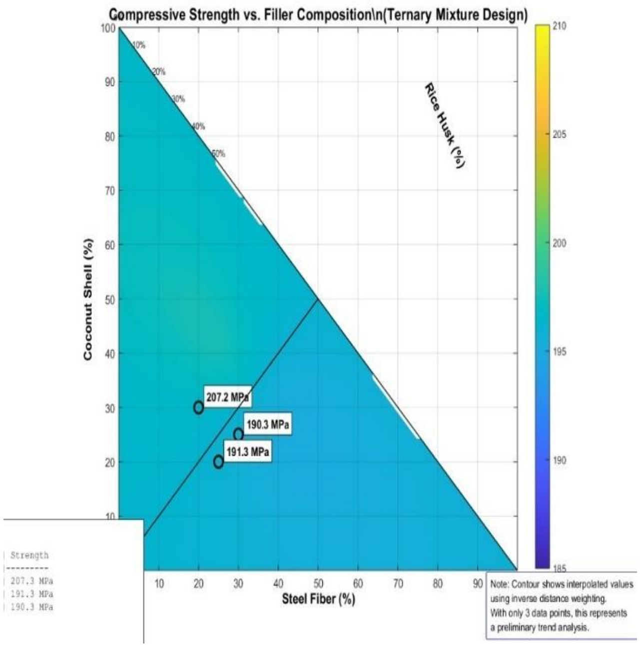

Fig. 9 Compression Strength vs Filler Compositions

6.4 Impact Strength Test

This test is performed by following the standard of ASTM D790 or ISO 178.

Commercial asbestos-based automotive brake pads exhibit Charpy impact strengths between 1818.18 J/m^2 and 2727.27J/m^2, based on studies comparing traditional pads with biomass composite[24]

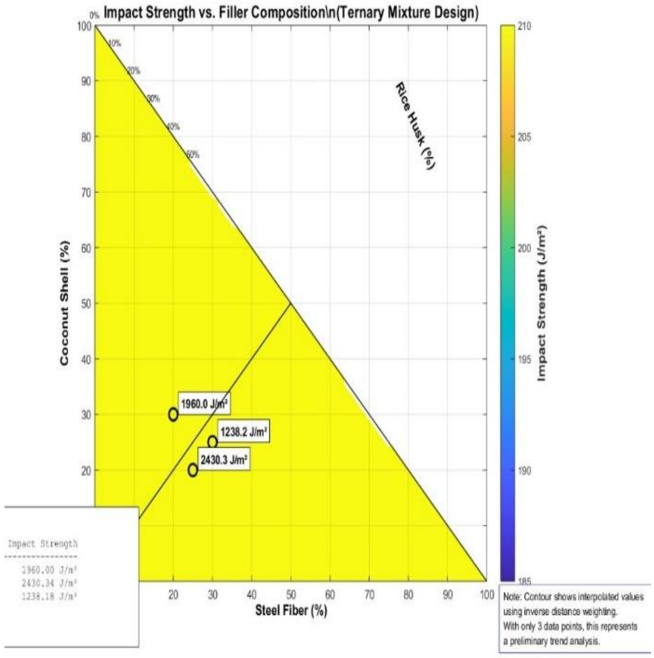

Fig. 10 Impact Strength vs Filler Composition.

Figure 10 represents impact strength vs filler composition. Sample 02 achieved the highest impact strength of 2430.38 J/$\mathrm{m}^2$and sample 01 has 1960 J/m^2 respectively. But sample no. 03 fall below the range. But other two meets the requirement.

6.5 Frictional Test

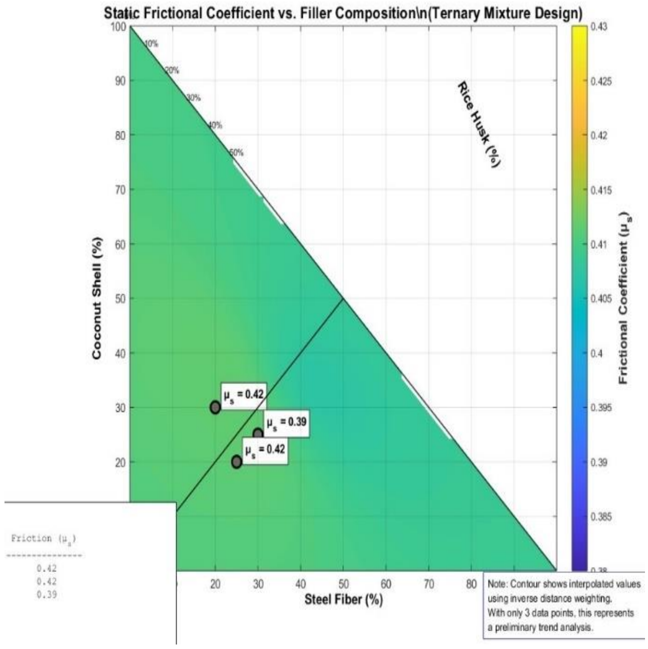

Fig. 11 Static COF (μ_s) vs Filler Composition

The test is performed by following standard of ASTM D1984 or ASTM G115. The figure 10 illustrates the static friction test result. Sample 01 and 02 recorded coefficients of 0.42 and 0.42, respectively, commercial street brake pads typically exhibit static friction coefficients ranging from 0.35-0.42[25]. Indicating sufficient frictional performance for braking applications. Sample 03 showed fall below lower range COF of 0.39, overall sample 01 and 02 meet the commercial static friction standards.

6.6 Density Test

Commercial brake pad friction materials typically have densities ranging from 1.01 to 2.06 g/cm³[26].

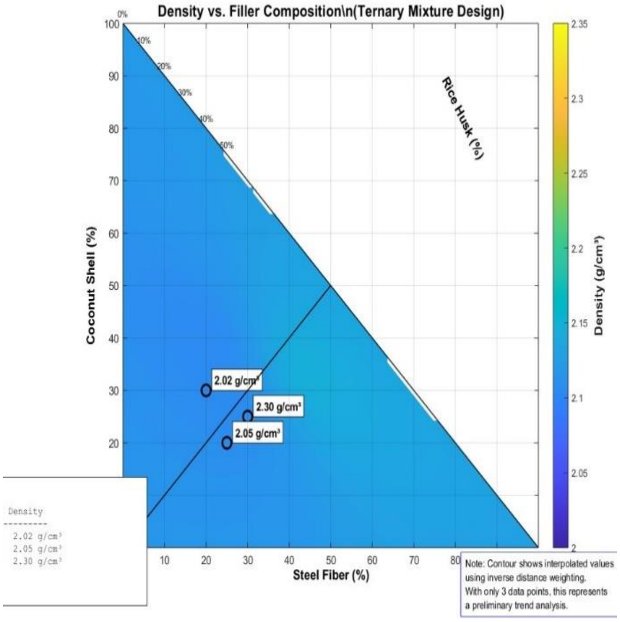

Fig. 12 Density (ρ_s) vs Filler Composition

In figure 12 represents density (ρ_s) vs filler composition. Sample 01 and 02 achieved densities of 2.02g/cm³ and 2.05 g/cm³ respectively. This indicates adequate compaction and material balanced close to comparable to commercial brake pads. In contrast, sample 03 showed a higher density of 2.30 g/cm³, suggesting excessive which may affect the overall performance. Overall, sample 01 and 2 meet commercial density standard.

6.7 Porosity Test

This test in performed under the standard of ASTM C373-14. The figure 13 illustrates apparent porosity vs filler composition. Sample 01 and 02 exhibited apparent porosities of 14.38% and 14.36% respectively.

The Commercial brake pad friction materials are designed with a porosity between 11% and 19%, suggesting balanced permeability and mechanical strength[27]. Sample 03 showed higher porosity of 22.54%, exceeding commercial range and indicating increased pored volume, which may comprise strength and durability. Overall, sample 01 and 02 meet commercial porosity requirements whereas sample 03 requires further compaction and materials integrity.

Table 3 shows the value of mechanical strength test & tribological test.

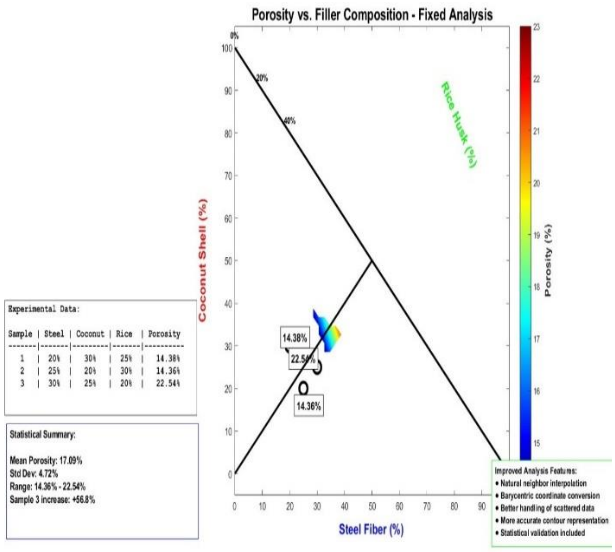

Fig. 13 Porosity (%) vs Filler Composition

Table 3 Mechanical Strength & Tribological Test Value

Sample No.	Hardness Test (Rockwell), (Kg.f)	Flexural Strength Test, (MPa)	Compression Strength Test, (MPa)	Impact Strength Test, (J/m^2)	Static Friction Test
01	78.67	32.18	207.25	1960.00	0.42
02	81.67	39.00	191.30	2430.34	0.42
03	76.67	32.50	190.30	1238.18	0.39

Table 4 Shows that physical porosity test value.

Table 4 Density & Porosity Test Value

Sample No.	Density Test, (g/cm^3)	Porosity Test, (%)
01	2.02	14.38
02	2.05	14.36
03	2.30	22.54

7. Conclusion

Based on the series of mechanical and physical tests, sample 01 and 02 consistently demonstrated performance comparable to commercial brake pads standards. Their densities and porosities fell within acceptable commercial ranges, supporting adequate compaction and balanced permeability. Compression and impact tests confirmed that sample 01 slightly exceeded commercial compressive strength, while sample 02 showed superior impact resistance. Both also achieved static friction coefficients within the typical commercial range, ensuring effective braking performance.

In contrast, sample 03 showed deviations: higher density and porosity, reduced flexural and compressive strengths, and lower static friction, indicating potential brittleness and reduced wear resistance. Overall, sample 01 and 02 are suitable candidates for further development, whereas sample 03 requires reformation and process optimization to align with commercial quality standards.

It will need better mixing techniques for uniform distribution. It is very important for better compaction. If it is ensuring that brake pad's performance enhanced more.

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