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Utilisation of Palm Kernel Shell, Rice Straw, Rice Husk and Rice Panicle For Automotive Brake Pad

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Abstract
Utilisation of palm kernel shell, rice straw, rice husk, and rice panicle for brake pad has been studied since the use of asbestos in brake pads production is being withdrawn due to its carcinogenic nature. The experimental research design used to develop the brake pad is by using friction modifying filler materials such as palm kernel shell (PKS), rice straw (RS), rice husk (RH) & rice panicle (RP) as base material in a binder (epoxy resin and hardener). Aluminium silicon as abrasive element and lubricant (graphite) were added to the composite using moulding technique to produce brake pads following standard procedure. The performance of the produced brake pads was checked and compared with existing commercial (asbestos-based) brake pad which was used as control in this case. It was observed that with the sample composite of PKS, RS, RH & RP produced, their particle size had a significant influence on the performance of the brake pad. The composites with 125µm (PKS, RS, RH & RP) have executed less hardness, density, water and oil absorption, and thermal conductivity constancy, while tensile strength and wear resistance of the composites were better compared to the other two composites 355µm and 500µm.it is recommended that careful material selection should be employed in selecting brake pad materials to enhance fabrication process as well as the general properties of brake pads to be developed in future studies. It is suggested that appropriate polymer mix should be used to enhance the strength of brake pads and reduce chain motion that leads to sudden failure of the pad in the event of high temperature.

Key words: *Brake pad, alternative materials, wear resistance, compressive strength*

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I. Introduction

It is common knowledge that the quest demanding the replacement of asbestos as brake and clutch lining at an affordable rate grows at a high pace than practically available in the world. According to Dagwa and Ibhadode (2008) the findings of health problems associated with long-term heavy exposure to airborne asbestos materials particles on the environment have led to a large reduction in the use of asbestos in vehicles and building materials[1, 2]. This is because of the concerns regarding airborne particles in factories and the disposal of asbestos-containing wastes. Gurunath and Bijwe (2009) experimented successfully with a newly developed resin to avoid shrinkage, a major problem that occurs at the end of the production of friction materials using phenolic resin as a binder[3]. Kumar et al. (2011) focused on metallic fillers, especially copper which was found best performer regarding friction and wear of brake frictional materials[4, 5].

Several studies have been carried out using different reinforced agricultural products such as Palm kernel shell, Coconut shells, Rice straw and rice husk, Banana peels, Cow Hooves, Cow bone, eggshells, etc. as economical and new materials in the development of brake pad material with commercial viability and environmental acceptability recounted that among the various kinds of agricultural products examined, lignocellulose fillers are most times considered as pretty materials to be utilised as fillers of thermoplastic polymers due to their excellent properties[6, 7].

It was observed that the composites have a significant increase in impact strength when compared to asbestos. Although, they have these setbacks; rapid wear, poor dispersion of heat, and distribution of the particles in the matrix.

Naemah (2011) testified that a good brake pad material must meet the following benchmarks:

i. It must be environmentally acceptable and be safe for use
ii. The contact materials must exhibit good resistance to wear effects
iii. To be able to withstand higher temperatures and high contact pressures
iv. The materials must exhibit a high frictional coefficient.
v. The frictional value must be stable over a temperatures and pressures range.

vi. The materials must have good resistance to environmental effects which arise from dust, pressure, and moisture, and must possess excellent shear strength of transferring frictional forces to structure[8].

Blau (2001) and Bashar, Peter, and Joseph (2012) detected that brake pad additives serve different functions and a difference of two or three percent of additive can change the performance of the friction material[9, 10]. Therefore, the control of the composition is of great significance. Blau (2001) grouped friction materials and additives based on their expected functions into the following: fillers and reinforcement, abrasives, friction modifiers, and binder materials. Bakry, Mousa, and Ali (2013) investigated the effect of agriculture fibre wastes such as corn, sugar bars, and palm fibres on friction coefficient and wear. The work aimed to replace composite components with environmentally friendly friction materials for brake linings and clutch facings. It turned out that they are capable of increasing friction coefficient and decreasing wear[11]. Cho, Kim, Kim, and Jang (2005) classified typical components of polymer composite friction materials for clutches and brakes in the following groups: reinforcements, binders, friction modifiers, and fillers. The friction materials are deformable; their task is to maintain a sufficiently high and stable friction coefficient and a good wear resistance during operation. They should possess the ability to resist heat induced deterioration, impact and centrifugal force during friction[12]. The tribological performances and mechanical properties of friction materials depend on the mentioned components. For instance, fibres play a critical role in determining the mechanical strength, thermal resistance, and friction and wear properties of the materials[12, 13].

It is a known fact that asbestos stands as one of the best frictional lining materials in use for now, although this asbestos has health effects such as lung cancer to the users in the environment. Since 1980s, the Environmental Protection Agency (EPA) and the Occupation Safety and Health Administration (OSHA) had banned asbestos products in clutch plates and brake bands which are still in used [14, 15]. This has resulted in a lot of research work going on to find an equal or better replaceable material for asbestos. Examples of some of the biodegradable agricultural materials being used by various researchers include the combinations of Palm kernel shell and Coconut shells, Rice straw and rice husk, Banana peels, Cow Hooves and Cow bone, etc. which have proven some positive results. But there is no work carried out using Palm kernel Shell (PKS), rice straw (RS), rice husk (RH) and rice panicle (RP) combination in any literature which has necessitated the need for this research work to be carried out in this direction.

The utilisation of these biodegradable materials as a substitute for asbestos brake and clutch linings has a huge prospect in the field of automobile, agriculture machinery and mechanical industries[16, 17]. Besides, being a cheap material resource from farms, palm kernel mills and rice mills, it gives an environmentally friendly alternative. Conventional synthetic materials (glass fibre, ceramics, copper, etc.) which are equally good have been developed and are in use but their rates of wear are very rapid, costly, and are not readily available in the market is a challenge; hence the target of this research.

II. MATERIALS AND METHODS

The materials used in the preparation of the experiment for the research are listed and shown in Figures 1 &2 as follows: 1. Fillers (Palm Kernel Shell, Rice Straw, Rice Husk and Rice Panicle) 2. Binder (Epoxy resin and hardener) 3.Abrasives (Aluminium silicon). 4. Lubricant (Graphite) 5. Control (A commercially bought asbestos brake pad)

Figure 1Fillers

Epoxy Resin & Hardener Aluminium Silicon Graphite

Figure 2 Binder, Abrasives & Lubricant.

Equipment used for the setup

i. Two three face electric motor
ii. Rockwell hardness Machine
iii. Set of callipers i.e. digital callipers
iv. Accuscope Microscope.
v. Universal Testing Machine (UTM)
vi. Electric furnace
vii. Wooden mould
viii. Wire brush
ix. Digital weighing scale (Nimbus)
x. Metallic mortar and pestle
xi. British standard sieve Range from 125 microns (µm) to 500µm
xii. Spatula
xiii. Plate
xiv. Hand gloves
xv. Ethanol
xvi. Water and other chemical materials bought from shops

2.1 Sample Formulation

The raw materials used in this experiment work were filler, binder, abrasive, lubricant, and additives. The natural brake pad materials were developed through the process of selection of raw materials, weighing, mixing, compacting and binding. There were three formulations with different composition of palm kernel shell, rice straw, rice husk and rice panicle content. The palm kernel shell, the rice straw, rice husk and rice panicle were collected, washed with ethanol, dried in the sun for about two (2) weeks and were crushed and ground to a fine powder (with a range of 125µm -500µm), using a hammer mill, sieved graded to powder and weigh separately before used for the production of the brake pad as shown in Figure 1.

Grouping was made based on the variation of palm kernel shell, rice straw, rice husk and rice panicle material in the formulation. However, abrasive, lubricant, binder, friction modifier and lubricant were kept the same for all formulations process. Table 1 shows the detail formulation of the different types of new composition materials.

Table 1 Composition of Brake Pad Samples Weight in Grams (g)

Materials for the Compositions	125µm Sample in grams	355µm Sample in grams	500µm Sample in grams
Palm kernel shell (PKS)	8.9	8.9	8.9
Rice Straw (RS)	8.9	8.9	8.9
Rice Husk (RH)	8.9	8.9	8.9
Rice Panicle (RP)	8.9	8.9	8.9
Aluminium silicon	8.9	8.9	8.9
Powdered Graphite	2.0	2.0	2.0
Epoxy resin	35.5	35.5	35.5
Resin hardener	17.5	17.5	17.5
Total	99.5	99.5	99.5

Three different combinations (such as sample A, sample B, and sample C) were prepared by altering Palm Kernel Shell, Rice straw, Rice Husk, and Rice Panicle contents particle sizes (See Table 1). The PKS, RS, RH and RP powder were base material, epoxy resin was binder material, a hardener, graphite was lubricant, and aluminium silicon were the abrasives.

2.2 Formulation of the Brake Pad

The brake pad consists of a series of unit operations including weighing, mixing, forming, cooling, post-curing and finishing. The particle sizes of each of the grounded samples of fillers, binders, abrasives and lubricants were collected and used in the production of the brake pad. The composition was properly mixed together for sixteen (16) minutes to achieve almost homogeneous mixture inside a container using a spatula before pouring into the wooden mould. The composite was then subjected to pressing. The products of the brake pads were taken into an electric furnace oven at a temperature of 40^0C for six (6) hours. The surplus materials on the produced parts were removed from the samples made with the aid of abrasive machine (grinding machine). The prepared materials were also taken to laboratory for the various tests. Figure 3shows the wooden mould, the materials and the various samples prepared for the various tests and a commercial bought brake pad served as control.

Figure 3Samples materials used for the tests

2.3 Test and Analysis

Test such as density, water and oil absorption, hardness/abrasive value determination, impact energy determination, tensile and compressive strength, and heat resistance/thermal conductivity tests were carried out. The details of the various tests are outlined as follows:

(i) Density:

The ASTM standard D792-00 specification was used to calculate the density of the composite specimens. A clean sample is weighed accurately in air using an electronic scale model: Nimbus, 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 [18].

$$\text{Density} = \frac{Mass\ (M)}{Volume\ (V)} \quad 1$$

where: P = Density in kg/m^3, M = Mass in m^3, V = Volume of liquid displaced in kg

(ii) Water Absorption Test

The composite samples were dried in an oven to constant mass and dipped in distilled water at room temperature. The water absorption rate was determined by weighing the samples (W_a). The samples were dipped in water at room temperature for 1 hour, 2 hours, 24 hours and finally for days. The sample was then removed, wiped with a tissue and weighed (Wь). At least three specimens for the sample were used. A digital electronic

scale, model: EHA901 was used with a precision of 0.01g to weigh the samples. Then percentage of water (PWA) absorption was the determined with the formula: PWA = $\frac{Wb-Wa}{Wa} X\ 100\%$[19]

(iii) Oil Absorption Test

The composite sample was dried in an oven and dipped in brake fluid (WEBBER Brake and Clutch fluid with SAEJ1703 and DOT 3 specification) at room temperature. The oil absorption was arrived by weighing the sample (O_a). The sample was dipped in oil at room temperature for 1hour (hr), 2hrs, 24hrs and 6 days, then removed, cleaned with a tissue and weighed (Oь). At least three specimens for the sample were used. A digital electronic scale, model: EHA901 was used with a precision of 0.01g to weigh the samples. Then percentage of oil absorption, (POA) was determined

POA = $\frac{Ob-Oa}{Oa} X\ 100\%$. 3

here O_a and O_b are original dry weight and wet weight after exposure respectively[19].

(iv) Hardness Value Determination Test

The hardness test was carried out by using Avery Denison Rockwell hardness (model: 6407) machine using the M-scale in line with ASTM 785 specification. A 6.35 mm steel ball indenter was used with minor and major load of 157.2 kN and 260.1 kN respectively. The sample has a dimension of 30 mm x 20 mm x 10 mm. Before the test was carried out, the mating surface of the indenter, plunger rod and test samples were thoroughly cleaned to remove the dirt. The sample was placed on anvils, which act as support for the test sample. A minor load of 157.2 kN was applied to the sample in a controlled manner without including impact or vibration and zero datum position was established. Then the major load of 260.1 kN was applied. The reading was taken when the large pointer came to rest or had slowed appreciably and dwelled for up to 2 seconds. The load was then removed by returning the crank handle to the latched position and the hardness value read directly from the digital scale.

(v) Wear Test

The wear test was carried out using three face electric motor which was powered to a speed of 250rpm, 350rpm, 400rpm and finally 450rpm. It is then stopped and attached the brake pad to it for about fifteen (15) seconds and measured the wear rates using digital calipers. The wear rate was determined by weighing the sample before and after each test. The formula used to convert the weight loss into wear rate is:

Wear rate = $\frac{\Delta w}{S \times A}$ 4

where ΔW = weight diff erence of the sample before and after the test in mg, S = total sliding distance (m) and A= applied load (N).

(vi) Compressive Strength Test:

Compressive strength test was executed at AAMUSTED, Kumasi Campus by using Universal Testing Machine (UTM), model WAW-1000H with capacity 1000kN as shown in Figure 4. The test was conducted under EN 206 – 1– 200. The sample was inserted into the compressive zone of the UTM and the values of the sample were imputed into a software called Max test. Then the load (10kN/S) was applied to the samples. The sample failed after the application of the load. The results were computed and the readings were recorded as

Compressive Strength = $\frac{Force\ (F)/Load\ (L)KN}{\text{Area (A)mm 2}}$ $\frac{F/L}{A}$ = N/mm^2 . 5

(vii) Tensile Strength Test

The tensile test was executed and the readings recorded. The test was conducted under BS EN 10002. The sample was inserted into the compressive zone of the UTM, model WAW-1000H and the values of the sample was imputed into a software called Max test. Then the load (10kN/S) was applied to the samples. The sample failed after the application of the load. The results were computed as:

Tensile Strength = $\frac{Force\ (F)/Load\ (L)\ KN}{\text{Cross} - \text{Sectional Area (A)mm 2}}$ $\frac{F/L}{A}$ = N/mm^2 6

Figure 4Universal Testing Machine (UTM) Setup.

(viii) Thermal Conductivity:

Thermo-gravimetric analysis (TGA) which is the changes in composites with increasing temperature was used to evaluate the thermal conductivity integrity of the brake pads. The size of the test sample was 185 mm × 14.5 mm. Each sample was kept in a mild steel crucible and heated in a furnace from 100 - 500°C. The change in the samples was monitored. At each observation when the set temperature was attained; a choke time of 10 minutes was allowed for even heat distribution into the sample. The thermal conductivity gains at each observation were plotted against the temperature.

III. RESULTS AND DISCUSSION

Figure 5 shows the results of the final formulated brake pads.

Figure 5Formulated Brake Pads

i.Effect of particle size of PKS, RS, RH, and RP Combination for Brake Pad Produced.

The sample composite labelled as 125µm and 355µm particle size gave a greater performance in water and oil absorption in that order. This shows that particle size affects brake pad production and its effectiveness. Sample with particle size 355µm had the fastest wear rate, followed by sample with particle size 500µm, while sample 125µm particle size compared favourably with the asbestos-based pad. This trend implies that particle size is an important factor that needs careful attention when wear is to be considered in the production of brake pads using a combination of PKS, RS, RH& RP at their correct ratio. This finding is in agreement withBlau (2001), and Bashar, Peter, and Joseph (2012). The decrease in wear rate with increased particle size could be attributed to a higher load capacity of formulation and better interfacial bond between the particles and the resin thereby reducing the possibility of particle pull out which may result in higher wear rate. This corroborates the finding of (Idris et al., 2013) cited in Olele, Nkwocha, Ekeke, Ileagu, &Okeke (2016)[20]. These results are tabulated in Table 2.

ii.Thermal Conductivity

Table 2 Thermal Conductivity of the Newly Developed Composite Brake Pad.

Temperature (^{0}C)	125µm	355µm	500µm
	Thermal conductivity Watts per Meter-Kelvin (W/mK)	Thermal conductivity (W/mK)	Thermal conductivity (W/mK)
20	0.129	0.115	0.113
40	0.129	0.115	0.113
60	0.129	0.121	0.115
80	0.139	0.123	0.115
100	0.248	0.232	0.121
120	0.248	0.242	0.223
140	0.251	0.243	0.233
160	0.254	0.245	0.241
180	0.354	0.248	0.243
200	0.356	0.351	0.245
220	0.358	0.351	0.348
240	0.362	0.353	0.351
260	0.362	0.353	0.351
280	0.468	0.458	0.453
300	0.468	0.461	0.456
320	0.469	0.461	0.458
340	0.469	0.463	0.461
360	0.574	0.565	0.461
380	0.575	0.567	0.563
400	0.576	0.569	0.565
420	0.578	0.571	0.567
440	0.678	0.571	0.569
460	0.689	0.672	0.571
480	0.689	0.673	0.671
500	0.689	0.673	0.671

Table 2presents the thermal conductivity values of each of the three samples of brake pads. From the Table the following observations were made at the mid-temperature between 240^{0}C to 260^{0}C, the three samples recorded conductivity values of 0.362, 0.353, and 0.351(W/mK) respectively. At temperature of 500^{0}C, the 125µm sample demonstrations the highest thermal conductivity (0.689 W/mK), followed by the 355µm (0.673 W/mK) and 500µm (0.671W/mK) samples respectively. This implies the 500µm sample has the lowest thermal conductivity of (0.671mK) among the three samples, as compared to 0.539W/mK of that of asbestos in the literature. It can be seen that the 125µm sample can absorb about (0.689) 68.9% of heat and absorption dissipate rate despite the smaller voids, this agreed to the work of Naemah (2011), and Biczó, Kalácska, Szakál, Fledrich (2016) work[8, 13]. The thermal conductive properties of the 125µm sample depend on its particle size and fluids (water and oil) absorption properties that make it a very good thermal conductor.

This justifies why particle size is a great determinant in brake pad production. The smaller the particle size, the better the conductivity of the prepared brake pads and vice versa.

iii.Wear Rate of Fabricated Brake Pads

Figure 6compares the results of wear behaviour of various composite brake pads tested under the condition of dry sliding, increasing load, time as well as rotation speed of the three-face motor. The test samples all revealed an increasing wear rate with time. One of the factors that may be attributed to showing such an increase in wear rate in the fabricated composite brake pads is the thermo-mechanical loading of the pads. Comparatively, the created composite brake pad had a more consistent wear rate. The friction constancy and wear rate of a good brake pad should be good over a significant period of time. Despite this, the composite

brake pad produced exhibited better material loss resistance under the same test scenarios as the standard (asbestos) brake pad. Good mixing and adhesion between filler, abrasives, and the epoxy as well as the hardener may be responsible for the improvement. For brake pad composite manufacturing, both are appropriate binders.

It was observed that the 355µm sample had a severe wearing effect of 137.945 mm^2/N after a period of 4.54s. Surprisingly, within the same period and similar loading application, wear of 64.346 mm^2/N was recorded for the 125µm sample. This is an indication of great enhancement in the wear of the product. By using the same number and amounts of components, the most determining factor for the occurrence of such change in wear resistance is the reduction in the particle size. Hence, for brake pad applications that require a drastic reduction in wear of brake pad, it is optimum to reduce the size of the particle utilised in such application. Reducing the particle size further provides a large surface area for maximum adhesion between the various particles and the binder which invariably increases strength and also reduces wear rate.

It is acknowledged that the wear process involves fracture, tribo-chemical effects and plastic flow. Transitions between regions subject by each of these commonly give rise to changes in wear rate. Greater formulation load capacity and a better interfacial connection between the particles and the resin might be responsible for the decrease in wear rate with decreasing particle size. This would reduce the likelihood of particle pull out, which could result in a higher wear rate.

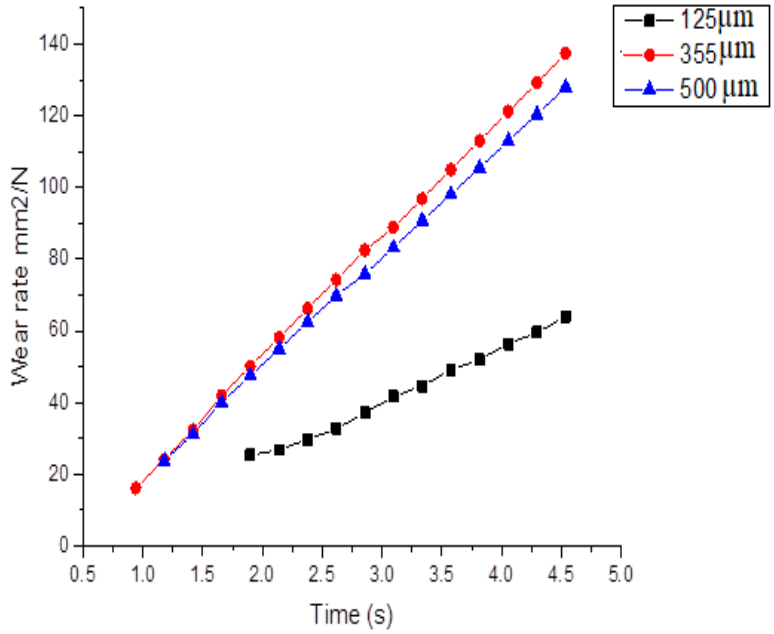

Figure 6 Graph of Wear rate and Time (s).

Table 3Abrasion Test

Samples	Initial Mass Kg before abrasion A	Initial Mass kg after abrasion B	Abrasion % (A-B) × (100) / (B)
125µm	0.0567	0.0565	0.35
355µm	0.0699	0.0693	0.87
500µm	0.0837	0.0832	0.60
	Total Average	0.2080	0.60%

Table 3 displays the abrasion of the samples of the newly formulated brake pad from (palm kernel shell, rice straw, rice husk & rice panicle) with 125µm, 355µm, and 500µm particle sizes and their abrasion rate recorded in percentages wear as; 0.35%, 0.87% and 0.60% respectively using wire brush on the various samples. Figure 7, shows a trend of wear of the formulated brake pads with 125µm, showing the least wear followed by the 500µm and 355µm. This finding of the study affirmed the previous studies conducted by Yawa, Aku and Amarea (2013), Idris et al. (2013) and Olele, Nkwocha, Ekeke, Ileagu and Okeke (2016), as captured in the literature[21].

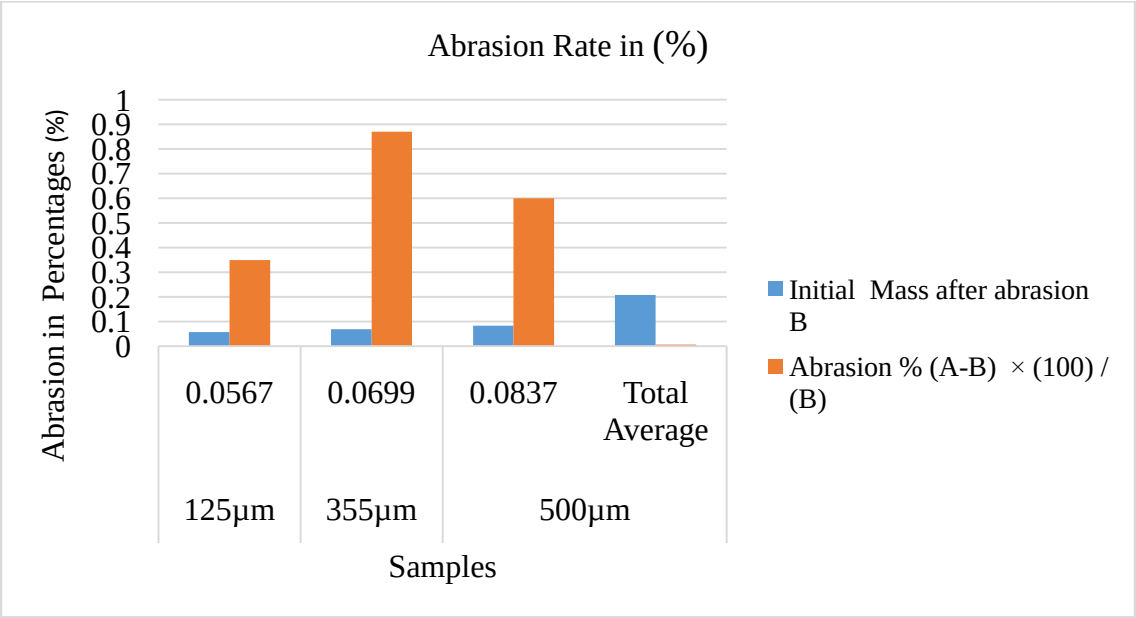

Figure 7Abrasion of samples of formulated brake pad.

iv.Tensile Strength

With reference to Figure 7, tensile strength increased slightly in all the fabricated samples. The brake pad with the lowest tensile strength was 125µm, which measured a maximum strength of 15.03 N/mm^2, after a fracture. The 355µm sample recorded an ultimate tensile strength of 10.067 N/mm^2, whiles that showed by the 500µm particle size brake pad was 25.302N/mm^2 at a displacement of 6.262 mm. An insignificant difference in strength was observed between the 355µm and 125 µm samples. The value of 21.648 and 21.819 N/mm^2 obtained as tensile strength for this brake pad produced is in the ranges of the recommended value of tensile strength between 20 and 27 N/mm^2 in the research works by (Chand, Hashmi, Lomash and Naikm, 2004)[22]. Moreover, this suggests that decreasing the particle size in the manufacturing of brake pads strongly helps in raising the tensile strength of the brake pad. This invariably improves the performance of the brake pads under braking conditions, as displayed in Figure 8, which affirmed the study of Yawa, Aku and Amarea (2013), Idris et al. (2013), and Olele, Nkwocha, Ekeke, Ileagu, and Okeke (2016)[20, 21].

As a result of varying particle sizes, samples showed different resistances to tensile force despite using the same number of constituents in their formulation. Better design of load capacity and an improved interfacial linking between the particles and the resin might be responsible for the increase in tensile strength with decreasing particle size. This would reduce the likelihood of particle pull out, which could result in higher tensile strength. As a result of this trend, the importance of particle size in the manufacturing of brake pads utilising palm kennel shell, rice straw, rice husk and rice panicle has been highlighted.

Comparing the stress and strain of the material produced in Figure 8, it can be seen that the 500µm has stress of 25.3N/mm^2, as against 119,25.5 before deformation, followed by the 125µm which has stress of 15.03N/mm^2 as against 77,15.3 before deformation. 355µm recorded the least value of all samples.

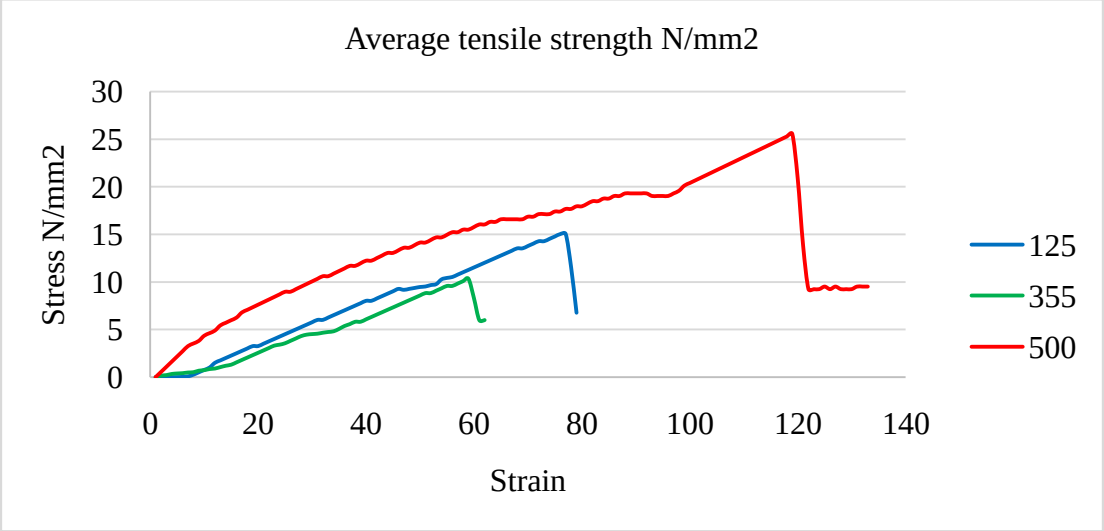

Figure 8Comparing the stress and strain of the material produced

v.Compressive Test

The results for the compression test conducted on the prepared brake pad samples are presented in Table 4. It revealed how the particle sizes were increased from 125µm to 500µm, and the compressive strength of each prepared brake pad was observed and their averages recorded as shown in the Table.

Table 4 Summery of Average Compressive Strength of the Brake Pad Material Produced

S/N	Sample	Sample Number	Force KN	Strength N/mm^2
1	125µm	1	22	25.4
2	355µm	2	16.68	17.4
3	500µm	3	193.35	175.67

From the Table, it can be seen that the 500µm had the utmost strength of 175.67 N/mm^2 when a force of 193.35KN was applied to the prepared brake pad material. The compressive strength values recorded in this work have seen an increase of 74.7N/mm^2 different from the values in the literature of Adeyemi et al. (2016) whose value recorded 101.1, whiles the 125µm and 355µm saw deviations[23] as shown clearly on Figure 9

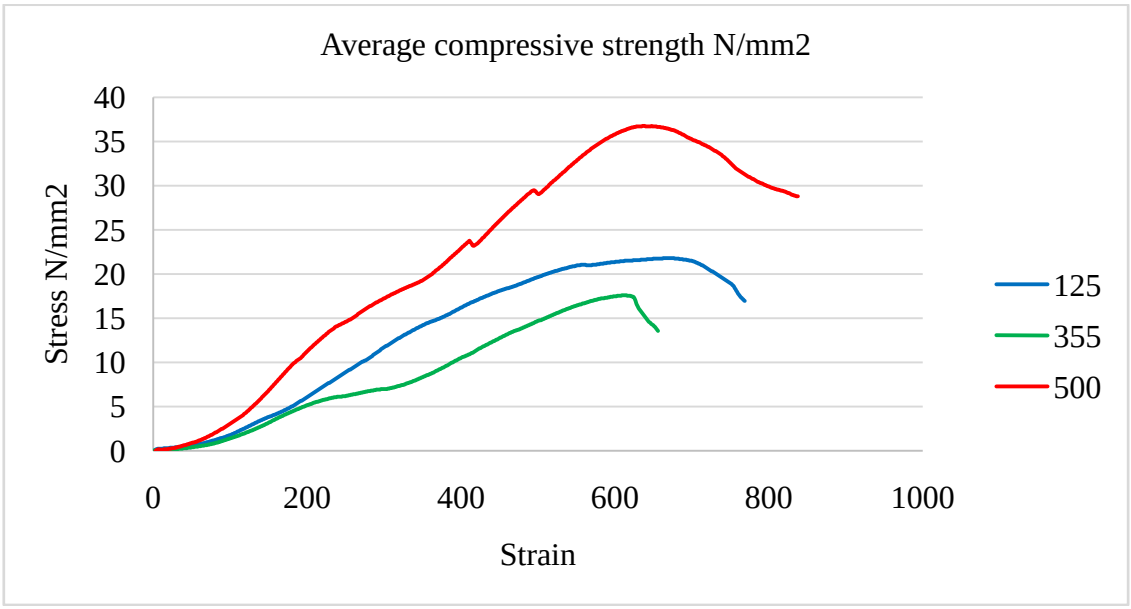

Figure 9Comparing the stress and strain of the material produced

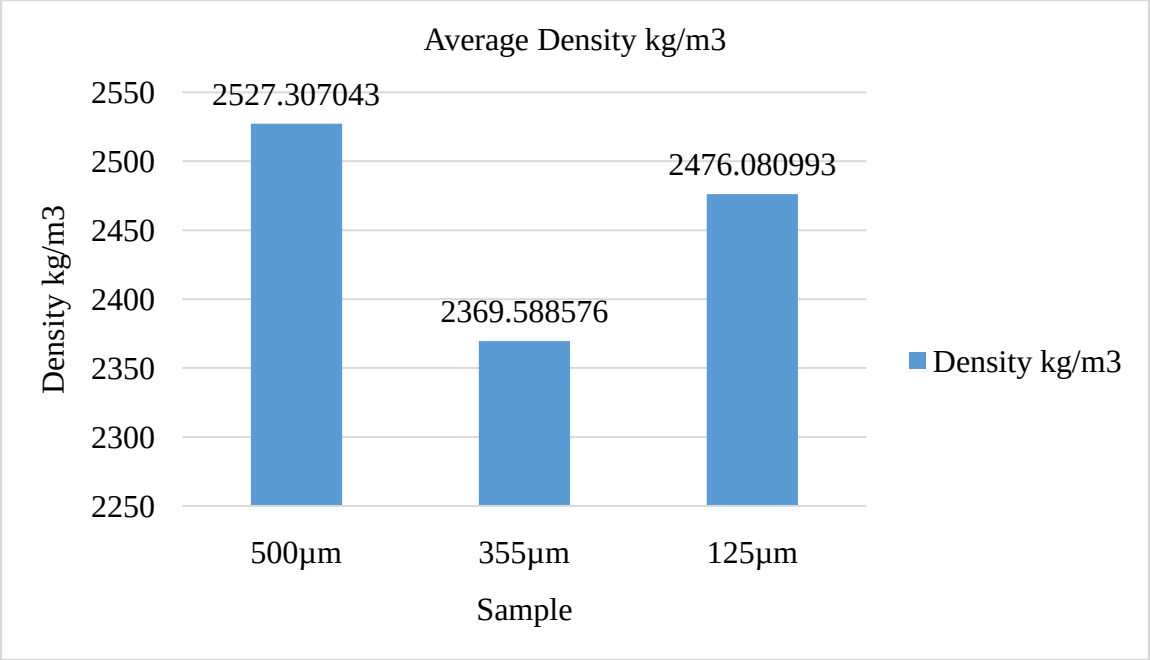

Figure 10: Averages of compressive strength Density kg/m^3

With respect to the averages density (kg/m^3) of the samples under investigation, the samples 500µm, recorded the highest density of 2527.307045 kg/m^3, followed by 125µm 2476.080993 kg/m^3, whiles the 355µm recorded the least density of 2369.588576 kg/m^3. See Figure 10for details. A lower density signifies better quality than the conventional brake pad in accordance with the standard recommended for brake pad application.

Table 5 Water Absorption Test

Particle size(µm)	Weights Gram(g)					Absorption (%)			
	Initial weight, W_0	Gain after 1 hour , ΔW_1	Gain after 2 hours, ΔW_2	Gain after24 hours24, ΔW_3	Gain after 6 days , ΔW_4	Abs. 1	Abs. 2	Abs. 3	Abs. 4
125µm	6.90	0.09	0.11	0.14	0.7	1.3	1.60	2.03	10.14
355µm	6.21	0.09	0.10	0.13	0.53	1.45	1.61	2.09	8.53
500µm	4.79	0.04	0.05	0.07	0.33	0.84	1.04	1.46	6.89

vi. Water Absorption of Fabricated Brake Pads

Table 5 shows how water changed non-uniformly as particle size decreased. The increased interfacial adhesion between the binder and particles reduces the absorption of water owing to decreasing porosity. As compared to the usual model, the findings were quite positive. It has been reported in the literature that 0.9 % of water is absorbed by standard brake pads[24].

Composite samples; 125µm, 355µm, and 500µm absorbed less water as compared to a traditional brake pad, that is asbestos. This means that they are more effective at absorbing water than the standard model. Owing to their higher water absorption, composite pads that are exposed to water during application will likely have a greater resistance to water which makes them very good for use as brake pads. Water absorption rates of each composite deviated from that of the conventional model by 0.40(125µm), 0.55(355µm), and -0.06(500µm) respectively for the first one hour but the rate of absorption retarded as they remained in the water from 2 hours onwards as shown in Figure 11. The 500µm showed a negative variance which means that the composite absorbed less water than the conventional model, demonstrating its superiority over the latter. Thus the composite with a particle size of 500µm exhibited the lowest water absorption rate, outperforming that of the conventional brake pad.

This implied that the 500µm particle size composite pad developed in this study had superior water absorption than the conventional model and would be more resistant to environmental water on an application since the lesser the value of the absorption rate, the healthier the material for the brake pad production substitute.

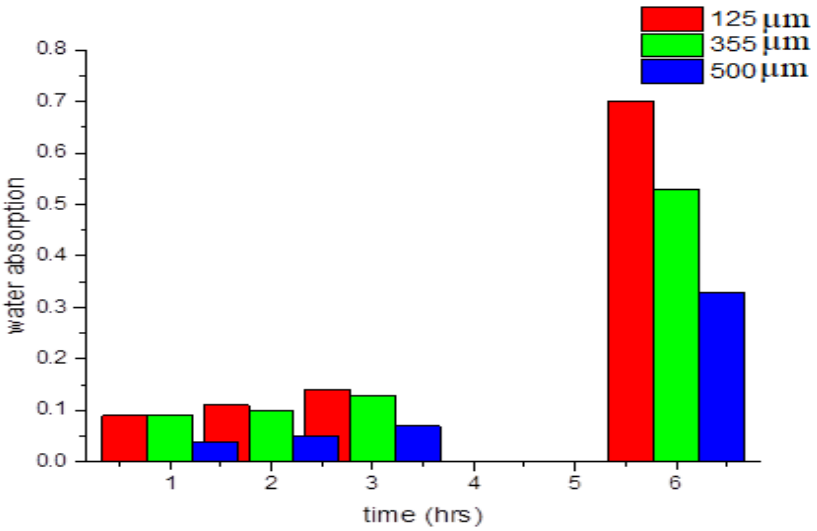

Figure 11Water Absorption.

vii.Oil Absorption of Fabricated Brake Pads

Figure 12 represents how oil absorption changes as particle size decreases due to decreasing porosity. As compared to the usual model, the findings were quite positive. It has been reported that SAE oil absorption (%) is 0.38% in standard brake pads for 24 hours.[24]

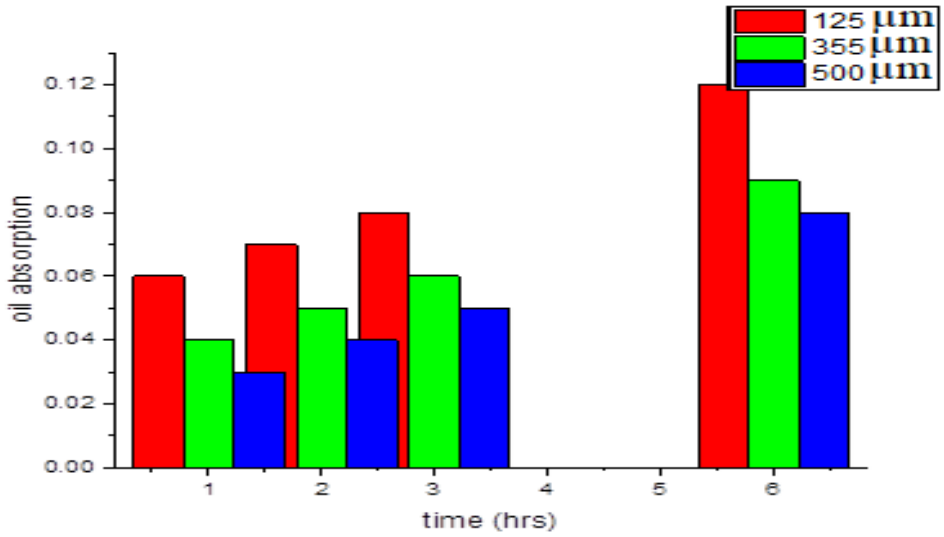

Figure 4.9: Oil Absorption of samples. Source: Test Experiment Results (2021)

Figure 12Oil Absorption of Fabricated Brake Pads

It was also observed that there is a lower rate of oil absorption which could be attributed to the enhanced interfacial bonding between the binder and filler particle resulting in a reduction in porosity. The results were comparable to those of the conventional model with oil absorption rates of 0.3%. The oil absorption rates of each composite deviated 0.71(125um), 0.43(355 µm), and 0.22(500µm) respectively from that of the conventional model for the first one (1) hour but the rate of absorption slowed as they remained in the oil from 2 hours onwards. Composite samples 125µm, 355µm and 500µm absorb less oil than the traditional (asbestos) brake pad. This means that they are more effective at absorbing oil than the standard model is. Due to their superior oil absorption, composite pads that are exposed to oil during application will likely have a greater resistance to oil making it an excellent material for brake pads. The values in this experiment are within the accepted range of values obtained in the works of Bala et al., (2016); Haruna, Abdulrahman, Abolarin&Muriana (2019)[24, 25].

viii. Properties of the Formulated Brake Pad Compared with Commercial Existing Asbestos Brake Pad.

Table 6 displays the properties of the formulated composite samples of 125µm, 355µm and 500µm made of (PKS, RS, RH & RP) brake pad, compared with the commercial existing asbestos-based brake pad used as a control. These values were compared with those quoted in the literature. The Table revealed that the flame resistance, specific gravity (g/cm3), density, water absorption after 24 hours in (%), SAE oil absorption after 24 hours in (%), wear rate (mg/m), hardness values (HRB), abrasion, compressive strength (N/mm^2), tensile strength (MPa) and thermal conductivity compared well for both the newly prepared one and commercial brake pads.

Thermal conductivity of the 125µm, 355µm and 500µm samples were found as 0.689 (W/mK), 0.673 (W/mK) and 0.671(W/mK) respectively at a temperature of 500^oC and that of the asbestos was 0.539 (W/mK). As compared with asbestos all three new samples have proven to be the best. Besides, the formulated brake pad relates well with quoted values for the compressive, wear, and their water and oil absorption and thermal conductivity. Poor comparison with other quoted values may be due to differences in test conditions and environments. This conformed to the study of Dagwa and Ibhadode (2007)[1].

In conclusion, the results suggest that the new formulated samples composed of (PKS, RS, RH& RP) brake pad has mechanical and physical properties which are similar to the existing asbestos-based brake pad. Thus, the composite (PKS, RS, RH & RP) of 500µm may be considered as a potential substitute for asbestos as brake pad/friction lining materials.

Unlike asbestos-based brake pad, the composite brake pad developed work is environmentally friendly since it does not give off any pungent/bad smell after grinding it and also use it as a brake pad compared with the asbestos type. The newly fabricated composite brake pad and the asbestos one were both put in fire to test which one will give off a bad smell. It was also realised that the asbestos produced a pungent smell as compared to the new fabricated composite brake pad. This revealed that there is no or minimal health implication in its usage *vis-à-vis* that imposed by the asbestos type. This conclusion is consistent with information gathered from other researchers [24].

Table 6 Formulated brake pad Compared with the Existing one (Asbestos)

Properties of Materials	Newly formulated (Palm Kernel Shell, Rice Straw, Rice Husk & Rice Panicle)			Asbestos based (Commercial)
	125µm,	350µm	500µm	
Flame Resistance (%)	Charred ash 14%	Charred ash 16.5%	Charred ash 17%	Charred ash 9% [a]
Specific gravity g/cm^3)	1.85	1.85	1.85	1.890
Density	2.47	2.36	2.52	3.25
Coefficient of Friction	-	-	-	0.30–0.40
Water absorption 24 hours in (%)	1.3	1.45	0.84	0.8 - 0.9 [c]
SAE oil absorption 24 hours in (%)	1.01	0.73	0.52	0.30
Wear rate (mg/m)	0.35	0.87	0.60	3.800
Hardness values (HRB)	125	120	115	101.1
Compressive strength (N/mm^2)	25.4	17.4	175.67	101.1
Tensile Strength (Mpa)	15.03	10.067	25.302	7.00
Thermal conductivity (W/mK)	0.689	0.673	0.671	0.539

IV. CONCLUSION

The new developed pad with 500µm particle size gave a superior performance in water and oil absorption which shows that particle size affects their production and operations. Also,the composite sample of palm kernel shell, rice straw, rice husk and rice panicle materials can be effectively utilized as a replacement for asbestos as brake pad materials. In addition, properties like density, water absorption, oil absorption, abrasion resistance, hardness, tensile strength, compressive strength, and thermal conductivities of the fabricated composite brake pads compared well with that of the existing commercial asbestos brake pad. Furthermore, greater resistance to water and oil, and the best in thermal conductivity makes it an excellent material to be used for brake pad.

REFERENCES

[1]. I. Dagwa and A. Ibhadode, "Determination of optimum manufacturing conditions for asbestos-free brake pad using Taguchi method," 2006.

[2]. A. Ibhadode and I. Dagwa, "Development of asbestos-free friction lining material from palm kernel shell," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 30, pp. 166-173, 2008.

[3]. P. Gurunath and J. Bijwe, "Potential exploration of novel green resins as binders for NAO friction composites in severe operating conditions," *Wear*, vol. 267, pp. 789-796, 2009.
[4]. M. Kumar and J. Bijwe, "Role of different metallic fillers in non-asbestos organic (NAO) friction composites for controlling sensitivity of coefficient of friction to load and speed," *Tribology International*, vol. 43, pp. 965-974, 2010.
[5]. M. Kumar and J. Bijwe, "Non-asbestos organic (NAO) friction composites: Role of copper; its shape and amount," *Wear*, vol. 270, pp. 269-280, 2011.
[6]. A. Bledzki and J. Gassan, "Composites reinforced with cellulose based fibres," *Progress in polymer science*, vol. 24, pp. 221-274, 1999.
[7]. V. P. Cyras, S. Iannace, J. M. Kenny, and A. Vázquez, "Relationship between processing and properties of biodegradable composites based on PCL/starch matrix and sisal fibers," *Polymer Composites*, vol. 22, pp. 104-110, 2001.
[8]. B. Naemah, "Application of Palm Waste Product for Raw material in organic brake friction materials," *Department of Mechanical Engineering, UTem, Melaka, Malaysia*, 2011.
[9]. P. Blau, "Compositions, functions, and testing of friction brake materials and their additives; TOPICAL," Oak Ridge National Lab.2001.
[10]. D. Bashar, B. Peter, and M. Joseph, "Effect of material selection and production of a cold–worked composite brake pad," *Journal of Engineering of a Pure and Applied Science*, vol. 2, p. 154, 2012.
[11]. M. Bakry, M. Mousa, and W. Ali, "Friction and wear of friction composites reinforced by natural fibres," *Materialwissenschaft und Werkstofftechnik*, vol. 44, pp. 21-28, 2013.
[12]. M. H. Cho, S. J. Kim, D. Kim, and H. Jang, "Effects of ingredients on tribological characteristics of a brake lining: an experimental case study," *Wear*, vol. 258, pp. 1682-1687, 2005.
[13]. R. Biczó, G. Kalácska, Z. Szakál, and G. Fledrich, "Composite friction materials for brakes and clutches," *Scientific Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology*, vol. 30, p. 21, 2016.
[14]. K. Hendre and B. Bachchhav, "Tribological behaviour of non-asbestos brake pad material," *Materials Today: Proceedings*, vol. 38, pp. 2549-2554, 2021.
[15]. S. Jadhav and S. Sawant, "A review paper: Development of novel friction material for vehicle brake pad application to minimize environmental and health issues," *Materials Today: Proceedings*, vol. 19, pp. 209-212, 2019.
[16]. T. Sheferaw, "Development of Asbestos Free Brake-Pad Using Banana Peel Hybrid Composite," ASTU, 2021.
[17]. J. Abutu, S. A. Lawal, M. Ndaliman, and R. Lafia-Araga, "An overview of brake pad production using non–hazardous reinforcement materials," 2018.
[18]. V. Aigbodion, U. Akadike, S. Hassan, F. Asuke, and J. Agunsoye, "Development of asbestos-free brake pad using bagasse," *Tribology in industry*, vol. 32, p. 12, 2010.
[19]. M. Afolabi, O. Abubakre, S. A. Lawal, and A. Raji, "Experimental investigation of palm kernel shell and cow bone reinforced polymer composites for brake pad production," *International Journal of Chemistry and Materials Research*, vol. 3, pp. 27-40, 2015.
[20]. P. Olele, A. Nkwocha, I. Ekeke, M. Ileagu, and E. Okeke, "Assessment of palm kernel shell as friction material for brake pad production," *International Journal of Engineering and Management Research (IJEMR)*, vol. 6, pp. 281-284, 2016.
[21]. D. Yawas, S. Aku, and S. Amaren, "Morphology and properties of periwinkle shell asbestos-free brake pad," *Journal of King Saud University-Engineering Sciences*, vol. 28, pp. 103-109, 2016.
[22]. C. Navin, S. Hashmi, S. Lomash, and A. Naik, "Development of asbestos free brake pad," *Journal MC*, vol. 85, pp. 13-16, 2004.
[23]. A. I. Olabisi, A. N. Adam, and O. M. Okechukwu, "Development and assessment of composite brake pad using pulverized cocoa beans shells filler," *International Journal of Materials Science and Applications*, vol. 5, pp. 66-78, 2016.
[24]. K. C. Bala, M. Okoli, and M. S. Abolarin, "Development of automobile brake lining using pulverized cow hooves," 2016.
[25]. V. Haruna, A. Abdulrahman, M. Abolarin, and R. Muriana, "Evaluation of Sheanut Shell-Reinforced Automotive Brake Pad," *Arid Zone Journal of Engineering, Technology and Environment*, vol. 15, pp. 510-518, 2019.