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Research Paper

Development of Avehicle Brake Pad Using Composites of PalmKernel Fiber and Groundnut Shells As Filler Material

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Abstract
This study investigated the development and assessment brake pad using palm kernel fiber (PKF) and groundnut shell as filter.Palmkernelfiber(PKF)ofdifferentparticlesizeswerecombinedwithgroundnut shellused asfiller to produce brake pads following standardprocedure.Theperformanceoftheproducedbrakepadswasevaluated,andcomparedwithc ommercial(asbestosbased)brakepad.Natural waste has been used to produce fillers and fibers, including palm kernelfiber and fiber, groundnut shell, maize husk and rice straw. This study seeks to explore research using combinationsof fillers and fibers at different ratios with a view to studying their effects onbrake padproperties using various mixturesfor the production. Composite materials from fiber and fillers have been seen to improve compositemechanical properties, reduce costs and increase impact strength. The choice of fiber,filler,binder,particlesizeandcompositionplayimportantresponsibilityinthecomposite of the brake pad performance. Itwasobservedthatpalm kernel fiberparticlesize and groundnut shell as fillerhaveasignificantinfluenceontheperformanceofpalm kernel fiberbasedbrake pads.

In order to obtain better physical properties,palm kernel fiber and groundnut fiber brake padswere studied and the compositionpercentagewasoptimized.

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I. Introduction

Thebrakingsystemisanindispensablecomponent of an automobile, and is composed of manypartsincludingbrakepads,mastercylinder,wheelcylinders, and a hydraulic control system(Maleque*et al.*,2012). The brake pad is an important part of the brakesystem and consists ofsteel braking plates with frictionmaterials bound to the surface facing the brake disc. Thebrakepadgenerallyconsistsofasbestosfibresembeddedin polymeric matrix, along withseveral other ingredients(Olele,Nkwocha, Ekeke,Ileagu&Okeke, 2016).The use of asbestos inbrake padshas become a source of concern due to its carcinogenicnature and problem ofdisposal, consequently, it is beingphased out. The current trend in the automotive industryisthedevelopmentanduseofasbestosfreebrakepads. Brake pads are components of disc brakesused in automobiles. They are steelbackingplateswithfrictionmaterialsboundtothesurfacefacingthebrakedisc.Brakepadsareusedin the braking systems to control the speed of the automobile (Nagesh, 2014) by converting the kineticenergyoftheautomobiletothermalenergybyfrictionanddissipatingtheheatproducedtothes urroundings.
In the recent time the production of composite materials has grown significantly worldwide,which means many industries and technology sectorsare using polymercomposite materialsto successfully replace traditional composite materials **(**Nagesh, 2014). The investigation of new materials,especially agricultural waste as a filler material,is providing new and low-cost materials

fordevelopmentofbrakepadswhicharecommerciallyviableandenvironmentallyacceptableand which have all the required properties. Brake pads are used to control the speed ofavehicleviathebrakingsystem(Idris, 2015).Frictionmaterialsinbrakingapplicationsystemsareconsidered as the most important sections in a vehicle performance. The brake padmaterialmust beable tosustainahigher and uniformcoefficient offrictionalongsidethebrakedisc.

Industrial and agricultural wastes are currently receivingattentionasalterativerawmaterialstoasbestosinthemanufacture of brake pads (Leman *et al.*,2008).The use ofsuitablewastematerialscanprovideaddedvaluesandreduce environmental problems and costs associated withdisposal.

Brake pads use as automobile brakes are of two types: drum brakes and disc brakes.Thedrumbrakeislocatedinsideadrumsothatonapplicationofthebrakes,thebrakeliningis forced outward and pressed against the drum, while disc brakes operate in similarwayexcept that theyareexposed to theenvironment (Deepika, 2013). Asbestos had a fewengineering properties that madeit very suitable for inclusion in brake linings, and was themostpreferred filler material up till 1990 .The use of asbestos isbeen avoided due to itscarcinogenic nature. Therefore, anew asbestos free friction material and brake pads hasbeendeveloped.

The use of thermosetting resins to produce moulded brake lining instead of knittedlinings were made by combining fiber with resin and polymerizingresin under elevatedpressure and temperature. The fabrication and performance evaluation of a composite materialfor wear resistance application (Bashar, 2012) made use of an agro-waste (palm kernel fiber s -PKF) asfiller material with sulphur, cashew nut shell liquid, calcium carbonate, brass chips,

quartz,iron ore, ceramics, and carbon black. Similarly, coconut shells based brake pad was producedwith a formulation of grinded coconut shells (filler), epoxy resin (binder –matrix), iron chips(reinforcement), methylethylketone peroxide (catalyst), cobalt nephthanate (accelerator),ironand silica(abrasives), and brass(friction modifier) (Yawas, 2016).

The major component in the brake pad is the liningmaterials,whicharecategorizedasmetallic,semi-metallic,organic and carbon-based, depending on the composition ofthe constituent elements. Typical formulations consist of morethan10ingredients,andmorethan300materialsareindifferent brands (Edokpia, 2014). These ingredients are classified into fourbroadgroups:binders,reinforcingfibresorstructuralmaterials, fillers, and frictional additives/modifiers, based onthe major function they perform apart from controlling frictionandwearperformance.Thebinderholdstheingredientstogether, to maintain structural integrity of the brake liningunder varying mechanical and thermal stresses. The structuralmaterialsprovidethestructuralreinforcementtothecomposite matrix; fillers make up the free volume of the brakelining and friction modifiers stabilize the coefficient of frictionand wear rates. These components perform synergistically incontrollingfrictionandwear performanceofthebrakepad.

Palm Kernel fiber (PKF) is recovered as by-product in palm oilproduction. Large quantitiesof PKF are generatedannuallyandonlysomefractionsareusedforfuelandotherapplicationssuchaspalliativeforun-tarredroadandinproducingactivatedcarbon.

TheunusedPKFaredumpedaroundtheprocessingmill,constituting environmental andeconomic liability for the mill.Although,PKFmustbegroundintofineparticlestobesuitable for

inclusion in brake lining, available information intheliteratureareontheungroundedshellparticles.Coefficients of friction of PKF on metal surfaces were in therangeof0.37-0.52 (Lagel, 2016). In contrast, frictioncoefficient intherangeof0.30-0.70isnormallydesirablewhenusingbrakelining material (Bala, 2016). Ithas been found that incorporation ofPKFintheproductionofstructurallightweightconcretesincreasedthemechanicalstrength.Thus,PKFappearedsuitableforuseasbasematerialinfrictioncomposites,becausethey are subjectedtohardandvariablebrakingforces.

Mostcommercialautomotivebrakepadfrictionmaterialscontain multiple components (Kumar, 2011) and divided into four groups: fibers, fillers, binders, andfriction modifiers. Fibers provide mechanical strength in the composition. Friction modifiersinfluences the brake pads frictional properties and contain a mixture of abrasive as well aslubricants.

Fillermaterialsaremainlyusedforbrakepadproductiontoimprovebrakemanufacturability and reduce production costs and as functional modifiers. A small amount offiller is usually added to improve or optimize performance of bake pad material. Harderparticles, for instance Al_2O_3 is added to increase the COF (μ) which is the force of frictioncausedbythescrapingthesurfaceof the materialand the disc(Bijwe, 1997). Bindersholdallthecomponentstogetherinthebrakepadapplication,therebyreducingthe component shear rate (Blau, 2001). Binder contribute to the brake pad friction and wear rate(Rohatgi, 2012)The binder offers mechanical unity to the friction materials by firmlycombining the otherthree components in order to improve thecomposites properties.Inthepast fifty years,phenolic resins (unmodified or modified) have been employed as binders inthe preparation ofthe friction materials due to their good thermal and mechanical properties

in addition to lowercosts(Chan., 2004)**Methodology TheRawMaterialsPreparation**

Existing agricultural waste cannot be used directly in the formulation of the final brake pad.Therefore, some treatments such as mechanical and chemical treatments are required earlier inthe brake pads composition. The following are some of the natural fiber treatment methodsproposedaccordingto theliterature.

PalmKernelFiber

5kgofpalmkernelfiberwasobtainedfrom apalmoilprocessingmill. The fibers were collected using rubber bucket and thoroughly washed with water and soap to remove residual oil and extraneous materials.Thereafter, the fibers were sun dried for three (3) days. The driedfiberswerepounded using mortar and pestle untilthedesiredparticlesizewasobtained.Thefine particles of thefiberswereclassifiedintodifferentparticle sizes.

PalmKernelfiber **asBrakeLiningIngredient**

Palm Kernel fiber (PKF) is recovered as by-product in palm oilproduction. Large quantitiesof PKS are generatedannuallyandonlysomefractionsareusedforfuelandotherapplicationssuchaspalliativeforun-tarredroadandinproducingactivatedcarbon. TheunusedPKFaredumpedaroundtheprocessingmill,constituting environmental and economic liability for the mill.Although,PKFmustbegroundintofineparticlestobesuitable forinclusion in brake lining, available informationintheliteratureareontheungroundedshellparticles.

Coefficients of friction of PKF on metal surfaces were in therangeof0.37-0.52 **(**Deepika,2013)In contrast, frictioncoefficient intherangeof0.30-0.70isnormallydesirablewhenusingbrakelining material. It has been found **(**Nagesh , 201) thatincorporation ofPKSintheproductionofstructurallightweightconcretesincreasedthemechanicalstrength.Thus, PKFappearedsuitableforuseasbasematerialinfrictioncomposites,becausethey are subjectedtohardandvariablebrakingforces. Reported that PKF did not change significantly in physicalstructureandweight,forappreciabletimeduration,whenexposed to organic solvent. It isalso important that the frictionmaterials experience very little or no changes on contactingvaryingenvironmentalconditions:wetordryweather,orhydraulicfluidspillingover. Theseobservationstherefore,stimulatedtheinterestinconsidering PKF for use as friction material in brake lining.Hence, the aim of this research is to develop a new asbestosfreebrakepadfromPalmkernelfiber,whichisreadilyavailableandnontoxic.

Brakepadformulation

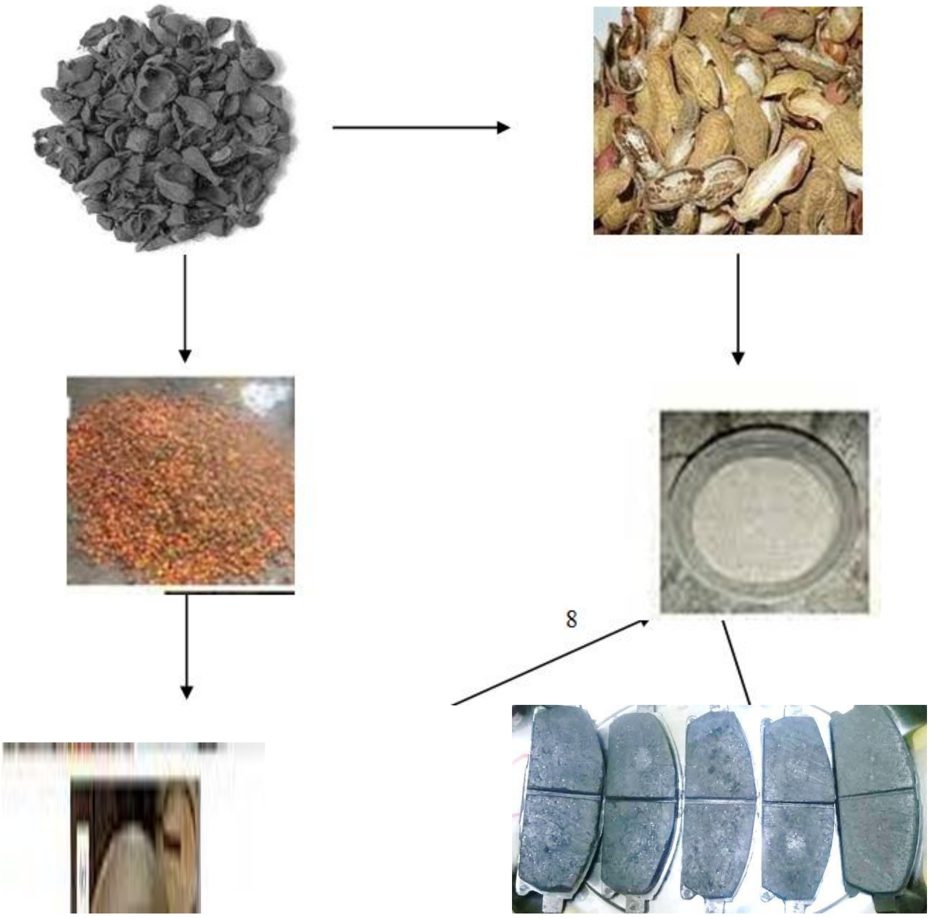
Production of the brake pad consists of a series of unit operations including mixing,cold and hot pressing, cooling, post-curing and finishing (Fono-Tamo., 2013). The samples were producedusing compression moulding machine. EachofthethreePKSgritsizeswasusedtoformulate brake pad by mixingwith brass chips, steelfibre,graphite,latexrubber,calciumcarbonate,resinbinder, carbonblackpowder and groundnut shell was used as the filler.Aftermixing, the mixture was compacted in a mould to assumethe required shape. A compressive force of 50 KN wasappliedthroughapunch,byahydraulicspress,foraperiod of 20 min.The brake pad produced was curedby heating in a wooden oven at a temperature of 80^0C for45 minutes, and allowed

to cool. Afterward the brake pad sampleswere subjected toperformancetests.Theproducedbrakepadsamplesandacommercialbrakepad(producedfromas bestos)weretested for wear/application, disc temperature rise, and discstopping time (brakingefficiency) at different speeds.

GroundnutShell

Groundnut shell was collected and washed with water to remove sand and put in a sodiumhydroxide(NaOH)solutionhavingacompositionratioof1:20withwatertoremoveimpurit iessuchas lignin and pectin. After this, the groundnut shell was washed in distilled water to reduce the sodiumhydroxideinthe shelland sundried tillallthe moisture content inthe shelldried up. Thedried shell was ground in a grinding machine to reduce its size, after which the shell wassieved into a 200 and 400 um sieve size. The shell particles were then mixed in a two-rollmixingmill togetherwithotherconstituentsto filler the brake pad with palm kernel shell.

Fig. 1: Diagrams of materials used for the formulation of PKF + GS brake pad



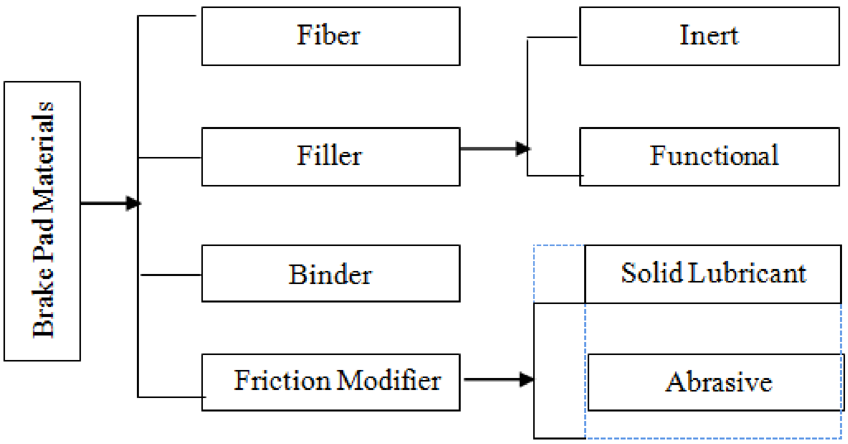


Fig. 2: Diagram of materials combination for the production of brake pad

Microstructure analysis

The microstructure analysis of the samples was carried out by grinding the samples

using 200, 300 and 500 grit papers respectively. Dry polishing was then carried out on

thesesamplesandtheinternalstructureswereviewedunderthecomputerizedMetallurgicalmicros cope.

Brinellhardnesstest

The resistance of the composites to indentation was carried outusing the Brinellhardnesstesting equipment of BS240, a Tensometer (M500-25kN, hardened steel ball ofdiameter *D* toindent the test specimen. Based on ASTM specification, a steel ball of D = 10mm diametersteel ball was used, and the load applied P was kept stable at 3000 kgf. Thediameter of theindentation, d, was measured along two perpendicular directions, using anopticalmicrometerscrewgauge.ThemeanvaluewasusedtoobtaintheBrinellHardness Number(BHN)usingequationbelow.

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

WhereP=appliedload,D=diameterof hardenedsteel ball, d =diameter ofindentation.

Compressivestrengthtest

The compressive strength test was done using the Tensometric Machine. The samplesof diameter 29.40mm were subjected to compressive force, loaded continuously until failureoccurred.Theloadat which failureoccurredwas then recorded.

Ashcontent test

About 1.30 g ± 0.2 g of the samples were weighed in a cooled crucible which was ovendriedbyheatinginafurnaceto600°Cfor30 minutes.Thenthesampleswerecharredbyheatingin a hot plateafter which the charred sampleswereplaced ina furnace and heatedat600°Cfor minutes. Then cooled in a desiccator andweighed. This process of heating, cooling andreweighing were repeated until a constant

weight was obtained the ash content was calculatedusingequation below.

$$Ashcontent = \frac{W_2 - W_0}{W_1 - W_0} x\ 100 \quad (2)$$

WhereW_0=weightofemptycrucible,W_1=weightofcrucibleandsample,W_2=weightofcruciblean dresidueaftercooling.

Densitytest

The density of the samples was determined by weighing the samples on a digitalweighing machine and their volumes determined by liquid displacement method. Thedensitywasdetermined usingequation below.

$$Density,\ \rho = \frac{M}{V}$$

whereM=massoftestpiece(g),V=volumeofthetestpiece(cm^3)byliquiddisplacementmethod.

Wearratetest

Thewearrateforthesamplesweremeasuredusingpinondiscmachinebyslidingit over a cast ironsurface at a load of 10N, sliding speed of 125rev/min and sliding distance of2000m.Theinitialweightofthesampleswasmeasuredusingasinglepanelectronicweighing machine with an accuracy of 0.02g.During the test, the pin was pressed againstthecounterpart rotating cast iron disc of Rockwell hardness 65HRC of counter surfaceroughnessof 0.3μm by applying the load. A friction detecting arm connected to a straingauge held andloaded the pin samples vertically into the rotating hardened cast iron disc.After runningthrough a fixed sliding distance, the samples were removed, cleaned withacetone, dried, andweighed to determine the weight loss due to wear. The difference inweight measured beforeandafterthetestsgive thewear ofthe samplesand thewear rateiscalculated byequation

Wear rate $= \frac{\Delta W}{S}$

WhereΔW=weightdifferenceofthesamplebeforeandafterthetest(mg),S=isthetotalslidingdistan ce(m).

Waterabsorptiontest

The samples were weighed on a digital weighing machine and soaked in water at roomtemperature for 24 hours. The samples were then removed, cleaned and weighed. The waterabsorptionrate was calculated thus:

Waterabsorption $= \frac{M2M1}{M_1} x\ 100\ \%$

whereM_1=mass ofthe sample(g),M_2=mass of the sampleafterabsorbingwater(g).

FlameResistanceTest

Weigh about 1.30g ± 0.2g of the samples in a cooled cruciblepreviously oven dried byheating in a furnace at 600 ^{0}C for 30 minutes. Then the samples were charred by heating in ahot platethereafter,the charred samples were taken into the furnaceandheatedat600 ^{0}Cfor30minutes.Thencooledinadessicator andweigh.Thiscycleofheating,coolingandweighingwererepeateduntilaconstant weightwasobtained.

Calculation:

%ash=$\frac{W2-W0}{W_1-W_0} x\ 100$

WhereW_0=weight of empty crucibleW_1=weightof cruciblesampleW_2=weight ofcrucibleandresidue i.e.aftercooling.

Density(ρ)= $\frac{M}{V} x 10$

Where M is the mass of test piece (g) and V is the measuringvolumeoftestpiece(cm^3)byliquiddisplacementmethod

SpecificGravityTest Subsequentlytheirspecificgravitiesweredeterminedbydividingtheunitweightofthesampleinai rbytheunitweight of the sample in air and water. The formula is show below.

Specificgravity(sg)=$\frac{W_a}{W_a - W_b}$

WhereWaistheweightofsampleinair(g);andWbistheweightofsampleinwater(g).

Result

Table 1: Brake pad Formation from the combination of PKF and GS

S/N	MATERIAL	FUNCTION	QUANTITY (g)	PROPORTION
1	Palm Kernel fiber	Base material	300	30.5
2	Groundnut Shell	Filler	80	10.2
3	Steel Fibre	Reinforcement	60	7.5
4	Calcium Carbonate	Hardening Agent	330	31.5
5	Resin Binder	Binding Agent	200	25.3
6	Graphite	Lubricant	32	4.5
7	Brass Chips	Abrasive	50.5	6.2

Table 2: Brake pad application with speed

WEAR RATE (mg)	DISC TEMPEATURE (^{0}C)	STOPING TIME (sec)	SPEED (Km/h)
10	2	2	10
15	4	2.5	20
20	6	5.0	30
25	8	6.5	40
30	10	7.0	50
35	12	12	60
40	14	10	70
45	16	12	80
50	18	14	90

55	20	16	100

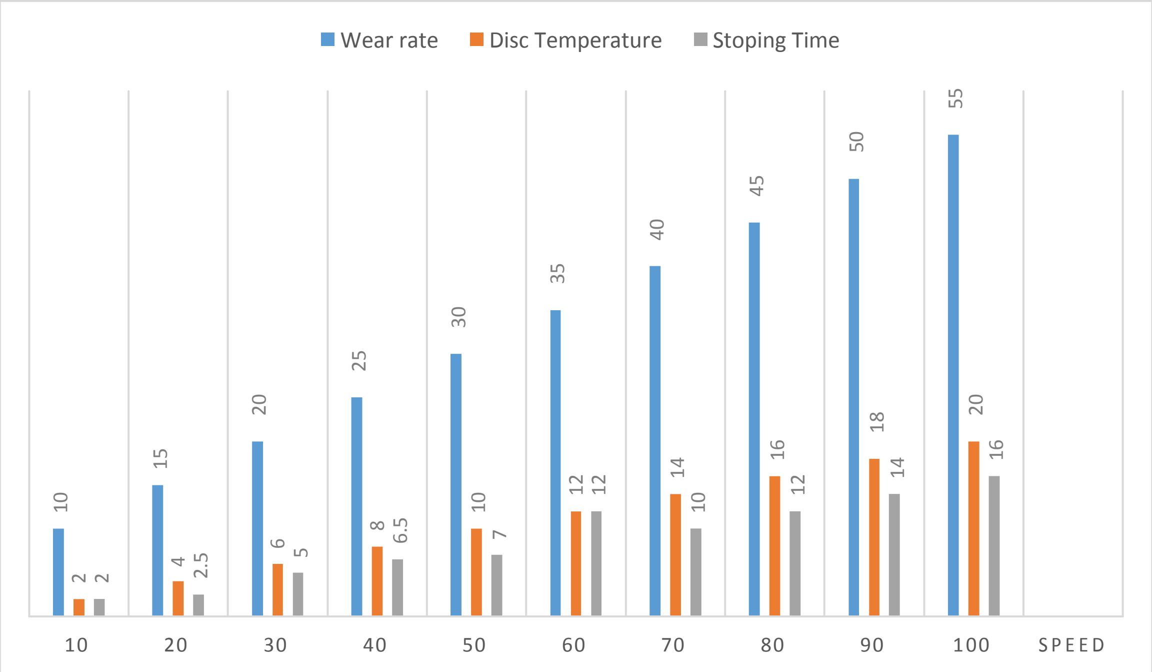


Fig. 3: Graph of Brake pad application Vs speed

Discussion

Effect of epoxy resin binder and palm kernel fiber on brake pad performanceThepresenceofPKFandlowbindercontent(epoxyresin)inthemixtureincreasedth ewearratesof the pad. Thewaterandoilabsorption rate forGS-basedbrakepadwasclosedtotheconventional brakepad witha%deviationof0.001 and0.022.GS-based brake padsareenvironmentalfriendlyandcost effective. Whenthewt%ofPKFincreased in the composition,the compressive strength of the sample also increased. Thereason for the increase may beattributed to the percentage and ratio of the composite in thepad. The pad' hardness valuesincreased when the wt% of PKFsamplesincreased in thecomposition. Assessment of thewear behaviour of the brakepadsampleswhensubjectedtodifferentspeedsispresented in Fig.
1. All the samples including the asbestosbased exhibited marginal increase in wear rate

with speedup to 80km/h. The asbestos brake pad had the lowest wearratefollowedbythePKFsample.ThePKFbasedsamplesshoweddifferentresistances towear. The presence of PKSparticlesprovidesahigherthermalstability,increasedabrasionandslidingwearresistanceanddelaysthetransition from mild to severewear (Olele, 2016).
However,whenthebrakepadsamplesweretestedatspeedsabove80km/h,theypresentedsharpin creases in wear rates. It is well known that wear processinvolves fracture, tribochemicaleffects and plastic flow.Transitions between regions dominated by each of thesecommonlygiverisetochangesinwearrate.Thisbehaviourbeyond70km/hspeedcouldbeduetosubsurface deformation of the brake pad as a result of hightemperature.
The PKF brake pads generally did not show anydifference in behavior in terms of disctemperature risewith speed. They maintained the same Temperaturechange. However, at speeds below 40 km/h the asbestosbrake pad had a lower disc temperature rise while the PKFsamples maintained lower values of temperature change.The Asbestos sample was higher beyond 30 km/h speed.Thus, the PKF brake pads are a better choice ahead of theasbestos in applications where disc temperature rise is ofgreatconcern.
Atspeedbelow60km/hallthePKFpadswiththe exception of sample A, had lower stoppage time (thatis,betterbrakingefficiency)whencomparedwiththeasbestos pad beyond 60km/h and up to 90 km/h.

Conclusion

Although asbestos brake pads have good tribological and mechanical properties, they arecarcinogenicinnature.Fromthestudies,betterphysicalpropertieswereobtainedwithpalm

kernel fiber brake pads as the percentage of composition was optimized. In palmkernelfiber,bothfillermaterialsandbinderimprovedthemechanical,tribological,andphysic alpropertiesofthebrakepadsampledeveloped.Thesestudiesalsoindicatethatchemical and physical treatments also used to subdue poor wettability and enable highermoistureabsorption.The wear rate improved with the addition of filler material in the brake padsamplepreparation. Wear rate of the developed composite also affected by the speed significantly.The smaller quantity of the filler, binder and fiber material had effect on the composite wearrateandgavebetter.The performance of the composite material such as mechanical and physical propertieshave been reported to be affected by the filler materials in the composition. In addition,various studies so far have found that as the composite filler material content decreases thepropertiesforexampleshardness,compressivestrength,thermalconductivityandtensilestreng th,ofthecompositeproducedincrease,whilethedensity,oilandwaterabsorptionofthedevelopedbr akepadsampleincreaseswhen thefillercontent ofthecompositeincreases.

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