Plantain Peels as a Friction Material in Brake Pad Production

Iloabachie I.C.C. [1], Chiegwu M. A[2], Chime A.C. [3], Ikpeama L.C[4]
[1]Department of Mechanical Engineering,
University of Agriculture and Environmental Sciences, Umuagwo.
[2]Department of Mechanical Engineering,
Institute of Management & Technology, Enugu
[3]Department of Agricultural &Bio-Environmental Engineering,
Institute of Management & Technology, Enugu
[4]Department of Science Laboratory Technology,
Institute of Management & Technology, Enugu
DOI: 10.56201/ijemt.vol.11.no2. 2025.pg250.264

Abstract

This work studied the suitability of plantain peels as a friction material in the development of a brake pad. Ripe plantain peels used in this work was domestically sourced, washed, oven dried at a temperature of about 60°C. The dried plantain peels was pulverized using a locally made pulverizing machine then, sieved using a set of sieves arranged in descending order of fineness to obtain uniform particle size and carbonized in heat treatment furnace. The brake pad composite was produced by varying the composition of powdered plantain peels in the order 5wt. %, 10 wt. %, 15wt. %, 20 wt. % and 25 wt. % in Gum-Arabic resin. The formulated brake pad composite was poured into a wooden mould 50 mm × 50 mm × 8 mm, placed in a hot platen press at temperature of about 180°C, at a molding pressure of about 15MPa and a curing time of 5 minutes. Post-heat treatment of the composites was performed in a hot air oven for a period of 4 hours at 180 °C. The produced brake pads were evaluated for hardness, compressive strength, wear rate, co-efficient of friction and flame resistance. The SEM/EDS of the produced brake pad was also examined. The results indicated about 3.41 wear rate at 15wt. % and increasing hardness and compressive strength with increase in weight percent of the plantain peels. 0.3 to 0.4 coefficient of friction and improved flame resistance due to carbonization of the plantain peels were also observed. The SEM/EDS micrograph revealed the brake pad as mixture. These results showed that carbonized powdered plantain peels can be used a friction material to develop brake pad.

Keywords: *plantain peels, hardness, wear rate, flame resistance, co-efficient of friction, carbonization*

Introduction

Automobile braking system is made up of many parts like brake pads on each wheel, a master cylinder, wheel cylinders, and a hydraulic control system. Brake pads constitute indispensable parts of braking system in every automobile equipped with disc brake. Aigbodion et al., (2010) stated that brake pads are steel backing plates with friction material bound to the surface facing the brake disc. Different types of brake materials are used in different braking systems. They are often categorized into four classes of ingredients: binders, fillers, friction modifiers, and reinforcements Maleque et al., (2012). The brake pads generally consist of asbestos fibers embedded in polymeric matrix along with several other ingredients. The significance of brake pad Bashar et al., (2012) expressed is to transform the kinetic energy of a vehicle to heat energy via friction and at the same time ejecting the heat to the surrounding environment.

Drum brakes and disc brakes are two major types of automobile brakes. In drum brakes, the brake shoes are located inside a drum. While drum brakes tend to be enclosed, disc brakes on the other hand tend to be exposed to the environment Bono and Dekyrger, (1990). The use of drum brakes on all four wheels was common on most cars before the late 1960's. The pads for these drum brakes made use of organic brake pads composed of resins and asbestos in addition to other materials which helped improve braking and wear. The trend however, changed between late 1960's and early 1970's, when disc brakes were introduced by automobile manufacturers owing to its better braking performance.

Research in Medicine revealed that the use of asbestos induces adverse respiratory conditions. Hence, the use of asbestos fiber as Rinek and Cowen, (1995) noted has been on the decrease because of its carcinogenic nature.

Adebisi et al., (2011) and Wannik et al., (2012) separately argued that developing brake materials to meet the desired properties of brake pad like stable friction coefficient and a lower wear rate at various operating speeds, pressures, temperatures, and environmental conditions in the automotive sectors involves many factors. This, therefore, calls for appropriate combination of materials at reasonable costs and Maleque and Dyuti (2010) observed that material selection is rather a complex process.

Leman et al., (2008) observed that the utilization of industrial or agricultural wastes as a source of raw materials for composite development is on the increase. Iloabachie (2018) opined that the availability of natural fillers and ease of fabrication have continued to tempt researchers to try locally available inexpensive agro waste materials to study the feasibility of reinforcement purposes and to what extent they satisfy the required specifications of good reinforced polymer composites for different engineering applications.

Composite brake pad constituents' materials Bashar et al., (2012) are composed of varied composition of abrasives, friction modifiers, binders, fillers and reinforcements. Brake pad material Abutu et al., (2018) is a heterogeneous substance composed of different elements with each constituent element having its own functions like improvement of frictional properties at low and high temperature, reduce noise, prolong life, increase strength and rigidity as well as reduce porosity. The life span of commercial brake pads Abutu et al., (2018) noted varies from one system to another depending on the materials constituent besides braking procedure and maintenance requirements.

Morshed and Haseeb (2004) investigated and compared the physical and chemical characteristics of four commercial automotive brake shoe lining materials used in heavy vehicles and observed that the swell resistance of the locally produced friction material compares favorably with that of the imported materials though, with lowest density and highest water absorption.

Idris et al., (2013) 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.

Dagwa and Ibhadode (2008) and Deepika et al. (2013), also developed a non–asbestos– containing friction pad material using an agro –waste material base, palm kernel shell (PKS) as a reinforcement material and reported that palm kernel shell exhibited more favourable properties than other agro–waste investigated.

Fono–Tamo and Koya, (2013), developed brake pad materials for automobile using palm kernel shell and studied the mechanical properties of the developed brake pad. The results showed that the developed pad has an average hardness of 32.34 and average shear strength of 40.95 MPa. The coefficient of friction of the developed brake pad also showed a frictional coefficient of 0.43.

Acharya and Samantrai (2012) studied the wear and friction behaviour of rice husk using randomly oriented unmodified and modified rice husk as reinforcement in epoxy matrix (Araldite LY556 and hardener HY 951). The results showed that the wear rates decreased with increase in the rice husk fibres addition under all testing conditions and therefore, concluded that the addition of the rice husk fibres in epoxy is very effective in the improvement of the composite wear resistance and the optimum fibre fraction which gave the optimum wear resistance to the composite is found to be 10 w%.

Iloabachie et al. (2023) developed automobile brake pad using powdered *Pentaclethra macrophylla pod* in bio-epoxy resin and concluded that powdered *Pentaclethra macrophylla pod* can effectively replace asbestos in developing asbestos-free brake pad.

Plantain is a term that loosely refers to any banana cultivar usually cooked before eaten. Although, no known botanical distinction exist between bananas and plantains, Redhead (1989) however, stated that a clear distinction may exist between plantains and bananas in countries where only a few cultivars of banana are consumed with no distinction in the common names used in countries where many cultivars are consumed. When ripe, plantains may be eaten raw, since their starches are converted to sugars in the ripening process. As was noted by Cronauer and Krikorian, (2012), Valmayor et al., (2000) and Vu (2005), the term "plantain" in botanical usage applied only to true plantains, while other starchy cultivars used for cooking are called "cooking bananas".

Plantain is a member of the family Musaceae and the genus Musa. It is a tree-like perennial herbaceous plant having an underground rhizome. Musa Paradisciaea (French plantain). Musa Acuminate (Gross, Michel and Cavendish) and Musa Corniculata (Horn plantain) are the major species of this plant. It is known as Ogede agbagba' in Yoruba, 'Ayaba' in Hausa and 'Ogadejioke' in Igbo Okareh et al., (2015). Plantain is a staple food grown throughout the tropics, constitute a major source of carbohydrates for millions of people in Africa, the Caribbean, Latin America, Asia and the Pacific. Though, is a tropical plant that is native to India Ayanwale et al. (2016), however, Nigeria is one of the largest plantain producing countries in the world FAO, (2006). The outer covering pod of the fruit is greenish in color when unripe; also, the fruit is slightly curved in length and when ripe, the outer covering pod has yellowish color with dark patches. When plantain is peeled, the inner fruit is slightly yellowish Ayanwale et al. (2016).

The plant Oladiji et al., (2010) opined is made up of long, overlapping leafstalks and bears a stem which is 1.22 to 6.10 m high. It has a life span of about 15 years Philips, (1982). The fruits grow in clusters, with each separate plantain of the cluster being about 1 inch in diameter and somewhat longer than a banana fruit Okareh et al., (2015). And as was noted by Swennen, (1990a) the fruit requires about two and a half to four months after shooting to be ready for harvesting or a total of about eight to twelve months after planting.

Okareh et al., (2015) stated that different parts of the plant such as the leaves, root, fruit stalk, bract and fruit have been used for medicinal and domestic purposes. Peel is the main by-product of the plantain processing industry and represents about 30 % of the fruit. This by-product constitutes an environmental problem because it contains large quantities of nitrogen and phosphorus and its high water content makes it susceptible to modification by microorganisms.

This research work, therefore, seeks to evaluate this agro waste i.e. plantain peels and establish its suitability in the development a composite material for the production of brake pad.

Methodology

Materials

The following materials were used in this research work; Gum Arabic as binder, plantain peels (reinforcement/filler), silica (abrasive), graphite (friction modifier).

Methods

Drying and Carbonization of Plantain peels

The plantain peels were sundried for eight hours to reduce the moisture content before ovum drying at 60^oC for three hours to constant weight Iloabachie et al (2018). The dried plantain peels were ground to different particle sizes using a grinding machine to form plantain peels powder. Sieving was carried using a set of sieves arranged in descending order of fineness in accordance with BS1377:1990 standard as was reported by Rajan et al., (2007). The plantain peels powder were packed in a graphite crucible and fired in electric resistance furnace at temperature of about1000^oC to form plantain peels ash.

Chemical Analysis of Plantain Peels

The chemical composition analysis of the plantain peels was carried out using X-ray Fluorescence (XRF) analysis technique while the mineralogical composition analysis was done using computerized X-ray diffractometer that uses Cu Kα radiation at a scan speed of 40/min 2Ѳ in a standard laboratory within the country.

Sample Preparation

While the weights of the plantain peels powder and gum Arabic resin were varied those of the silica (abrasive), graphite (friction modifier) was kept constant. Measured quantity of gum Arabic resin was poured into a glass container. Powders of the plantain peel reinforcement, friction modifier and abrasives were thoroughly mixed in another glass container before pouring into the resin and stirred vigorously to obtain a homogenous mixture. The formulated homogenous mixture was transferred to a mould kept in a hot platen press at temperature of about 150^oC at 9.81107N/m^2 pressure for three minutes. It took about 30-40minutes to cure. The formulated brake pad was cured in an oven at a temperature of about 130^oC for 8 hours Dagwa and Ibhadode, (2005). The filler percentage of the plantain peels in the formulation was varied from 5% to 25% to produce five different compositions Iloabachie et al (2019). The produced composite samples were allowed to cool to room temperature under sustained pressure before removal from the hydraulic press for various mechanical tests.

Compressive Strength Test

The compressive test was performed using Universal Testing Machine model TUE-C-100. The developed brake pad was subjected to compressive force, with load being continuously applied until failure occurred. The specimen samples were placed between the compression plates in the adjustable and bottom crossheads.

When the samples were firmly gripped between the compression plates, load was applied and the compressive strain was read from the output display unit. The load at which failure occurred was recorded.

Hardness Test

The hardness tests were performed according to ASTM D785 standard using Rockwell Scale K hardness testing machine. The developed brake pad was placed on the anvil and lifted against the indenter Iloabachie et al (2017). The anvil was lifted with the test specimen carefully until the green light in front of the panel was on. The red light on the panel signaled the completion of the test and the machine switched off automatically.

Flame Resistance Test

This test was carried out using a Bunsen burner. The specimen was placed on wire gauze positioned directly on the blue flame of a Bunsen burner. The specimens weight before and after burning was noted after 10 minutes on the flame Dagwa and Ibhadode, (2005).

Wear Rate

This was carried out using the pin-on-disc type test device. A disc rotor made of gray cast iron of 180 mm in diameter and 8mm thick was used. The test specimen was clamped rigidly in position along the disc of a grinding machine for 5 seconds. The pin was pressed against the rotating gray cast iron disc of counter surface roughness of 0.3 m at a load of about 20 N, sliding speed of about 5.02 m/s and sliding distance of 5km Dagwa and Ibhadode, (2005). The weights of the samples were taken before and after grinding. The weight difference from each sample indicated the loss in weight. The wear rate was determined by using the following equation

$$\text{Wear rate} = \frac{\Delta W}{S} \qquad (1)$$

Where ΔW is change in weight or weight loss i.e. weight difference before wear and after wear, S = sliding distance in m.

Co-efficient of Friction

The coefficient of friction of each test specimen was determined with the aid of an inclined plane and a 90^{o} wedge. Each specimen was placed on the inclined plane with the wedge in place. The wedge position was varied to increase the inclination angle until the test sample was just about to slide.

Results and Discussion

Figs. 3.1 and 3.2 show the variation of coefficient of friction (CoF) and wear rate with weight percent of plantain peels (reinforcement). The results showed that while the coefficient of friction increased as the weight percent of the plantain peels increased, the wear rate decreased with increasing plantain peels composition. At 25% plantain peels composition; it could also be observed that the decreasing trend of the wear rare reversed. This could not be said of the coefficient of friction where the increase continued up to 25% plantain peels composition. The increasing trend of the coefficient of friction with weight percent plantain peels may be likened to appearance of significant plastic deformation on the pin disc surface which corroborates the work of Iloabachie et. al (2023) where similar trend has been reported. This is also in line with the works of Idris et al. (2013), Dagwa and Ibhadode in Idris et al., (2013) and and Adeyemi et al. (2016). Idris et al. (2013) and Ibhadode and Dagwa in Idris *et al.* (2013) stated differently that the coefficient of friction for conventional brake pad ranges from 0.3 to 0.4. Nicholson (2014) reported the industrial standard range of 0.3 to 0.45 for automotive brake pad systems. The result of coefficient of friction of this work is within this range hence, agrees with the findings of the authors.

The lowest wear rate value of 3.41 was obtained at 15 wt. % of plantain peels and this may be attributed to closer packing of the particles in Gum-Arabic resin leading to stronger bond between the resin and the powdered plantain peels. The wear rate values obtained in this work though, are in line with those of Ikpambese et al. (2014) reported in epoxy resin however the lower values of wear rate obtain this work may be viewed as the effect of the resin used.

The hardness values and compressive strength values of the developed brake pads increased with increasing weight percent of the powdered plantain peels. A decrease in the hardness and compressive strength values were observed at 20 wt. % of the powdered plantain peels reinforcement. This decrease may be attributed to non-uniform distribution of the reinforcement particles within the resins Iloabachie et. al (2017). The hardness values results of this work are in line with that of other agro materials from other researches as Iloabachie et. al (2023) pointed out. The observed general increase in compressive strength as the weight percent of the powdered plantain peels increased was an indication of proper dispersion of the powdered pod in the resins resulting to better particle/resin interaction Iloabachie et. al (2017). Also, better particle/resin interaction may have improved the ability of the developed brake pad to resist deformation. Edokpia et al (2014) and Ademoh and Adeyemi (2015) had previously established similar trend.

Fig. 3.4 shows the resistance to flame by the developed plantain peels /Gum-Arabic brake pad composite. The flame resistance of the produced brake pads increased as the plantain peels reinforcement weight percent increased. This may be likened to proper bonding between the powdered plantain peels and the Gum-Arabic resin. Also, carbonization of the plantain peels enhanced the thermal stability of the produced brake pad. Aigbodion and Akadike, (2010) had argued that carbonization particles in a brake pad composite during thermal decomposition constitute adequate physical barriers thereby inhibiting transport of decomposed volatile product out of the brake pad composite.

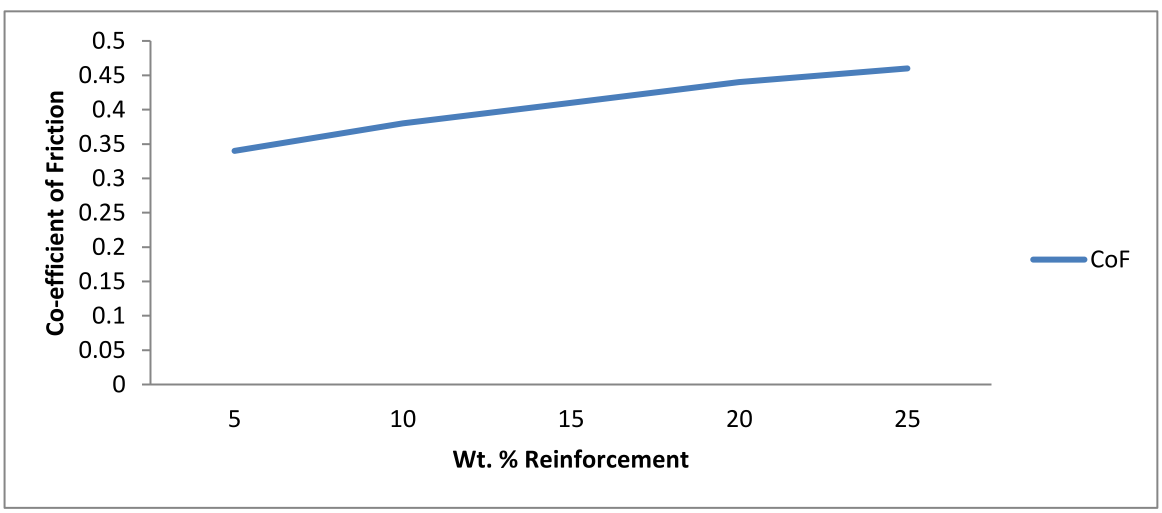


Fig. 3.1: Variation of Coefficient of Friction with Weight Percent of Plantain Peels

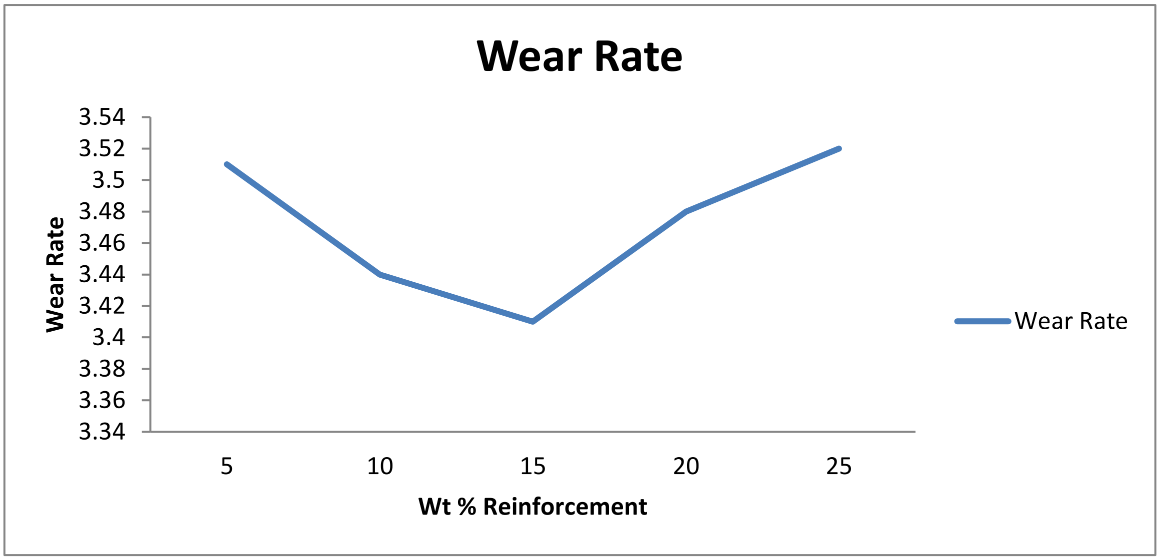


Fig. 3.2: Variation of Wear Rate with Weight Percent of Plantain Peels

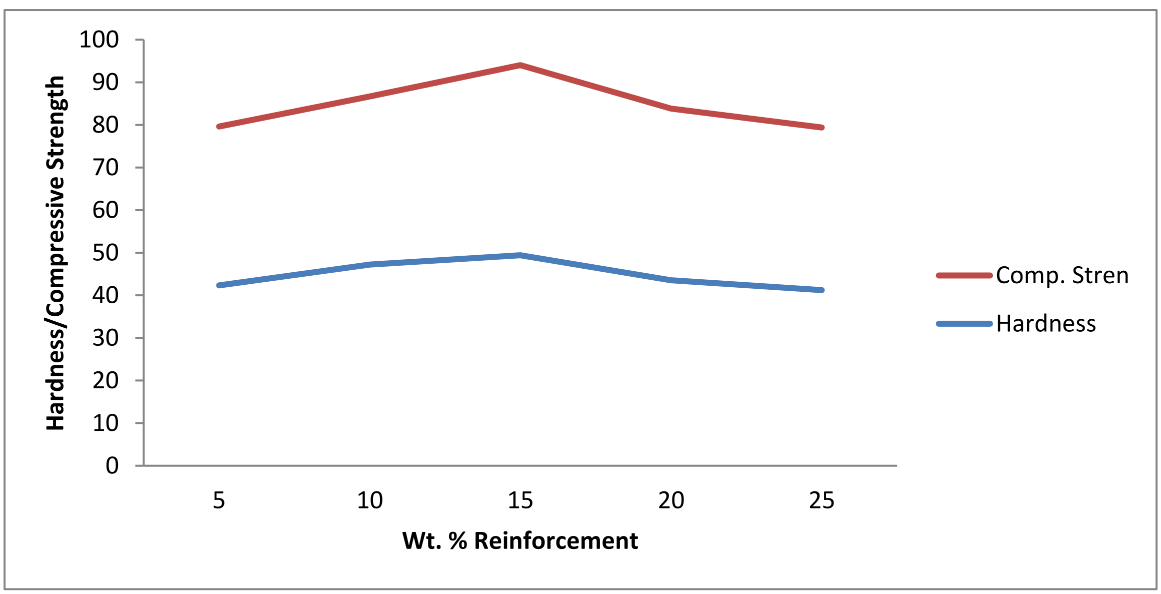
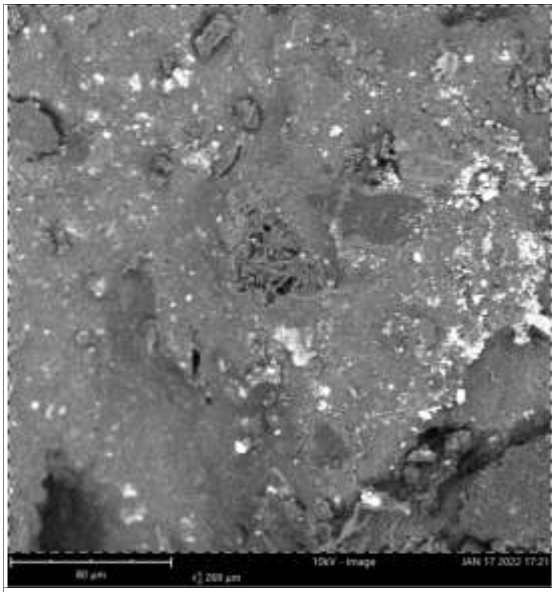


Fig. 3.3: Variation of Hardness and Compressive Strength with Weight Percent of Plantain Peels

Fig. 3.4: Variation of Flame Resistance with Weight Percent of Plantain Peels

Result Analysis

The SEM/EDS micrographs of the developed brake pads using powdered plantain peels in Gum-Arabic resin. Abrasive wear mode that is abrasive in nature with wear debris, scratches, shallow and deep grooves formed could be observed in the SEM micrograph, Fig. 3.5. The SEM micrograph also revealed the heterogeneous nature of the samples, confirming the brake pad samples as a mixture of different additives of varying shapes. Furthermore, the energy dispersive spectrographs (EDS) of the developed brake pad samples as could be observed in Fig. 3.5 revealed that the elemental distribution of the elements has a good combination which again confirms the heterogeneity in the nature of the developed brake pad composites samples.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	61.57	54.60
8	O	Oxygen	38.43	45.40

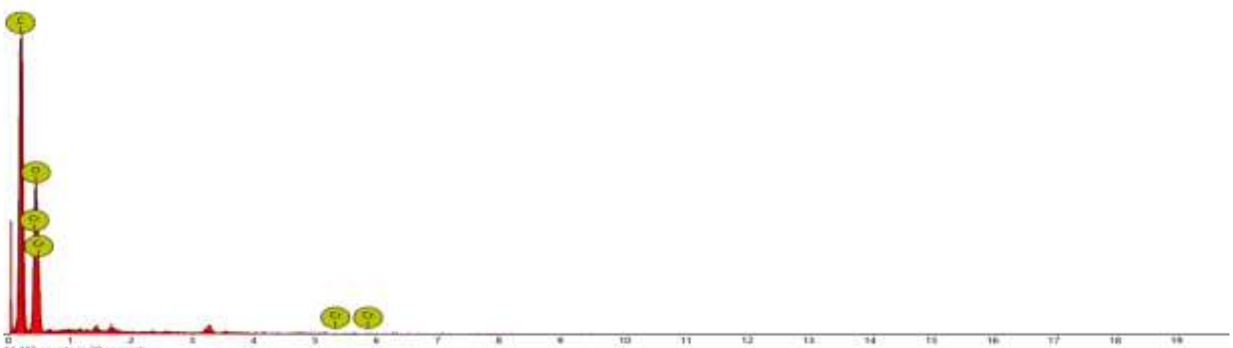


Fig. 3.4: SEM/EDX of Developed 20wt. % Carbonized Powdered *Plantain Peels* Brake Pad Sample in Gum-Arabic Resin (Hardness & Wear Resistance)

Conclusion

The following conclusion can be from this work:

- Carbonized plantain peels can be used as effective friction material to replace asbestos in brake pad production.
- Coefficient of friction of the developed brake pad increased as the the wear rate decreased.
- Hardness of the developed brake pad increased as amount of powdered plantain peels increased.

References

Abutu, J., Lawal, .S.A., Ndaliman, .M.B., Lafia Araga, .R.A. (2018). An Overview of Brake Pad Production Using Non–Hazardous Reinforcement Materials. ACTA TECHNICA CORVINIENSIS Bulletin of Engineering Tome XI. PP 143-155.

Acharya S. K., & Samantrai S. P. (2012). The Friction and Wear behaviour of Modified Rice Husk filled Epoxy Composite. International Journal of Scientific and Engineering Research. 3(6), 180–184.

Adebisi, A.A. and Maleque, M.A. and Shah, Q.H. (2011). Surface Temperature Distribution in a Composite Brake Rotor, International Journal of Mechanical and Materials Engineering 6 (3): 356-361.

Aigbodion, V.S., Akadike, U., Hassan, S.B., Asuke, F., Agunsoye, J.O. (2010). Development of Asbestos – Free Brake Pad Using Bagasse. Tribol. Ind. 32 (1), 45–50.

Adeyemi, I. O., Nuhu, A. A., Thankgod, E. B. (2016). Development of Asbestos-Free Automotive Brake Pad Using Ternary Agro-Waste Fillers. *Journal of Multidisciplinary Engineering Science and Technology (JMEST*) 3 (7) 5307-5323.

Bashar, D.A, Madakson P. B, Manji J. (2012). Material Selection and Production of a Cold-Worked Composite Brake Pad, World J of Engineering and Pure and Applied Sci.; 2 (3):92.

Bono, S.G., Dekyrger, W.J., (1990). Auto Technology, Theory and Service, 2nd ed. DELMAR Publishers, New York, 45–48.

Cronauer, S.S., Krikorian, A.D. (2012). "Banana (Musa spp.)". In Y.P.S. Bajaj (ed.). Trees I. Biotechnology in Agriculture and Forestry. Springer Science & Business Media. p. 233. ISBN 9783642705762.

Dagwa, I.M. and Ibhadode, A.O.A, (2005). Design and Manufacture of Experimental Brake Pad Test Rig Nigerian Journal of Engineering Research and Development , Basade Publishing Press Ondo, Nigeria, vol. 4(3). 15-24.

Dagwa I. M., & Ibhadode A. O. A. (2008). The Development of Asbestos–Free Friction Pad Material from Palm Kernel Shell. Journal of the Braz. Soc. of Mech. Science and Engineering, 2 (154).

Deepika, K., Bhaskar, R. C., & Ramana, R. D. (2013). Fabrication and Performance Evaluation of a Composite Material for Wear Resistance Application. International Journal of Engineering Science and Innovative Technology. (2)6.

Fono–Tamo,R. S., & Koya, O. A. (2013). Evaluation of Mechanical properties of Friction Pad developed from Agricultural Waste. International Journal of Advancements in Research & Technology. 2(154), 2278–7763.

Iloabachie I. C. (2018). Development of Coconut Shell Reinforced Polyester Composite for Industrial Application. M.ENG. Thesis, Dept of Metallurgical & Materials Engineering Nnamdi Azikiwe University, Awka.

Iloabachie I.C., Atuanya C.U., Ogbu C.C. (2023). Optimization Analysis of Hardness Test for Powdered *Pentaclethra Macrophylla* Pod /Bio-Epoxy Resin Based Brake Pad Composite Using Central Composite Design.

Leman, Z., Sapuan, S.M. Saifol, A.M. Maleque, M.A. and Ahmad, M.M. (2008). Moisture absorption behaviour of sugar palm fibre reinforced epoxy composites' Short Communication, International Journal of Materials and Design 29 (8): 1666-1670.

Maleque, M. and Dyuti, S. (2010). Materials selection of a bicycle frame using cost per unit property and digital logic methods. International Journal of Mechanical and Materials Engineering 5 (1): 95-100.

Iloabachie, I.C.C., Ezema I.C, Onyia C. N, Chime, A.C. (2019). Effect of Carbonization and Particle Size on the Impact Strength and Water Absorption Properties of Coconut Shell /Polyester Composite. *International Research Journal of Advanced Engineering and Science*. Volume 4, Issue 2, pp. 438-441.

Maleque, M.A., Atiqah, A., Talib, R.J. and Zahurin H. (2012). New Natural Fibre Reinforced Aluminium Composite for Automotive Brake Pad. International Journal of Mechanical and Materials Engineering; 7, (2), 166-170.

Iloabachie, .I.C.C, Obiorah, S. M, Ezema, I.C, Henry, V.I, Chime, O.H. (2017). Effects of Carbonization on the Physical and Mechanical Properties of Coconut Shell Particle Reinforced Polyester Composite. *International Journal of Research in Advanced Engineering and Technology.* Volume 3; Issue 1; Page No. 62-69

Morshed, M. M. & Haseeb, A.S.M.A. (2004). Physical and Chemical Characteristics of Commercially Available Brake Shoe Lining Materials: A Comparative Study, Journal of Materials Processing Technology, 155–156, pp. 1422–1427.

Okareh, O.T., Adeolu, A.T., Adepoju, O.T. (2015). Proximate and Mineral Composition of Plantain (Musa Paradisiaca) Wastes Flour; A Potential Nutrients Source in the Formulation of Animal Feeds. African Journal of Food Science and Technology 6(2) pp. 53-57.

Edokpia, R. O., Aigbodion, V. S., Obiorah, O. B., Atuanya, C. U. (2014). Evaluation of the Properties of Eco-friendly Brake Pad Using Egg Shell Particles–Gum Arabic. *Science Direct®, Elsevier* B.V. DOI: 10.1016/j.rinp.06.003.

Oladiji, A.T., Idoko, A.S., Abodunrin, T.P., Yakubu, M.T. (2010). Studies on the Physicochemical Properties and Fatty Acid Composition of the Oil from Ripe Plantain Peel (Musa paradisiaca). African Scientist, 11(1) 73-78.

Iloabachie I.C.C, Okpe B.O, Nnamani T.O, Chime A.C. (2018). The Effect of Carbonization Temperatures on Proximate Analysis of Coconut Shell. *International Journal of Advanced Engineering and Technology*. Volume 2; Issue 1; Page No. 30-32.

Philips, T.A. (1982). An Agricultural Notebook. Longman, Nigeria p.125. Plantains (Musa spp) as Determined by Instrumental Neutron Activation Analysis. Journal of Radioanalytical and Nuclear Chemistry, 270(2): 407-411.

Rajan T.P.D, Pillai R.M, Pai B.C., Satyanarayana K.G, Rohatgi, P.K (2007): Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, Composites Science and Technology, 67, 3369–3377.

Redhead, J. (1989). M. Boelen (ed.). Utilization of Tropical Foods: Trees. FAO Food and Nutrition Paper. Food and Agriculture Organization of the United Nations. p. 32. ISBN 9789251027769.

Valmayor, R.V., Jamaluddin, S.H., Silayoi, B., Kusumo, S., Danh, L.D., Pascua, O.C., Espino, R.R.C. (2000). "Banana Cultivar Names and Synonyms in Southeast Asia". In A.B. Molina; V.N. Roa (eds.). Advancing Banana and Plantain R&D in Asia and the Pacific. Bioversity International. p. 55. ISBN 9789719175131.

Vu, T.T. (2005). Modes of Action of Non-pathogenic Fusarium oxysporum Endophytes for Bio-enhancement of Banana Toward Radopholus similis. Cuvillier Verlag. p. 1. ISBN 9783865374752.

Wannik, W.B., Ayob, A.F., Syahrullail, S., Masjuki, H.H. and Ahmad, M.F. (2012). The effect of Boron Friction Modifier on the Performance of Brake Pads, International Journal of Mechanical and Materials Engineering 7 (1): 31- 35.

Yawas, D. S., Aku, S. Y., Amaren, S. G. (2016). Morphology and Properties of Periwinkle Shell Asbestos-Free Brake Pad. Journal of King Saud University – Engineering Sciences 28, 103-109.

Ademoh A. N., Adeyemi I. O. (2015). Development and Evaluation of Maize Husks (Asbestos–Free) Based Brake Pad. *Industrial Engineering Letters –IEL*, 5(2), 67–80.

Produced Brake Pad

Carbonized Plantain Peels

Ripe Plantain

Ripe Plantain Peels

Wear Properties/ COF of Powdered Plantain Peels/ Nigerian Gum-Arabic Resin Based Brake Pad Composite.

Sample	WR	COF
5	3.51	0.34
10	3.44	0.38
15	3.41	0.41
20	3.48	0.44
25	3.52	0.46

Results of the Mechanical Properties of Un-Carbonized Powdered *Pentaclethra Macrophylla* Pod/Nigerian Gum-Arabic Resin Based Brake Pad Composite.

Sample	Hardness	Compressive strength
5	42.34	37.28
10	47.18	39.53
15	49.4	44.62
20	43.52	40.34
25	41.22	38.16

Flame Resistance in Gum-Arabic

Sample	FR
5	12.42
10	17.35
15	18.24
20	21
25	23