Effect of Kenaf Core Fibre (*Hibiscus cannabinus*) as one of the Dispersing Phases in Brake Pad Composite Production

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Abstract.
Brakes are essential parts of all means of transportation. Their function is to slow or stop a vehicle by friction. Asbestos has been widely used in the production of brake pads. However, its application poses adverse effects on human health and the environment. The aim of this study was to determine the effect of kenaf core fibers as one of the dispersing phases in brake pad composite production. The materials and methods employed in the study, followed procedures in established standards and literatures. The materials were grounded into fine powder and sieved into grade sizes of 100 μm and 200 μm. They were weighed on a digital scale according to a specified composition and mixed thoroughly for about five (5) minutes to obtain homogeneity of the mixture. Afterwards, the mixed compositions were placed inside a 5 cm × 3 cm × 2 cm cylindrical mould. These mixtures were then compacted on a hydraulic press and allowed to dry at an ambient temperature of 37 °C. A series of physio-mechanical tests such as porosity, ash content, density, compressive strength, hardness and wear rate were conducted on the developed brake pad samples as well as the control samples. The results showed that the average values for porosity, ash content and density of the developed samples enhanced with kenaf core fibres were 0.813%, 57.25% and 1.389 kg/m³ respectively. These values compare well with that of the control samples. Also, the hardness, wear rate and compressive strength of the samples enhanced with kenaf fibers gave average values of 121.25 BHN, 10.121×10⁻² g/km and 105.75 MPa respectively. These values also compare well with that of the control samples. From the results gotten and all the properties determined, the study showed that kenaf core fibres has good potentials as dispersing phases for brake pad composite production.

Key words: Kenaf, Core fibers, Brake pad, Composites, Mould.

1.0 INTRODUCTION
Brakes are important parts of any means of transportation. They help to slow or stop a vehicle by friction, converting kinetic energy to heat energy which is then dissipated. In the past asbestos and some semi metallic materials were used to manufacture brake pads. Asbestos became progressively more popular among brake pad manufacturers because of its sound absorption, average tensile strength, and resistance to heat, electrical and chemical damage. However, studies have shown that they are carcinogenic. They release tiny particles suspension to the atmosphere as the pads wear out in service. When inhaled, these dusts can cause certain health issues including a number of lung and brain diseases [1]. There is a paradigm shift from the use of asbestos in the manufacturing industry as many researchers are continually carrying out various research works to evaluate other materials that can serve as a preferred alternative to asbestos [2]. Semi-metallic brake pads in the other hand produce much noise and dust. This no doubt, encourages noise and air pollution, needless to talk about the attendant respiratory diseases the dust could cause [3]. This is why researchers are continually seeking to develop other materials that could offer competitive performance like the asbestos and semi-metallic brake pads. worked on the evaluation of palm kernel fibers (PKFs) for production of asbestos-free automotive brake pads. The results were compared with commercial asbestos based brake pads. Results showed that PKF can be suitable
for replacement of asbestos brake pads with epoxy resin as a binder. The samples however, exhibited a relatively high wear rate which is not desirable for a brake lining material. Aku et al., (2012) studied the use of periwinkle shell as a potential material for asbestos free brake pad using spectroscopic and wear analysis [5]. They found out that periwinkle shell could be used for the production of non-asbestos brake pad. Thermal decomposition was observed in terms of global mass loss by using a DTA/TGA thermo-gravimetric analyzer. Fourier transform infrared spectrometry (FTIR) was also carried out on the periwinkle shell particles [6]. The result of these tests showed a lower density than that of the asbestos brake pad. The various results obtained were compared with asbestos which confirmed that periwinkle shell can be used as a material for brake pad production [7]. Although, all these researchers have carried out various research works on the related study but none of them have used Kenaf core fibre as a dispersing phase as a possible mix in a typical palm kernel-based brake pad composite [8].

Hence, considering the various challenges connected to brake pad formulation and utilization, the aim of this study was to determine the Effect of Kenaf Core Fibre (Hibiscus cannabinus) as one of the Dispersing Phases in Brake pad composite production [9]. Kenaf plants are natural occurring plant fibres that grow rapidly in any type of soil [10]. They reach 12-18 feet in 150 days and are readily available. Studies have also shown that Kenaf fibres have good mechanical properties ranging from high hardness to high compressive strength [11].

2.0 METHODOLOGY
The methods used to achieve the stated objectives followed established standards and published journals. The study was purely experimental. The methods are classified into the following:

- Kenaf core fibre extraction and preparation
- Brake pad sample production
- Physio-mechanical properties determination

2.1 Kenaf core fibre extraction and preparation: A Kenaf core fibre was extracted from the kenaf stem using water retting process. This process ensured the degradation of the pectic materials, hemicellulose and lignin and also improved the quality of the fibre. The fibre was placed in water for 14-24 days and the bast was separated from the core.

2.2 Brake pad sample production: In order to assist fibre dispersion, the composite materials were grounded into fine powder & sieved into grade sizes of 100μm and 200μm. The components were mixed using the composition shown in the Table 2.1 below:

| S/N | MATERIAL       | SAMPLES (wt %) |
|-----|----------------|----------------|
|     |                | A  | B  | C  | D  |
| 1.  | Palm Kernel Shell | 20 | 20 | 20 | 20 |
| 2.  | Kenaf          | 10 | 20 | 30 | 40 |
| 3.  | Silica         | 35 | 25 | 15 |  5 |
| 4.  | Steel Dust     | 10 | 10 | 10 | 10 |
The mixtures were then placed inside a cylindrical mould with of 5cm height x 3cm radius. These mixtures were then compacted on a Hydraulic press. Thereafter the moulded materials were removed and allowed to dry at ambient temperature of 37°C.

2.3 Physio-Mechanical Properties Determination

i. **Porosity Test**: This was evaluated from the formula as stated by [12].

\[
\text{Porosity (P)} = \frac{M_2 - M_1}{D} \times \frac{100}{V}
\]

\(D = \text{density of water; } M_2 = \text{the mass of test sample after absorbing water (g); } M_1 = \text{mass of test sample before absorbing water (g); } V = \text{Volume of test sample (cm}^3\).\)

ii. **Ash Content Determination**

About 1.20g of the samples were weighed in a cooled crucible which was oven dried by heating in a furnace to 550°C for about 1 hour. Then the samples were charred. The samples were then cooled in a desiccator and weighed. The ash content formula is in line with that of Bala (2017) and was calculated according to the formula below:

\[
\% \text{ ash} = \frac{W_2 - W_0}{W_1 - W_0} \times 100
\]

Where \(W_0 = \text{weight of empty crucible; } W_1 = \text{weight of crucible + sample; } W_2 = \text{weight of crucible and residue i.e. after cooling.}\)

iii. **Density Test**

A clean sample was weighed accurately in air using an electronic pocket scale and then suspended in water. The weight of the sample when suspended in water was determined and the volume of the sample was determined from the effect of displacement by water. The formula below was then used to calculate the sample density:

\[
\text{Density (} \rho \text{)} = \frac{m}{V}
\]

Where \(m = \text{the mass of test sample (g) and } V = \text{the measuring volume of test piece (cm}^3\) by liquid displacement method

iv. **Brinell Hardness Test**

This was determined by a Brinell hardness tester with 10 mm steel ball indenter and applied force of 2 KN. The samples were placed on anvils acting as support for the test samples. A minor force was applied to the test sample in a controlled manner then the major force was applied. The reading was taken when the large pointer came to rest and dwelled for about 4s. The load was then removed by returning the crank handle to the latched position and the hardness values was noted from the digital scale.

v. **Wear Rate Test**

The sample was tested by using pin on wear tester. The sample weight was taken before and after test using a digital measuring scale. The weight difference of each sample indicated the loss in weight. The tester provided a friction temperature range of 110°C which was adjusted. The sample was fixed in the tester which rotated with a speed of 1000 rpm for 5 minutes. The disc diameter was 200 mm. The wear rate was then calculated using the formula (Madeswaran 2016)
Wear rate \[ \Delta_w = \frac{\Delta_w}{S} = \frac{2\pi ND \times t}{S} \]  
(3.5)  
Where, \( \Delta_w \) = weight loss; \( S \) = sliding distance; \( D \) = diameter of disc; \( N \) = speed (rpm); \( t \) = time

vi. Compressive Strength  
The compressive strength test was done using the Tensometric Machine. The samples of diameter 25.2 mm were subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded. This method tallies with that of Aigbodion (2010).

3.0 RESULTS AND DISCUSSION  
This chapter discusses the test results obtained for the study. The results are presented on Tables 3.1 to 3.3 and Figures 3.1 to 3.3.

### Table 3.1: Porosity rates (%) of the developed brake pad composites samples

| Particle Sizes (μm) | Sample A (10% KF) | Sample B (20% KF) | Sample C (30% KF) | Sample D (40% KF) | Average | Control Sample (Asbestos) |
|---------------------|-------------------|-------------------|-------------------|-------------------|---------|---------------------------|
| 100                 | 0.84              | 0.81              | 0.81              | 0.79              | 0.813   | 0.90                      |
| 200                 | 0.90              | 0.86              | 0.85              | 0.80              | 0.853   | 0.94                      |

### Table 3.2: Ash content rates (%) of the developed brake pad composites samples

| Particle Sizes (μm) | Sample A (10% KF) | Sample B (20% KF) | Sample C (30% KF) | Sample D (40% KF) | Average | Control Sample (Asbestos) |
|---------------------|-------------------|-------------------|-------------------|-------------------|---------|---------------------------|
| 100                 | 45                | 55                | 68                | 71                | 57.25   | 46                        |
| 200                 | 42                | 51                | 67                | 69                | 59.75   | 48                        |

### Table 3.3: Density rates (kg/m³) of the developed brake pad composites samples

| Particle Sizes (μm) | Sample A (10% KF) | Sample B (20% KF) | Sample C (30% KF) | Sample D (40% KF) | Average | Control Sample (Asbestos) |
|---------------------|-------------------|-------------------|-------------------|-------------------|---------|---------------------------|
| 100                 | 1.511             | 1.421             | 1.357             | 1.265             | 1.389   | 1.32                      |
| 200                 | 1.621             | 1.532             | 1.432             | 1.303             | 1.472   | 1.41                      |
Fig 3.1: Brinell hardness values (BHN) of the developed brake pad composites samples

Fig 3.2: Wear rates ($\times 10^{-2}$) (g/km) of the developed brake pad composites samples
3.1 DISCUSSION
Table 3.1 shows the results of the porosity values for the developed brake pad composite samples and that of the control. It can be seen that as the percentage of Kenaf core fibre increases for each sample, the porosity values decrease [13, 20]. Also, as the particle sizes increases for each sample, the porosity values of the sample increases. This was attributed to the fact that as the sieve size increases, an increase in the number and size of pores in the samples will allow more water molecules to seep in. The values obtained for the 100 μm sample ranges from 0.79 – 0.84% while the values obtained for the 200 μm samples has higher porosity of 0.80 – 0.90% for samples A to D [14]. It can also be seen that the average porosity of the sieve grade samples as the percentage of kenaf core fibre increased were found to be 0.813% and 0.853% respectively [21-24]. The average porosity value for each percentage increase in kenaf were compared to that of asbestos brake pad (0.9 %) and they are within the range of a standard brake pad [24, 26].

Table 3.2 shows the results of the ash content values for the developed brake pad composite samples and that of the control [26, 32]. It can be seen that as the percentage of kenaf increases, the ash content increases for each sample. Also, the ash content decreases as the particle size increases for each sample [32, 34]. The 200 μm sieve grade samples gave results within the range of 45 – 71% for samples A to D while the samples with 100 μm gave values between 42 – 69%. The average ash content value for percentage increase in kenaf compare well to that of asbestos brake pad (56%). This value also compares well with the research carried out by [19].

Table 3.3 shows the results of the density values for the developed brake pad composite samples and that of the control. It can be seen that the density values generally decreased as the percentage composition of Kenaf increased from sample A to D. This is due to the fact that the density of Kenaf being an organic material is less dense hence, as more of it is added, the density of the sample reduces [34, 35]. It can also be observed that as the particle sizes increased, the density values increased. The 100 μm sieve grade sample gave results ranging from 1.265 kg/m³ – 1.511 kg/m³ for samples A to D while the samples of the 200 μm gave values between 1.303 kg/m³ – 1.621 kg/m³. The average density value for each sieve size were compared to that of asbestos brake
pad (1.32 kg/m³) and differed by 0.069 and 0.152 respectively [36-39]. These values compare well with that of Idris (2013) who worked on eco-friendly asbestos free brake-pad using banana peels. Figure 3.1 shows the results of the hardness values for the developed brake pad composite samples and that of the control [40, 41]. It can be seen that as the percentage of Kenaf fibres increases for each sample, the hardness values of each sample increases [42, 44]. Also, as the particle sizes increases for each sample, the hardness values of each sample decreases. It was observed that the brinell hardness values obtained for the 100 µm sample ranges from 120 – 146 BHN while the values obtained for the 200 µm samples had values ranging from 106 – 132 BHN for samples A to D [45, 46]. The average hardness obtained from the hardness test for this material (129.5 BHN) compares with that of the control (standard brake pad hardness value of 101 BHN) and was seen to be within the range. This value is also in line with what [47] reported in his work.

Figure 3.2 shows the results of the wear rates for the developed brake pad composite samples and that of the control. As the percentage composition of Kenaf fibres increased, the wear rate decreased [48-50]. Also, it was seen that the wear rates increased as the particle sizes increased. The wear rates of the 100 µm sample gave results ranging from 4.121 – 4.162(×10⁻²) (g/km) while the 200 µm sample gave values from 5.211 – 5.379 (×10⁻²) (g/km). The values also compare well with that reported by [51, 54].

Figure 3.3 shows the result of the compressive strength of the produced samples with percentage increase in kenaf core fibre [55, 56]. It can be observed that the compressive strength of each sample increased gradually as the percentage of Kenaf increased. Also, the compressive strength decreased as the particle size increased [57]. This can be attributed to the fact that the surface area and pore packaging capability of the filler in the resin are decreasing with increasing particle size. The 100 µm sieve grade samples gave the higher compressive strengths of 99 – 126 MPa for samples A to D while the samples of 200µm gave values between 91 – 102 MPa. It can also be seen that the average compressive strengths of the samples are 107.75 MPa and 98.5 MPa respectively [58]. The average compressive strength for each particle size with increasing kenaf also compares well to that of asbestos brake pad (110 MPa) and showed better properties [31].
4.0 CONCLUSION
The research was carried out with as much waste and eco-friendly material as possible and these materials can be sourced locally. Four test samples of brake pad composite enhanced with kenaf core fibers were made with two different particle sieve sizes, 100 μm and 200 μm. These samples were then tested for hardness, compressive strength, ash content, porosity, density and wear rate[32]. The results were compared with brake pad composites produced from asbestos, as the control. The following conclusions can be drawn from the study:

- The 100 μm particle size samples of Kenaf gave the best brake pad sample properties in all. The porosity, density and wear rate of the produced samples decreased in value as percentage of kenaf core fibre increased, while the ash content, hardness and compressive strength increased as percentage of kenaf increased [59, 61].
- As the particle size increased, ash content, hardness and compressive strength of the produced samples decreased in value, while the density, porosity rate and wear rate increased as particle size increased.

Based on the above test results of these brake pads composite, Kenaf core fibre can be used as a dispersing phase for brake pad composites, because the derived properties are within the range of that of the standard commercial brake pads.

5.0 Recommendation

- More research should be encouraged in the production of brake pads from organic and locally available materials.
- The government should empower more universities with proper testing laboratories so as to ease stress and economies of testing.

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REFERENCES
(1) Aaron, G. (2017). Disc brakes vs. Drum brakes: How they work and which is better [web blog post]. Retrieved from: https://www.thoughtco.com/disc-vs-drum-brakes-533862
(2) Aderiye, J. (2014). Kaolin Mineral Material for Automobile Ceramic Brake Pad Manufacturing industry. International Journal of Technology Enhancements and Emerging Engineering Research. 2(3). ISSN 2347-4289.
(3) Adeyemi, I. O., Ademoh, N. A., &Okwu, M. O. (2016). Development and Assessment of Composite Brake Pad Using Pulverized Cocoa Beans Shells Filler. International Journal of Materials Science and Applications, 5(2), 66-78. doi: 10.11648/j.ijmsa.20160502
(4) Aigbodion, V.S., Agunsoye, J.O. 2010. Bagasse (Sugarcane waste): Non-Asbestos Free Brake Pad Materials. LAP Lambert Academic Publishing, Germany, ISBN 978-3-8433-8194-9.
(5) Aigbodion, V. S., Akadike, U., Hassan, S. B., Asuke, F., &Agunsoye, J. O. (2010). Development of Asbestos Free Brake Pad Using Bagasse. Tribology in Industry, 32(1), 1-18.
(6) Aku, S. Y., Yawas D.S., Madakson, P.B., &Amaren, S. G. (2013). Characterization of Periwinkle shell as asbestos-free brake pad materials. Pacific Journal of Science Technology, 13(2), 57–63.
(7) Altair Engineering incorporated (2016). Composite Resins. [Web blog post] Retrieved from: http://www.altairenlighten.com/in-depth/composite-resins/
(8) Amaren, S. G., Aku, S. Y., & Yawas, D. S., (2013). Evaluation of the Wear and Thermal Properties of Asbestos Free Brake Pad Using Periwinkle Shell Particles. Results in Physics, 3, 99-108. DOI: 10.1016/j.rinp.2013.06.004
(9) Arnab, G., Raji G. (2008). Asbestos Free Friction Composition for Brake Linings Bulletin of Material Science, 31(1), 19–22.
(10) Anon (2004). Automotive Brake Repairs Trends and Safety Issues [web blog post]. Retrieved from: http://www.sirim.my/amtee/pm/brake.htm
(11) Bala, K. C., Okoli, M., Abolarin, M. S., (2016). Development of automobile brake lining using pulverized cow hooves, Leonardo Journal of Science, 15(28), p. 95-108.
(12) Belhocine, Ali, & Ghazaly, Nouby Mahdi. (2015). Effects of material properties on generation of brake squeal noise using finite element method. Latin American Journal of Solids and Structures, 12(8), 1432-1447. https://dx.doi.org/10.1590/1679-78251520
(13) Benyahia, A., Merrouche, A., Rakbi, M. and Kouadri, Z. (2013). Effect of Chemical Surface modifications on the Properties of Alfa Fibre-Polyester Composites, 53(4), 403-410. Retrieved from http://dx.doi.org/10.1080/03602599.2013.844828
(14) Bono, S.G., Dekyrger, W.J., 1990. Auto Technology, Theory and Service, 2nd edition, DELMAR Publishers, New York, 45–48.
(15) Booker, B. U., (1992). Compression Moulding method of making brake linings. US Patent 5156787. United States patent and trademark office. Pp 123-127
(16) Chan, D., Stachowiak, G. W. (2004). Review of Automotive Brake Friction Materials. Proceedings of the Institute of Mechanical Engineering. Part D. Journal of Automobile Engineering. 218, 953–966. DOI: 10.1243/0954407041856773
(17) 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.
(18) Dagwa, I.M., Ibhadode, A.O.A. 2006. Determination of optimum manufacturing conditions for asbestos-free brake pad using Taguchi method. Nigerian Journal of Engineering Research and Development. Basade Publishing Press Ondo, Nigeria, pp. 1–8, 5(4).
(19) Deepika, K., Bhaskar, C., Reddy, R., & Reddy, D. (2013). Fabrication and Performance Evaluation of a Composite Material for Wear Resistance Application. International Journal of Engineering Science and Innovative Technology (IJESIT), 2(6), 60-71.
(20) 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. DOI: 10.1016/j.rinp.2014.06.003.
(21) Egeonu, D., Oluah, C., Okolo, P. (2015). Production of eco-friendly brake pad using raw materials sourced locally in Nsukka. Journal of Energy Technologies and Policy Volume 5, No. 11.
(22) Elakhame, Z. U., Alhassan, O. A., & Samuel, A. E. (2014). Development and
Production of Brake Pads from Palm Kernel Shell Composites. *International Journal of Scientific & Engineering Research*, 5(10), 735-744.

(23) Elzev, M.R. Vancheeswaran, S. Myers, R. Mclellan, 2000. Multi criteria optimization in the design of composites for friction applications. *In: International conference on brakes 2000, automotive braking technologies for the 21st -century, Leeds, UK*, pp: 197-205.

(24) Farrell, G., Simons, S. A., & Hillocks, R. J. (2002). Pests, diseases, and weeds of Napier grass, Pennisetum purpureum: a review. *International Journal of Pest Management*, 48(1), 39-48.

(25) Gachoki, J. J., &Kathenya, M. D. (2011). Design of Brake Pad Friction Material. *(Undergraduate project, University of Nairobi)*.

(26) Giwa, O. A. (2017). Development of Organic Non-asbestos brake pad using African star apple seed shell. *(Undergraduate Project, Federal University of Agriculture Abeokuta)*.

(27) Hase, S. B., &Belkar, S. B. (2015). A study of development and performance characteristics of NAO brake linings with fly ash. *International Journal of Multidisciplinary Research and Development*, 2(2), 225-226. Holifield, P., & Weil, N. (2009). Materials of Brake Pads. [PowerPoint slides]. Retrieved from: http://www.powershow.com/view/3e0d21YmFkN/Materials_of_Brake_Pads_powerpoint_ppt_presentation

(28) Hussein, S. S. &Mostapha, M. (2011). The Effect of Filler Content on Properties of Coconut Shell Filled Polyester Composites. *Malaysian Polymer Journal*, 6(1), 87-89.

(29) Idris, U. D., Aigbodion, V. S., Abubakar, I. J., & Nwoye, C. I. (2013). Ecofriendly asbestos free brake-pad: using banana peels. *Journal of King Saud University - Engineering Sciences*. 27. DOI: 10.1016/j.jksues.2013.06.006

(30) Imaekhai, L., &Ugboya, A. P. (2013). Critical Evaluation/Reassessment of Automotive Brake Friction Materials (abmf). *Standard Scientific Research and Essays*. Vol 1(11): 275-288.

(31) Ikpambese, K. K., Gundu, D. T., &Tuleun, L. T. (2014). Evaluation of Palm Kernel Fibers (PKFs) for Production of Asbestos-Free Automotive Brake Pads. *Journal of King Saud University – Engineering Sciences* DOI: 10.1016/j.jksues.2014.02.001.

32. Ishidi, E. Y., Kolawole, E. G., Sunmonu, K. O., Yakubu, M. K., Adamu, I. K., &Obel, M. C. (2011). Study of Physio-Mechanical Properties of High Density. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 2011*, 2(6):1073-8.

33. Kazan-Allen, L. (2010). Asbestos-Related Diseases. *International Ban Asbestos Secretariat*. Retrieved from http://ibasecretariat.org/prof_ards.php

34. Kazan-Allen, L. (2017). Current Asbestos Ban. *International Ban Asbestos Secretariat*. Retrieved from http://ibasecretariat.org/alpha_ban_list.php

35. Khurmi, R. S., & Gupta, J. K. (2008). A textbook of machine design. Ram Nagar, New Delhi-110 055, *Eurasia publishing house (PVT.) Ltd*.

36. Kim, S.J., Kim, K.S., Jang, H., 2003. Optimization of manufacturing parameters for brake lining using Taguchi method. *J. Mater. Process. Technology*, pp 136:202–208.

37. Madesarwaran, A., Natarajasundaram, B., & Ramamoorthy, B. (2016). Reformation of Eco-Friendly Automotive Brake Pad by Using Natural Fibre Composites. *SAE Technical Paper*. DOI:10.4271/2016-28-0164.

38. Majethia, K. (2017). Non-metallic and composite material. [web blog post]. Retrieved
from: https://kishanmajethia.wordpress.com/2017/07/17/non-metallic-and-composite-materials/

39. Maleque, M. A., Atiqah, A., Talib, R. J., & Zahurin, H. (2012). New natural fibre reinforced Aluminum composite for automotive brake pad, (IJMME), 7(2) 166-170.

40. Malhotra, V.M., P.S, Valimbe, M.A. Wright, 2002. Effects of fly ash and bottom ash on the frictional behaviour of composites. Fuel, 81:235-44.

41. Monforton, G. & Partners (2017). History of Brake Systems. [web blog post]. Retrieved from: https://www.gregmonforton.com/evolution-brake-systems.html

42. Mott, L. R. (2004). Machine Elements in Mechanical Design(4th edition). Upper Saddle River, New Jersey, Pearson Prentice Hall.

43. Mutlu, I. (2009). Investigation of Tribological Properties of Brake Pads by Using Rice Straw and Rice Husk Dust. Journal of Applied Sciences, 9, 377-381. DOI: 10.3923/jas.377.381.

44. Namessan, N.O., Maduako, J.N., Iya, S. (2012). Effect of polyester and filler on water absorption behavior, density and porosity of kenaf (Hibiscus cannabinus) fibre reinforced brake pads. International Journal of Basic and Applied Sciences Vol: 12 No 3

45. Nuhu, A. A., & Adeyemi, I. O. (2015). Development and evaluation of maize husks (asbestos-free) based brake pad, 5(2), 67-80

46. Nwigbo S. C. & Asogwa, I. O., (2016). Production and performance evaluation of brake pad made from rice husk and palm kernel shell powder. International Journal of Agriculture and Biosciences, 5(6), 391-398.

47. Olumodeji, J. O. (2013). Assessment of Agricultural Waste for Production of Brake Pads. International Journal of Engineering Research & Technology, 2(11),

48. Omenkeukwu, H. C. (1987). Development of Automobile Brake Linings Using Local Materials (Master's thesis, University of Nigeria). Retrieved from: http://www unn.edu.ng/publications/files/Omenkeukwu_Humphery_Chijioke_19873289.pdf

49. Onyeneke, F.N., Anaele, J. U. &Ugwuegbu, C. C. (2014). Production of Motor Vehicle Brake Pad Using Local Materials (Periwinkle and Coconut Shell). The International Journal of Engineering and Science (IJES). Retrieved from: http://www.theijes.com/papers/v3-i9/Version-1/C0391017024.pdf

50. Patrascu, D., Balau, A., Caruntu, C.F. &Pastravanu, O. (2009). Modelling of a Pressure Reducing Valve Actuator for Automotive Applications. Control Applications, (CCA) & Intelligent Control, (ISIC)

51. Revati, R., Abdul Majid, M. S., Ridzuan, M. J. M., Normahira, M., Mohd Nasir, N. F., Rahman, M. N. Y., Gibson, A. G. (2017). Mechanical, thermal and morphological characterization of 3D porous Pennisetum purpureum / PLA biocomposites scaffold. Materials Science and Engineering, 75, 752–759, DOI: 10.1016/j.msec.2017.02.127

52. Rudramurthy et al., (2014)Evaluation of the Properties of Eco-friendly Brake Pad Using Coconut Shell Powder as a Filler Materials.

53. Ruzaidi, C.M., Kamarudin, J.B., Shamsul, J.B., Mustafa Al Barkri, A.M., & Rafiza, A.R. (2011). Comparative study on thermal, compressive, and wear properties of palm slag brake pad composite with other fillers. Aust. J. Basic Application Sciences pp 5, 79.

54. Society of Automotive Engineers (2013). Introduction to foundation brake design.
55. Strezov, V., Evans, T. J., & Hayman, C. (2008). Thermal conversion of elephant grass (Pennisetum purpureum Schum) to bio-gas, bio-oil and charcoal. *Bio-resources Technology*, 99, 8394-8399.

56. Swamidoss, V. F., & Prasanth. (2015). Fabrication and Characterization of Brake Pad Using Pineapple Leaf Fibre. *International Journal of Research in Computer Applications and Robotics*, 3(3), 107-111.

57. Tomasek, V., Kratošová, G., Yun, R., Fan, Y. & Lu, Y. (2009). *Journal of Materials Science*. Effects of Alumina in Nonmetallic Brake Friction Materials on Friction Performance, 44(1) 266–273 DOI: 10.1007/s10853-008-3041-z.

58. Vijay, R., Jees, J. M., Saibalaji, M. A. &Thiyagarajan, V. (2013) Optimization of Tribological Properties of Non-Asbestos Brake Pad Material by Using Steel Wool *Advances in Tribology*, 1-10, DOI:10.1155/2013/165859.

59. Walker, J., Jr. (2007). *High-Performance brake systems: Design, Selection and Installation*. (Illustrated ed.). Forestlake, MN: CarTech.

60. Woodford, C. (2017). Brakes: The Science of Stopping. [web blog post]. Retrieved from: [http://www.explainthatstuff.com/brakes.html](http://www.explainthatstuff.com/brakes.html)

61. Xiao, X., Yin, Y., Bao, J., Lu, L., & Feng X. (2016). Review on the Friction and Wear of Brake materials Advances in Mechanical Engineering. 8(5) 1–10. DOI:10.1177/1687814016647300