Evaluation of Morphological Properties of Asbestos-free Brake Pads From Rice Husk Fiber Composite.

Elakhame Z. Uwagbai (1), Shuaib – Babata Y. Lanre (2), Busari O. Yusuf (2), Lawal S. Sius(3)

1) Department of Prototype Design and Development, Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria.
2) Department of Minerals and Metallurgical Engineering, Faculty of Engineering, University of Ilorin, kwara, Nigeria.
3) Department of Mechanical Engineering, Faculty of Engineering, Federal University of Technology, Minna, Niger, Nigeria

Corresponding Address: elakhamezeberu@fiiro.gov.ng, +2348038831703

ABSTRACT: Brake pads are essential for controlling speed in automotive braking systems by converting kinetic energy into heat. Traditionally, these pads have been made of friction material attached to steel backing plates. However, the use of alternative materials is necessary to meet sustainability goals and reduce health risks associated with asbestos exposure. Natural fibers and agricultural waste offer an innovative and cost-effective solution that is environmentally friendly. This study aim to develop sustainable brake pad materials as alternatives to asbestos-based pads. While materials like rice husk, steel dust, quartz, graphite, and gum arabic show promise, further research is needed to assess their performance, durability, and feasibility for commercial use. The study compares the performance and environmental impact of natural fiber brake pads to traditional materials through literature review, experimental testing, and comparative analysis. Brake pads made from environmentally friendly materials offer a sustainable option with optimal braking performance and economic benefits. However, more research and testing are required to confirm their performance and durability in real-world conditions. Nonetheless, the study's results are promising, as the formulated brake pads have a composition and distribution similar to commercial pads and contain performance-enhancing compounds. These findings provide a foundation for future development and optimization of brake pad formulations that meet industry standards. Manufacturers can use this information to improve their production processes, develop high-quality brake pads, and meet industry standards.

KEYWORDS: Microstructure, rice husk, scanning electron microscope, asbestos, brake pad

1. INTRODUCTION

Brake pads are essential components in automotive braking systems. They convert kinetic energy into heat to control speed. These pads consist of friction material attached to the disc brake rotor surface using steel backing plates. classified brake pad materials into four groups: non-metallic, semi-metallic, fully metallic, and ceramic [1].

The prohibition of asbestos fiber in brake pads has had a significant impact on their composition and performance. As a result, there has been an increase in heat generation and brake fade, leading to longer stopping distances and decreased road safety. Recognizing the urgent need for alternative materials and technologies, researchers have been exploring various options [2].

One promising alternative is the use of natural fibers, such as palm kernel fibers (PKF), in brake pads. Recent studies have shown that PKF can effectively replace asbestos in brake pad composition. This not only addresses environmental concerns but also reduces the health hazards associated with asbestos exposure [3].

Another innovative solution lies in the use of basalt-based brake pads. These pads have demonstrated comparable or even superior performance in terms of friction coefficient, wear resistance, and thermal stability [4]. This suggests that they have the potential to mitigate the negative environmental impacts of brake pad production while ensuring optimal braking performance [5].

In a ground breaking development, researchers have successfully developed a new type of brake pad material derived from palm kernel shells [3]. This material has been found to meet the standards set by the Standards Organization of Nigeria (SON). This breakthrough in brake pad technology offers a sustainable and environmentally friendly alternative to traditional materials, without compromising on braking performance [6].

The prohibition of asbestos fiber in brake pads has led to the search for alternative materials that are sustainable and environmentally friendly. Natural fibers, such as palm kernel fibers and basalt-based brake pads, have emerged as promising options [4]. The development of brake pads derived from palm kernel shells represents a significant advancement in sustainable brake pad technology, ensuring road safety while minimizing negative impacts on the environment and employee health……..

[2] utilized a Nigerian gum Arabic binder and agricultural composites made from cashew nut shells to create a brake pad. The study found that cashew nut shells can be effectively used as ingredients in commercial brake pads, resulting in improved performance and durability. This innovative approach not only provides a sustainable alternative to

traditional brake pad materials but also highlights the potential for utilizing agricultural waste in various industrial applications………

The morphology and wear properties of palm ash and PCB waste brake pads further [7] demonstrate the potential of biomass-based materials. These experiments showcase the adaptability and sustainability of such substitutes, emphasizing the potential of using biomass-based polymers as binders in brake pads. Additionally, the use of natural binders like gum Arabic and agricultural composites presents opportunities for local sourcing and economic gains in areas where these materials are abundant [8]. Exploring unconventional sources like PCB waste and palm ash also highlights the possibility for creative and novel methods in brake pad manufacturing [6].

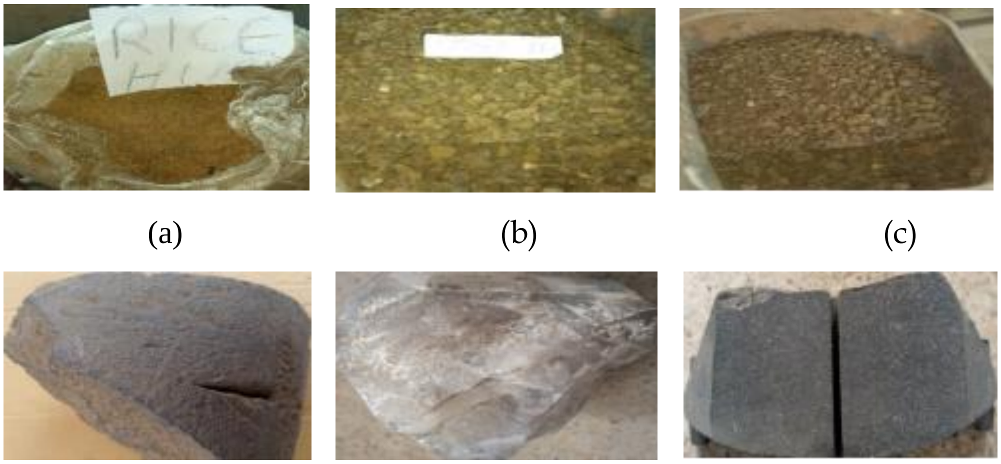
Recent studies have shown that brake pad composites can be successfully replaced by palm slag [8] brake pads outperformed commercial asbestos-based brake pads. Using the powder metallurgy technique, this effort aimed to create eco-friendly friction composite brake pads from locally available raw materials and compare them to commercial brake pads [9] also reported on this topic [10] conducted a performance investigation on the construction of brake pads using two different manufacturing processes for the production of asbestos-free brake pads using cashew nutshell [12]. The objective was to determine the properties of pulverized rice husk, gum Arabic, quartz, steel dust, and graphite and incorporate them as base materials in the manufacture of automobile brake pads

Overall, the research and development of alternative brake pad materials offer promising solutions for sustainable and environmentally friendly braking systems. By embracing these alternatives, we can ensure road safety while minimizing negative impacts on the environment and promoting economic gains through local sourcing of materials.

2. MATERIALS AND METHOD

A. Materials

The raw composite materials utilized in this research comprised of rice husk, quartz, steel slag, graphite, and gum arabic. These materials were sourced from various locations as depicted in Figure 2.1. Rice husk, quartz, and steel slag were obtained from Ofada, Ogun State; Okpila, Esako, Edo State; and Africa Foundry, Ogijo, Shagamu, Ogun State, respectively. Graphite was acquired from Sama-Borkono, Warji, Bauchi State. Gum arabic was obtained from a local vendor registered with the industrial raw materials supplier trade group in Kano State, Nigeria.



(a) (b) (c)

(d) (e) (f)

Figure 2.1 displays photographs of the following raw materials: (a) Rice Husk, (b) Gum Arabic, (c) Steel Slags, (d) Graphite ore, (e) Quartz ore, and (f) Commercial brake pad.

B. Materials Milling

To obtain a fine powder, the Rice Husk (HR) particles were first sun-dried for a week. Subsequently, the dried particles were placed into a ball mill (Model 87002 Limoges, France, A50 - 43) and operated at a speed of 250 rpm, as depicted in Figure 2b. The milling process lasted for 48 hours and utilized 25 kg of pebbles with varying sizes (Dia 46.5mm, 39mm, and 30mm for Big, Medium, and Small pebbles, respectively).

Following the milling process, the resulting powder was sieved through a 75 m sieve using a Vibro sieve machine (Endecotts Limited, London, Vibro sieve machine Bs 410 standard sieves). Additionally, steel slags, quartz, and graphite were also milled into a fine powder using a hammer mill (Model 000T, Puissance: 1.5KV, No 13634), as shown in Figure 2b. The milled materials were then sifted to achieve a particle size of 100 m. These milling and sieving procedures were conducted following the methodology described by [13]

Figure 2.2 presents the samples of the milled and sieved materials obtained from the aforementioned processes.

(a) (b) (c)

(d) (e) (f) (g)

Figure 2.2 shows the machines and raw materials used in the process: (a) Hammer Mill, (b) Ball Milling Machine, (c) Rice Husk, (d) Processed Gum Arabic, (e) Steel Slags, (f) Graphite, (g) Quartz.

C. Formulations of the Brake Pads

The new brake pads were created by adjusting the weight percentages of the friction materials in commercial brake pads. Rice husk fiber, steel dusts, quartz, graphite, and gum arabic were added in different weight percentages. The samples are labeled X, Y, and Z in Table 1 to indicate their different compositions. The commercial brake pad is referred to as CBP, while X, Y, and Z represent the new brake pad formulations.

Table 2.1 displays the weight percentage of minerals in the newly formulated brake pads.

Brake additives	**Samples in percentage weight (%wt)**		
	X	Y	Z
Rice Husk	52.5	54	60
Gum Arabic	20.0	20	17
Steel Dust	10.0	10	10
Quartz	12.50	15	12
Graphite	5.00	1	1

D. Evaluation Properties of the raw Materials.

I. Mineralogy Analysis

XRD studies were performed using a Rigaku MiniFlex 600 diffractometer from Japan, following ASTM document number 1-20(2021) guidelines. The conditions included divergent beam slits, reception slits, scans ranging from 2 to 70°C, and continuous scanning.

II. Morphology and Elemental Composition

The samples were analyzed using a Phenom Prox scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDS) following ASTM C1255 - 18(2018) and ASTM E2809 - 13(2019) standards. The samples were dried at 60 °C in an oven.

III. Fourier Transform Infrared Spectrophotometer (FTIR).

The functional unit was determined using a Fourier transform infrared spectrophotometer. Samples were homogenized with anhydrous KBr, vacuum hydraulically pressed, and analyzed according to ASTM D6348-12(2020) standards.

3. RESULTS AND DISCUSSION

A. Chemical Composition Analysis

Table 3.1 displays the elemental compositions of the commercial brake pad (CBP) and laboratory samples, specifically in columns X, Y, and Z. The results indicate that the materials primarily consist of non-metals, metals, and semi-metals. To compare the compositions of the CBP-formulated samples (X, Y, and Z) with asbestos-based brake pads, the SON Catalogue 2005, Internal Classification Standard (ICS 43.04.10), and Nigeria Industrial Standard (NIS 247:1999) can be utilized. Consequently, the laboratory-tested brake pad specimens are expected to perform better [14].

Table 3.1: Elemental compositions of commercial brake pad (CBP) and laboratory samples (X, Y, and Z).

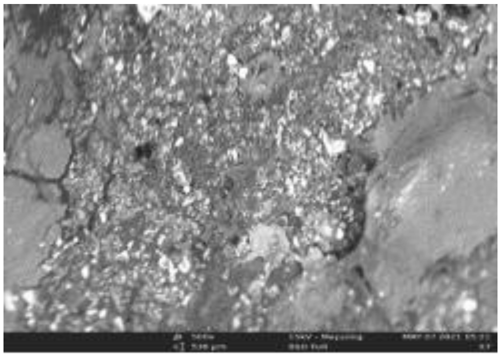
		CBP	X	Y	Z
S/N	Elements		Content (%)		
1	Mg	3.4962	4.9167	2.8661	2.4485
2	Al	17.1866	17.2439	22.6072	18.0212
3	Si	59.0689	66.2356	60.3708	66.3464
4	P	0.2200	0.3192	0.6147	0.6810
5	S	1.0152	0.4151	2.2521	1.0383
6	K	0.4174	0.6088	0.4765	0.3319
7	Ca	12.8922	1.6480	3.1506	2.7853
8	Ti	0.1011			0.1214
9	Mn	0.1017	0.1591	0.1297	8.0052
10	Fe	4.5340	8.1637	10.0721	0.0295
11	Ni	0.1270	0.0253	0.0611	0.0396
12	Cu	0.0269	0.0491	0.0467	0.0094
13	Zn	0.1665	0.0337	0.0318	0.0198
14	Nb	0.0093	0.0218	0.0206	0.0768
15	Mo	0.0345	0.0774	0.0754	0.0164

16	Ag	0.0088	0.0148	0.0162	1.0133
17	Sb	0.0045			0.0292
18	C	3.1001	2.0101	5.0023	0.0000
19	Pb	0.5893	0.0325	0.0305	
20	Cd		0.0352	0.0441	

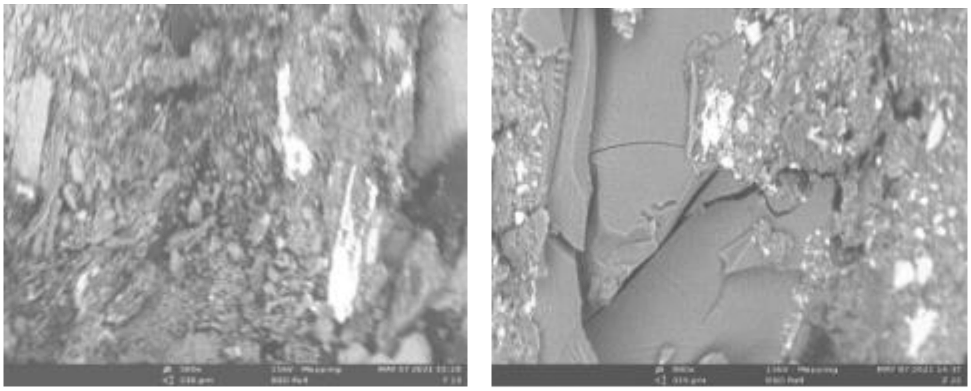
B. Morphological Analysis

Table 2.1 shows the uniform distribution of Aluminum, Carbon, Silica, and Calcium powders in resin. Magnesium, Sulfur, Iron, and other elements are randomly clustered in both the produced and commercial samples. Specimen X has a more evenly homogenized distribution, making it superior to other samples. Specimen Z, on the other hand, has an irregular and rocky surface topography, distinguishing it from the other samples. Observational studies reveal that the CBP sample has a spherical shape with numerous dents on its surface. In contrast, sample Z has regular edges, a spherical grain, and a rounded nature, indicating a mature sediment accumulation. Higher magnification also reveals a spongy surface and microcracks in sample [15].

CBP



X

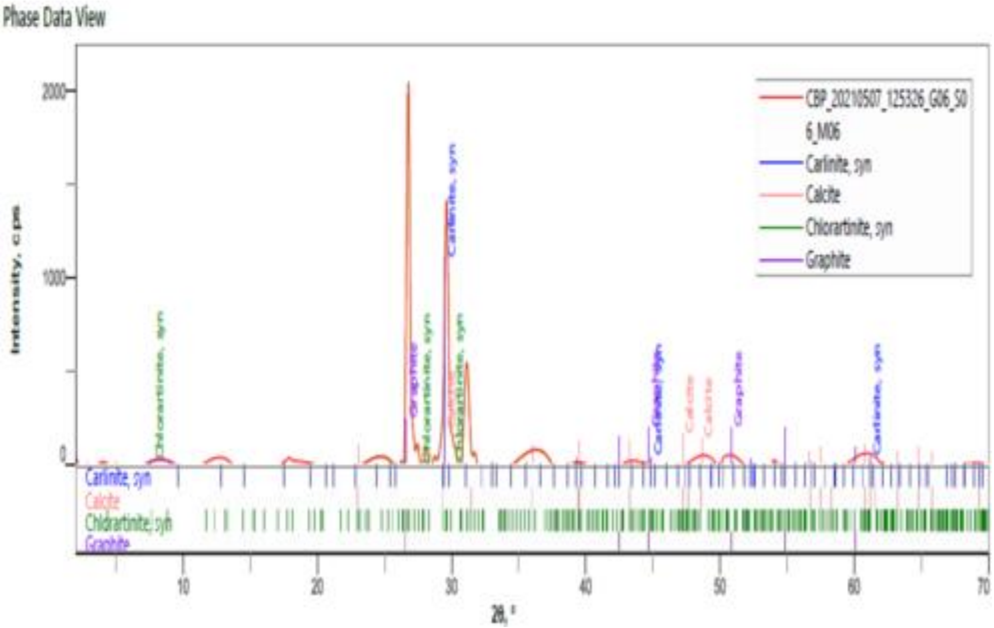


Y **Z**

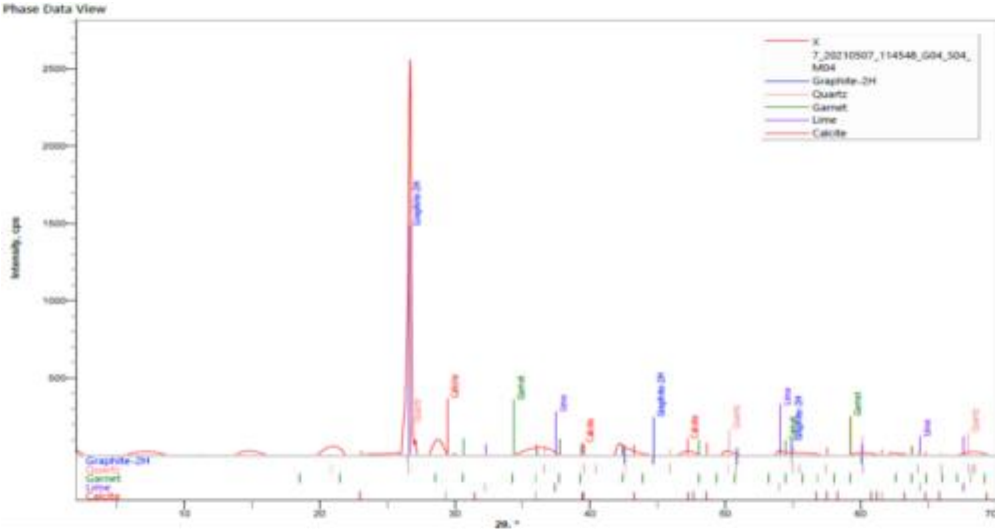
Figure 2.3 displays SEM micrographs of samples CBP, X, Y, and Z.

C. Mineralogy Analysis

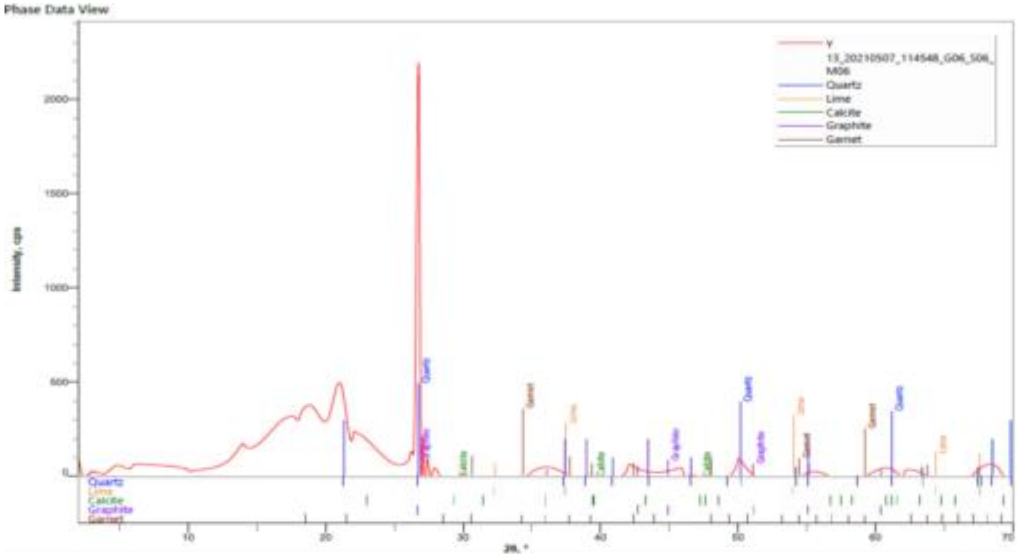
X-ray diffraction techniques were used to analyze the phase purity and crystallinity of a commercial brake pad. The sample, referred to as CBP, contains four phase compounds: Carlinite (Ti2S), Calcite (CaCO3), Chlorartinite Mg2 (CO3) Cl(OH).3H2, and Graphite (C). These compounds displayed sharp peaks at 2θ between 20 and 30o with an intensity of over 1000 cps. The laboratory samples X, Y, and Z consist of five phase compounds: Graphite (C), Quartz (SiO2), Garmet [3(Ca, Fe, Mg) O • (Al, Fe)], Lime (CaO), and Calcite (CaCO3). These compounds exhibited sharp peaks at a 2θ angle of 27O with an intensity of 1000%, indicating that the specimens are predominantly crystallites [16]


Phase Data View
Intensity, cps
2000
1000
0
CBP_20210507_125326_G06_S0
6_M06
Carlinite, syn
Calcite
Chlorartinite, syn
Graphite
Chlorartinite, syn
Graphite
Carlinite, syn
Calcite
10
20
30
40
50
60
70
2θ, °

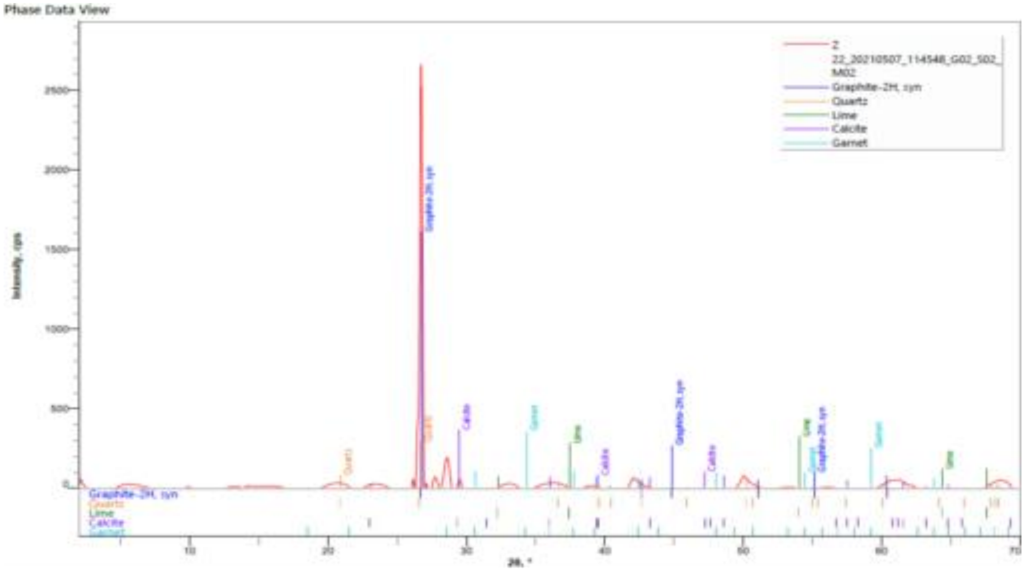
(CBP)


Phase Data View
Intensity, cps
2500
2000
1500
1000
500
X
7_20210507_114548_G04_S04_
M04
Graphite-2H
Quartz
Garnet
Lime
Calcite
10
20
30
40
50
60
70
2θ, °

X



Y

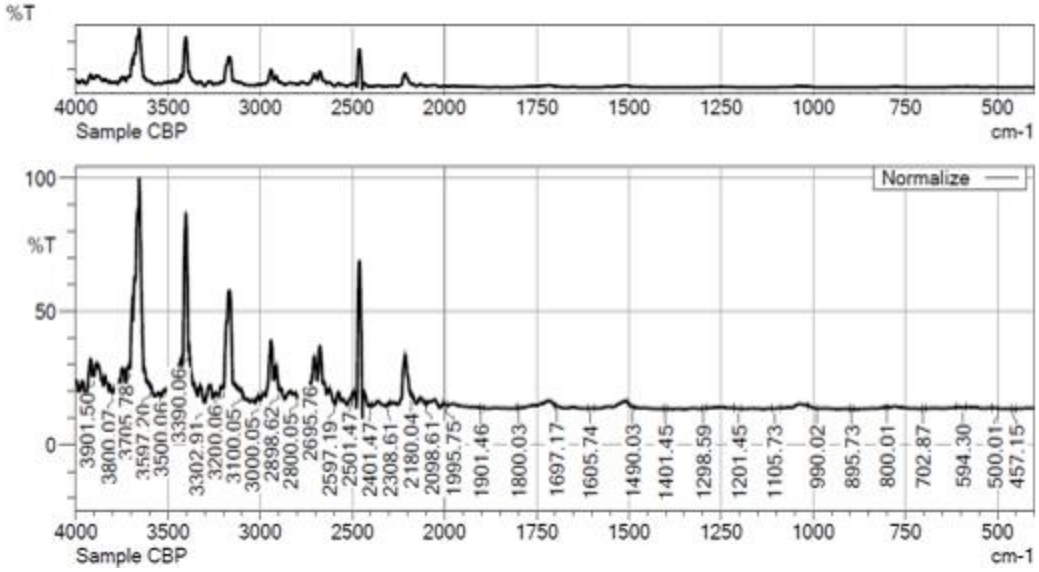


Z

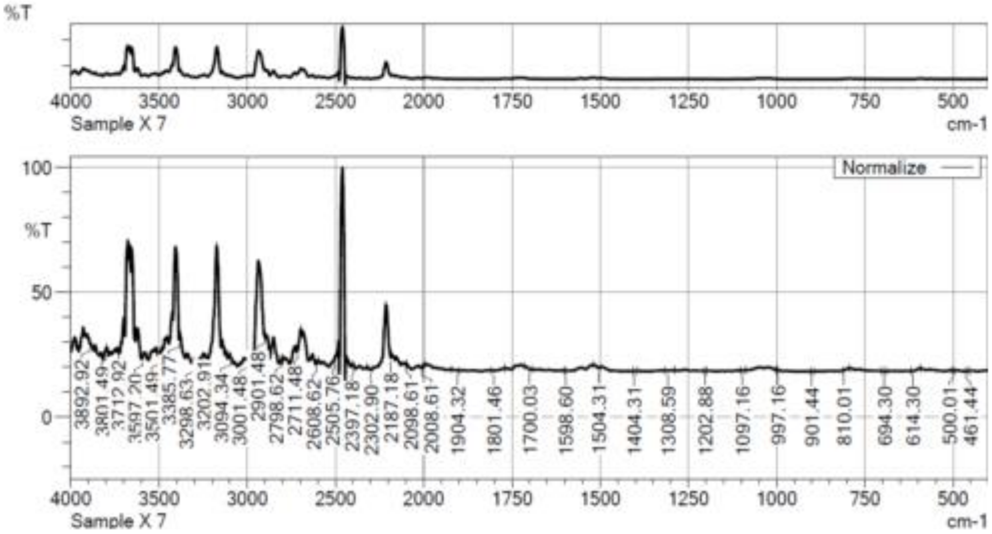
Figure 2.4 displays the spectrum of samples CBP, X, Y, and Z.

D. Functional Group Analysis

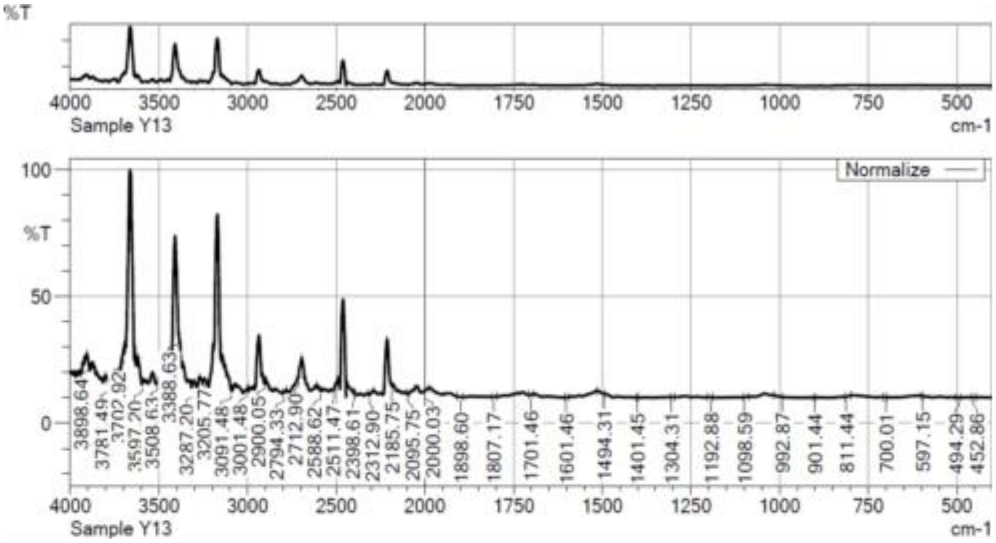
The CBP specimen shows bands indicating the presence of cyanide ion, thiocyanate ion, and related ions, as well as thiols (S-H stretch), methylamino, N-CH3, C-H stretch, methyne C-H stretch, aromatic C-H stretch, dimeric Oh stretch, and tertiary alcohol, OH stretch. Specimen X has peaks indicating the presence of methylamino, N-CH3, C-H stretch, pendant (vinylidene) C-H stretch, normal "polymeric" OH stretch, dimeric OH stretch, and tertiary alcohol, OH stretch. Specimen Y shows peaks indicating the presence of cyanide ion, thiocyanate ion, and related ions, as well as thiols (S-H) stretch, methylamino, N-CH3, C-H stretch, normal "polymeric" OH stretch, dimeric OH stretch, tertiary alcohol, OH stretch, and pendant (vinylidene) C-H stretch. Finally, Figure 2.5 Z displays peaks indicating the presence of cyanide ion, thiocyanate ion, and related ions, as well as C≡C medial alkyne (distributed), methylamino, N-CH3, C-H stretch, medial, cis-or trans-C-H stretch, aromatic C-H stretch, and normal "polymeric" OH stretch, dimeric OH stretch, and tertiary alcohol, OH stretch [17] [18].



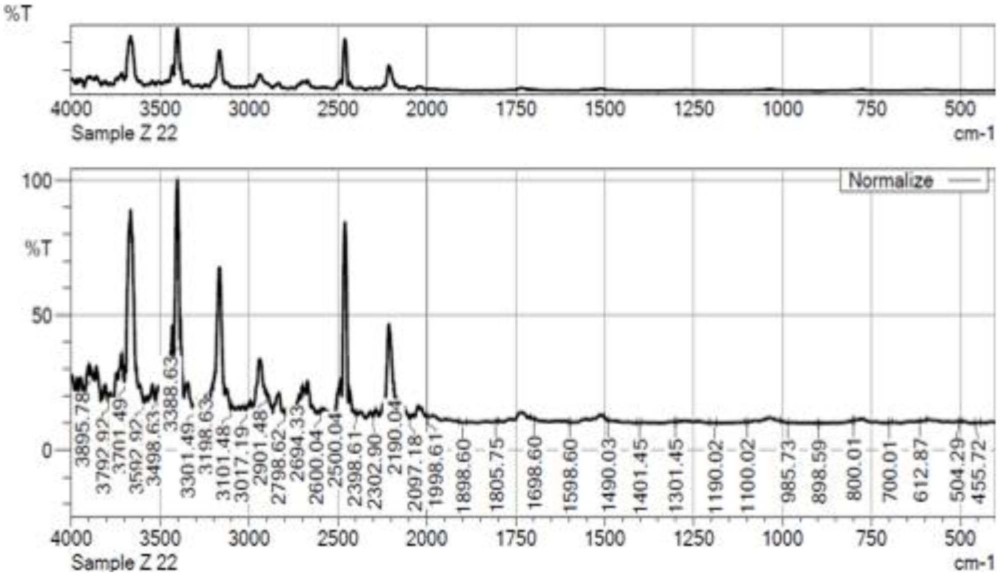
(CBB)


%T
4000
3500
3000
2500
2000
1750
1500
1250
1000
750
500
Sample X 7
cm-1
100
%T
50
0
Normalize
3892.92
3801.49
3712.92
3597.20
3501.49
3385.77
3298.63
3202.91
3094.34
3001.48
2901.48
2798.62
2711.48
2608.62
2505.76
2397.18
2302.90
2187.18
2098.61
2008.61
1904.32
1801.46
1700.03
1598.60
1504.31
1404.31
1308.59
1202.88
1097.16
997.16
901.44
810.01
694.30
614.30
500.01
461.44

X


%T
4000
3500
3000
2500
2000
1750
1500
1250
1000
750
500
Sample Y13
cm-1
100
%T
50
0
Normalize
3898.64
3781.49
3702.92
3597.20
3508.63
3388.63
3287.20
3205.77
3091.48
3001.48
2900.05
2794.33
2712.90
2588.62
2511.47
2398.61
2312.90
2185.75
2095.75
2000.03
1898.60
1807.17
1701.46
1601.46
1494.31
1401.45
1304.31
1192.88
1098.59
992.87
901.44
811.44
700.01
597.15
494.29
452.86

Y



Z

Figure 2.5 shows the FTIR spectrum of the samples CBP, X, Y, and Z.

4. CONCLUSION

In conclusion, the study found that the chemical composition of the formulated brake pads closely resembled that of the commercial brake pads. This similarity suggests that the lab-tested brake pads will perform well. Additionally, the SEM analysis revealed a uniform distribution of powders in the formulated brake pads, which aligns with the findings from the commercial brake pad analysis. Among the samples, specimen X exhibited the most evenly homogenized distribution, indicating its superiority. The laboratory samples also contained five phase compounds that are known to contribute to better performance. Furthermore, the FTIR analysis of the commercial brake pad identified several common functional groups that are associated with effective brake pad performance. Overall, these findings support the notion that the formulated brake pads have the potential to meet the standards set by the commercial brake pads.

Acknowledgement

REFERENCE

[1] AKINCIOĞLU, G., AKINCIOĞLU, S., Öktem, H., & Uygur, İ. (2021). Brake pad performance characteristic assessment methods. International Journal of Automotive Science and Technology, 5(1), 67-78.

[2] Ammar, Z., Ibrahim, H., Adly, M., Sarris, I., & Mehanny, S. (2023). Influence of natural fiber content on the frictional material of brake pads—a review. Journal of Composites Science, 7(2), 72.

[3] Balaji, M. S., Jitendra, K., Arumugam, E., & Sethupathi, B. P. (2023). State of the art on challenges for friction material manufacturers–raw materials, regulations, environmental, and NVH aspects. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 237(4), 926-942.

[4] Borawski, A. (2020). Conventional and unconventional materials used in the production of brake pads–review. Science and Engineering of Composite Materials, 27(1), 374-396.

[5] Borawski, A., Mieczkowski, G., & Szpica, D. (2023). Composites in Vehicles Brake Systems-Selected Issues and Areas of Development. In (Vol. 16, pp. 2264): MDPI.

[6] Cantoni, C., Cesarini, R., Mastinu, G., Rocca, G., & Sicigliano, R. (2009). Brake comfort–a review. Vehicle System Dynamics, 47(8), 901-947.

[7] Carlevaris, D., Leonardi, M., Straffelini, G., & Gialanella, S. (2023). Design of a friction material for brake pads based on rice husk and its derivatives. Wear, 526, 204893.

[8] Feo, M. L., Torre, M., Tratzi, P., Battistelli, F., Tomassetti, L., Petracchini, F., . . . Paolini, V. (2023). Laboratory and on-road testing for brake wear particle emissions: a review. Environmental Science and Pollution Research, 1-19.

[9] Irawan, A. P., Fitriyana, D. F., Tezara, C., Siregar, J. P., Laksmidewi, D., Baskara, G. D., . . . Hamdan, M. H. M. (2022). Overview of the important factors influencing the performance of eco-friendly brake pads. Polymers, 14(6), 1180.

[10] Khafidh, M., Putera, F. P., Yotenka, R., Fitriyana, D. F., Widodo, R. D., Ismail, R., . . . Ismail, N. H. (2023). A Study on Characteristics of Brake Pad Composite Materials by

Varying the Composition of Epoxy, Rice Husk, Al2O3, and Fe2O3. Automotive Experiences, 6(2), 303-319.

[11] Kukutschová, J., & Filip, P. (2018). Review of brake wear emissions: a review of brake emission measurement studies: identification of gaps and future needs. Non-exhaust emissions, 123-146.

[12] Kumar, V. V., & Kumaran, S. S. (2019). Friction material composite: types of brake friction material formulations and effects of various ingredients on brake performance–a review. Materials Research Express, 6(8), 082005.

[13] Manoj, E., Marshall, R. A., Muthupandi, K., Natarajan, R. B., Jacob, A., Jino, L., . . . Suthan, S. A. (2023). Investigation on the mechanical and tribological properties of silicon in an automotive brake pad. Materials Today: Proceedings.

[14] Nandiyanto, A. B. D., Al Husaeni, D. F., Ragadhita, R., & Kurniawan, T. (2021). Resin-based brake pad from rice husk particles: From literature review of brake pad from agricultural waste to the techno-economic analysis. Automotive Experiences, 4(3), 131-149.

[15] Papinniemi, A., Lai, J. C., Zhao, J., & Loader, L. (2002). Brake squeal: a literature review. Applied acoustics, 63(4), 391-400.

[16] Ragadhita, R., Al Husaeni, D. F., & Nandiyanto, A. B. D. (2023). Techno-economic evaluation of the production of resin-based brake pads using agricultural wastes: Comparison of eggshells/banana peels brake pads and commercial asbestos brake pads. ASEAN Journal of Science and Engineering, 3(3), 243-250.

[17] Saha, D., Sharma, D., & Satapathy, B. K. (2023). Challenges pertaining to particulate matter emission of toxic formulations and prospects on using green ingredients for sustainable eco-friendly automotive brake composites. Sustainable Materials and Technologies, e00680.

[18] Selvamurugan, T., & Balasubramanian, P. (2023). Development of almond shell powder and palm kernel fibre–reinforced cardanol oil toughened epoxy resin hybrid

composites: mechanical, wear, and antimicrobial properties. Biomass Conversion and Biorefinery, 1-11.