ISSN (e): 2250 – 3005 || Volume, 07 || Issue, 01|| January – 2017 ||
International Journal of Computational Engineering Research (IJCER)

Optimization of Mechanical Properties of PalmFruit FiberAutomobileBrake Pad

[1]ashutosh Giri, [2]soumya Suravi Jena,
Gandhi Institute of Excellent Technocrats, Bhubaneswar, India
Adarsha College of Engineering, Angul, Odisha, India

ABSTRACT

ThisworkinvestigatestheoptimizationofmechanicalpropertiesofPalmFruitfiberautomobilebrakepad. TheuseofnaturalfibersandAgro-basedwasteshasbeeneminentin the production of brake pads. For effective pad production,manyfactorsshouldbeconsideredindevelopingbrakematerialsso as to fulfill requirement such as, a stable friction coefficientand a lower wear rate at various operating speeds, pressures,temperatures, and environmental conditions in the automotivesectors [17]; [1]. This study employs Split-optimal custom designof the Design Expert (11.0) for sample formulation. Hardness,Compressive strength, wear rate and coefficient of friction weredetermined.TheResultoftheResponsesdeterminestheoptimumPFF content for the pad. This research will enlighten industriesandlocalproducerswhointendstoutilizePalmFruitfiberforthedevelopmentoftheAutomobilebrakepads.

Keywords -PalmFruit Fiber,Optimization,Brakepad,Brake,

I. INTRODUCTION

Thebrakingsystemiscomposedofmanyparts,includingbrakepads on each wheel, a master cylinder, wheel cylinders, and ahydraulic control system. The core of the braking device isfrictionmaterial,whichisexpectedtocontinueitsfunctioningreliablyandefficientlyforaprolongedtimeinadverseoperatingconditions[12].Differenttypesofbrakepadmaterialsareusedindifferentbrakingsystems.Theyareoftencategorized into four classes of ingredients: binders, fillers,friction modifiers, and reinforcements.Brake pads generallyconsistofasbestosfibersembeddedinpolymericmatrixalongwith several other ingredients. The use of asbestos fiber asreinforcementinthefrictionmaterialsstartedinthebeginningofthe20thcentury.Sinceasbestosfibermetmajorrequirementsofbrakefrictionmaterial,asbestosbasedfrictioncompositesbecamepopularallovertheworld.Lateron,medicalreportsregardingasbestosexposuretohumansprovedthat asbestos is carcinogenic and can cause deadly diseases.This resulted in ban of asbestos based friction materials in thedeveloped countries, and many developing countries are nowon the same path. Sequel to that, several research works havebeen carried out in the area of development of asbestos-freebrakepads.Currenttrendintheresearchfieldistheutilizationofindustrialoragriculturalwastesasasourceofrawmaterialsforcompositedevelopment[13].Thisprovidesmoreeconomical benefit and also environmental preservation byutilizingwastes.

Friction materials used in the brake lining of automobiles, arerequired to satisfy a number of performance demands. Theymustprovideadependable,consistentleveloffriction,
excellent resistance to wear, adequate heat dissipation, andstructural integrity, low cost and if possible, light weight. Nosinglematerialcanmeetalloftheseoften-conflictingperformancecriteria. Thechoice of materials is crucial indetermining the performance attained, yet to date, brakingmaterial compositions have been developed largely on the basisofempiricalobservations.[7].

Thedesignofexperiment(DOE)methodofapproach,processesvariablesthatarefirst'screened'todeterminewhichare important to the outcome (excipients type, percentage,disintegration time (DT) etc. Optimization connotes when thebest settings for the important variables are determined. Itinvolves the use of Response Surface Methodology (RSM) toinvestigateanappropriateapproximationrelationshipbetweeninput and output variables and identify the optimal operatingconditions for a system under study or a region of the factorfieldthatsatisfiestheoperatingrequirements.

II. LITERATUREREVIEW

A. Brake Pad

Brake pads are steel backing plates with friction materialbondedtothesurfacethatfacesthediskbrakerotor.Itisoneofthe important parts of an automobile braking system due to itsvital role [5]; [10]; [3].Friction between brake pad and diskconverts the kinetic energy of automobile to thermal energy [3].Twobrakepadsarecontainedinthecaliper,withtheirfrictionsurfacesfacingtherotor.Brakepadswereoriginallymade withorganicingredients,suchasasbestosandcarbon,heldtogetherby a strong resin. The first frictional brake material composedof cotton material impregnated with bitumensolution wasinvented by Herbert Frood in 1879 [15]; [4]. This led to theestablishmentofFerodoCompanythatstillsuppliesbrakepadmaterialsuptillnow[4].

Indiscbrakeapplications,thereareusuallytwobrakepadsperdiscrotor,heldinplaceandactuatedbyacaliperaffixedtoa wheel hub or suspension upright. Although almost all road-going vehicles have only two brake pads per caliper, racingcalipersutilizeuptosixpads,withvaryingfrictionalpropertiesinastaggeredpatternforoptimumperformance.Dependingonthe properties of the material, disc wear rates may vary. Thebrake pads must usually be replaced regularly (depending onpadmaterial),andmostareequippedwithamethodofalertingthedriverwhenthisneedsto takeplace.

Materials that make upthe brake padinclude; frictionmodifiers,powderedmetal,binder,fillersandcuringagents.

Frictionmodifierssuchasgraphiteandcashewnutshellsalterthe friction coefficient. Powdered metals such as lead, zinc,brass and Al increase a material resistant to heat fade. Bindersarethegluesthatholdthefrictionmaterialstogether.Phenolicresin is the most common binder in use. Fillers are added tofriction materials in small quantities to accomplish specificpurposessuchasrubberchipstoreducebrakenoise.Thebrakepad material is bonded to a stamped steel backing plate withhigh temperature adhesive to whichheat and pressure areapplied to cure the assembly. A slit is provided on the face ofthepadtoindicatetheallowablelimitofpadwearandprovideapathforbrakedustandgastoescape.Ametalplateorinsomeapplicationsmultipleplatescalledanti-squeal.Variousspringsandclipsareusedtoreducerattleaswellasreducebrakenoise.Shimsandplatesshouldbeinspected forwearandrustandcanbe reused when replacing pads. Fresh approved grease shouldbeappliedtotheshimspriortoinstallation[9].

B. Related Reviewson BrakePad

[2], developed asbestos-free automotive brake pad usingperiwinkle shell particles as frictional filler material. Five setsofbrakepadswithdifferentsievesize(710–125μm)ofperiwinkleshellparticleswith35%resinwereproducedusingcompressivemolding.Thephysical,mechanicalandtribological properties of the periwinkle shell particle-basedbrakepadswereevaluatedandcomparedwiththevaluesfortheasbestos-basedbrakepads.Theirresultsshowedthatcompressive strength, hardness and density of the developedbrake pad samples increased with decreasing the particle sizeof periwinkle shell from 710 to 125 μm, while the oil soak,watersoakandwearratedecreasedwithdecreasingtheparticlesize of periwinkle shell. The results obtained at 125 μm ofperiwinkleshell particles compared favorably with that ofcommercial brake pad. The results of the research indicated thatperiwinkleshellparticlescanbeeffectivelyusedasareplacementforasbestosinbrakepadmanufacture.[16],performed a tribological study to improve the performancecharacteristicsofthefrictionproduct(brakepad)byusingsteelwool, a metallic material which has an excellent structuralreinforcement property and high thermal stability which areindeed required to improve the performance of the brake pad.Underthestudy,fivefrictionalcompositesweredevelopedandoptimizedusingthesameingredientsinanappropriate proportion except steel wool (0%, 4%, 8%, 12%, and 16%)which is compensated by synthetic barite, and the synthesizedcompositions are designated as Na01 to Na05. The developedpads are tested for tribological behavior under conventionalenvironmentinastandardpinondisctribometer.Itwasobserved that increase in steel wool concentration resulted inhighcoefficientoffrictionandlowwearrateofpadasresultedin Na05 composition. SEM analysis of the wear surface hasproved to be useful in understanding the wear behavior of thecomposites.[6]developedasbestosfreefrictionliningmaterialfrompalmkernelshell.Inthestudythemechanicalandphysicalpropertiesaswellasthestaticanddynamicperformance compared well with commercial asbestos-basedlining material. [11] studied the friction and wear of frictionmaterials containing two different phenolic resins reinforcedwitharamidpulp,investigatedthefrictionandwearcharacteristics of automotive materials containing two differentphenolic resins (a straight resin and a modified novalac resin)usingapad-on-disc typefrictiontester.

[8]workedonfriction layer formation in a polymer composite material for brakeapplications. Their work concentrated on the characterizationof friction layer formation and correlation of friction layerpropertiestotheperformanceofarecentlydevelopedfamilyofpolymer matrix composites. They demonstrated that characterofthefrictionlayerdeterminesthefrictionperformanceoftheinvestigatedcompositematerial.Structureandchemicalcomposition of the friction layer generated on the frictionsurface significantly differs from the bulk. Mechano-chemicalinteraction occurring in the friction process is compared to a“non-friction”situationwherean“equivalent”apparenttemperatureandcompressiveloading,respectivelywereapplied to the same material. No simple relationship existsbetween composition of the friction layer and bulk materialformulation. Phase stability and kinetics of interactions for“friction”and“equivalentnon-friction”loadingconditionsdiffer significantly.[14], worked on the development of fly-ash based automotive brake linings. They developed frictioncompositeusingflyashobtainedfromaspecificpowerplantinIllinois. Additives such as phenolic resin, aramid pulp, glassfiber, potassium titanate, graphite aluminum fiber and copperpowder were used in the composite development phase inaddition to fly ash. The developed brake lining compositesexhibitedconsistentcoefficientoffrictionintherangeof0.35–0.4andwearrateslowerthan12wt.%.

III. METHODOLOGY

A. Material

The materials used during the course of this work are:Epoxy resin, palm kernel fiber (PFF), Aluminum oxides, IronOxide,Silica,Graphite,Metalchips(Ironfilings).

Table1:thecategoriesofthebrakepadmaterial.

S/N	Brakepad material	Materialchoice
1	BinderMatrix	EpoxyResin
2	Reinforcement	Aluminumoxideand iron filings
3	Filler	PalmFruitFiber
4	Abrasive	IronOxidesand Silica
5	Frictionmodifiers	Graphite

B. PalmFruitFiberDesignFormulation

Todevelopanoptimalmixforthesample,asplit-plotoptimal(custom) design which is a specialized form of the surfaceresponse method (RSM) was employed. three product attributesare measured as responses from the designed experiment andtheyare

- Response1:TheHardness(BHN)
- Response2:CompressiveStrength(MPa)
- Response3:WearRate(J/m^3)

TwoprimarycomponentswhicharethePFFandEpoxyvaryasshown:

- 10%≤A (Epoxy)≤20%
- 30%≤B(PFF)≤40%

Thesecomponentsrepresentatotalofsixteen(50)weight-percentofthetotal formulation,thatis:A +B=50wt%. Twograin/sievesizesof300micronsand600micronswerealsoconsideredasoneof the factors.

Other materials are kept constant throughout, making up theremaining50wt%asshownintable 2below

Table2:Compositionsofthebrakepadmaterial

S/N	**GrainSize(μm)**	**Epoxy(%)**	**PFF(%)**	**Ironoxide(%)**	**Silica(%)**	**Ironfilings(%)**	**Alumina(%)**	**Graphite(%)**
A	300	40	10	10	10	5	15	10
B	600	40	10	10	10	5	15	10
C	300	35	15	10	10	5	15	10
D	600	35	15	10	10	5	15	10
E	300	30	20	10	10	5	15	10
F	600	30	20	10	10	5	15	10

C. SamplePreparationProcedures

Forthepurposeofthiswork,atotalofsix(6)samplesdesignated with the sample ID as shown in Table 2 are to beprepared.Theproceduresforpreparingthesecompositionsareasfollows;

D. MechanicalTestsofSample

Hardness

The hardness test was carried out in accordance with ASTMA956 standards.In this dynamic test method, the ratio ofrebound velocity to impact velocity of a moving impact bodyisusedtodetermine thehardness.

CompressiveStrength

Thiswasdoneusingauniversaltestingmachineinaccordancewith ASTM D3410. The sample was locked securely in thegripsoftheupperandlowercrossbeamsofthetestingmachine. A small load was initially applied to seat the sampleinthegrips andthentheloadwasincreaseduntil failureoccurred.

WearRate

Wear measurement was carried out to determine the numberof materials removed (or worn away) after a wear test Sampletobemeasurediscarefullycleaned,andtheweightismeasuredbefore and after a wear test. The difference in weight beforeand after testrepresentsthe weightlosscausedby wear.

PalmFruitFiber(PFFs)Preparation

PalmFruitfibers(PFFs)werecollectedfromlocalpalmoil

$$Wearrate = \frac{\Delta w}{SlidingDistance}$$

Coefficientoffriction

…. (1)

mill at Enugu. The fibers were suspended in a solution ofcaustic soda (sodium hydroxide) for twenty- four hours toremove the remnant of red oil left after extraction. The fiberswere then washed with water to remove the caustic soda andsun dried for one week. The dried PFFs was grounded intopowder formusingaDouble grindingmill.

SampleFormulation

Each of the powdered constituents were weighed and pouredin a container. The contents were manually but thoroughlymixed for 15 to 20 minutes to obtain homogenous mixture.Then, desired amounts of epoxy resin were poured into aseparate container and the required quantity of hardener wasadded to form the matrix. The quantity of epoxy resin wasadded in the ratio of 2:1. The mixture was thoroughly stirredfor about 5 minutes to obtain uniform mixture. Thereafter, thematrixmixturewaspouredontothepowderedfrictionmaterialmixture and stirred further to obtain paste-like homogenousmixture. The formed paste was poured into mold cavities thatalreadyhadpowderedtalc appliedfor ease of componentremoval, the mixture was thereafter pressed with a hydraulicpressingmachineat100kNforcefor2minutesatroomtemperature and allowed to cure for 90 minutes and thereafterhardened by putting them under controlled temperature of150^{o}Cfor3hoursinanoventoensureacompletecuringoftheresin.

The coefficient of friction between the linings and steel wasdetermined using a steel inclined plane. The plane was kept at180° (horizontal position). Each sample was attached to astring and placed on the plane. The string was passed througha pulley, which was connected to a mass hanger. Standardmasseswereaddedtothemasshangeruntiltheliningbegantoslide along the surface of the steel plane. The coefficient offriction is the ratio of frictional force (equivalent to mass athanger to initiate sliding) to the normal reaction (weight ofbreaklining).Equation(3.2)wasusedtocalculatethecoefficientoffriction(μ)betweentheliningsandsteel.

$$\mu = \frac{F_r}{F_n}$$

…(2)

whereF_r=friction force(N), F_n=normalreaction (N).

E. ResponseSurfaceMethodology(RSM)

The design expert 11.0 software was used to apply responsesurface methodology (RSM). The central composite design(CCD)ofRSMwasusedtoobtainthesecondorderregressionpolynomial that optimizes the mechanical

properties responseofPFF.RSMtriesto fitapolynomialfunction(Equation3)todata.
$y=c_0+c_1x_1+c_2x_2+c_3x_1x_2+c_4\sigma^2+c_5\sigma^2$ …(3)

1 2

Figure1:BrakePadmadefromPFF

IV. RESULTS AND DISCUSSION

Coefficientsin TermsofCodedFactors

The coefficient estimate represents the expected change inresponse per unit change in factor value when all remainingfactorsareheldconstant.Theinterceptinanorthogonaldesignistheoverallaverageresponseofalltheruns.The coefficientsareadjustmentsaroundthataveragebasedonthefactorsettings.WhenthefactorsareorthogonaltheVIFsare1 ;VIFsgreater than 1 indicate multi-collinearity, the higher the VIFthe more severe the correlation of factors. As a rough rule,VIFslessthan10aretolerable.

Hardness=+97.00–2.75A–1.50C–1.75AB+ 0.75AC
CompressiveStrength=+134.86–22.50A–12.84C+16.20AB –9.17AC
Wear Rate = +3.91 + 0.0425A + 0.0117C + 0.6425AB –0.0225AC

A. PredictedandActualResultsforthethree(3)Responses

Hardness

Optimizationconductedonexperimentaldesigntableasshown in Fig. 2 shows the graphical representation of thepredicted and actual values of the experiment. Predicted valuewas 96.99 while actual was obtained as 99HRB showing highsimilarity for the predicted and actual values for the hardnessexperiment.

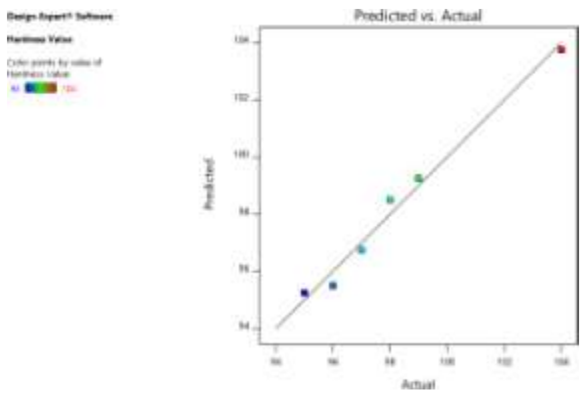

Figure2:PredictedandactualvaluesfortheHardness

CompressiveStrength

Figure 3 shows the graphical representation of the predictedand actual values of the Compressive strength experiment.Again, the graph confirms a high similarity for the predictedand actual valuesforthewearrateexperiment.

\

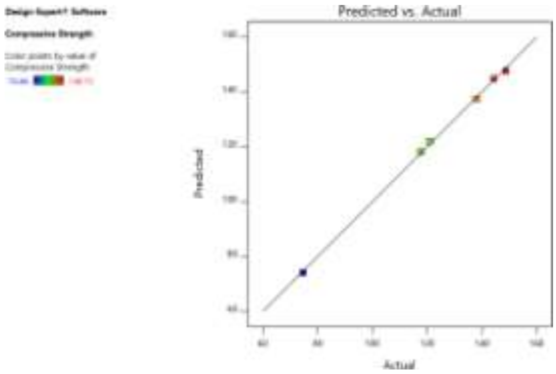

Figure3:PredictedandactualvaluesfortheCompressiveStrength

Wearrate

Fig. 4 shows the graphical representation of the predicted andactual values of the wear rate value from the experiment.Again, the graph confirms a high similarity for the predictedandactual valuesforthewearrateexperiment.

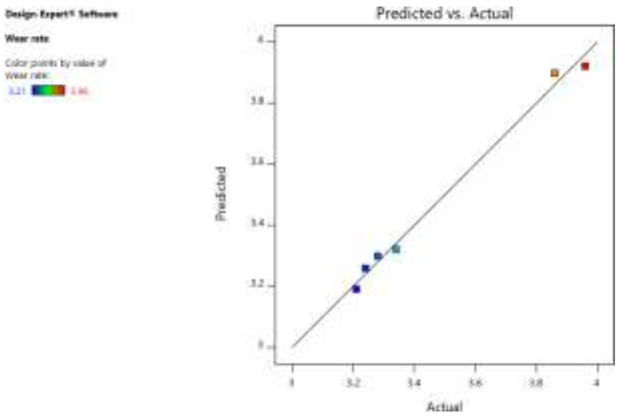

Figure4:PredictedandactualvaluesfortheWearrate

B. AnalysisofVariance

Analysis of variance (ANOVA) is a collection of statisticalmodels and their associated estimationprocedures usedtoanalyze the differences among group means in a sample. Thismethodwasutilizedtopredictifthereisanysignificantdifference in the mean of the experiment. ANOVA for theresponsesareshownin Tables3,4and 5respectively.

Table3:ANOVAfor Response1:Hardness

	Termdf	Errordf	F-value	P-value	
Whole-plot	1				
GrainSize	1				
Subplot	3	1.38	28.91	0.0775	notsignificant
A-PFF	1	1.00	40.33	0.0994	
B-Binder(Epoxy& Hardener)	0				
AB	1	1.42	5.44	0.1944	
Ac	1	1.00	3.00	0.3333	

Bc	0				
A²	0				
B²	0				

Table4:ANOVAforResponse2:CompressiveStrength

Source	Termdf	Errordf	F-value	P-value	
Whole-plot	1				
GrainSize	1				
Subplot	3	1.01	292.35	0.0423	significant
A-PFF	1	1.00	651.06	0.0249	
B-Binder(Epoxy& Hardener)	0				
AB	1	1.01	112.44	0.0590	
Ac	1	1.00	108.06	0.0611	
Bc	0				
A²	0				
B²	0				

Table5:ANOVAforResponse3:Wearrate

Source	**Termdf**	**Errordf**	**F-value**	**P-value**	
Whole-plot	1				
GrainSize	1				
Subplot	3	1.00	42.32	0.1124	notsignificant
A-PFF	1	1.00	1.64	0.4222	
B-Binder(Epoxy &Hardener)	0				
AB	1	1.02	124.86	0.0544	
Ac	1	1.00	0.4594	0.6208	
Bc	0				
A²	0				
B²	0				

C. InteractionoftheFactorson theResponse

From the result generated showing the contour diagram ofrelationshipbetweenthreevariables,i.e.,PalmFruitFiber(A)and Binder (Epoxy Resin) (B), to the Hardness Value of thesamples developed for the brake pad (Figure 5), it can beinferredthatthevalueofthecorrelationcoefficient(r)isabout 0.57forAwhileitis0.53atB.ThisshowsthatPFFcontributemore in terms of wear resistance for the material developed.Figure 5 shows the 3D surface plot of relationship betweenthree variables to the Wear rate of the Samples developed ofthe brakepad.

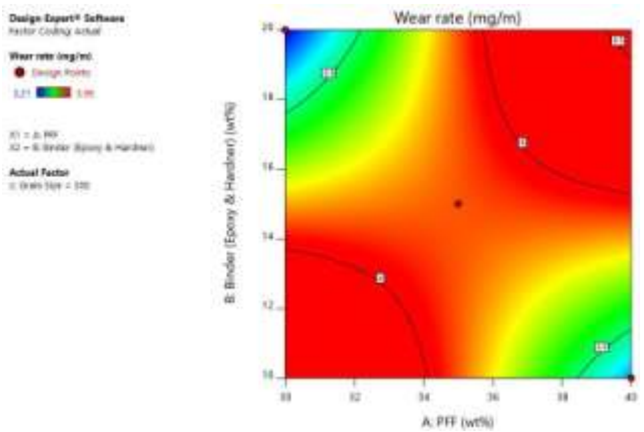

Figure 5: 3D surface plot of relationship between three variables to the WearrateoftheSamplesdevelopedofthebrakepad.

Again,fromtheresultgeneratedshowingthecontourdiagramofrelationshipbetweenthreevariables,i.e.,PalmFruitFibe r (A) and Binder (Epoxy Resin) (B), to the Hardness Value ofthe samples developed for the brake pad (Figure 6), it can beinferredthatthevalueofthecorrelationcoefficient(r)isabout 0.78forAwhileitis0.49atB.ThisshowsthatPFFcontributemore in terms of wear resistance for the material developed.Figure 6 shows the 3D surface plot of relationship betweenthree variables to the Compressive Strength of the Samplesdeveloped of the brake pad.

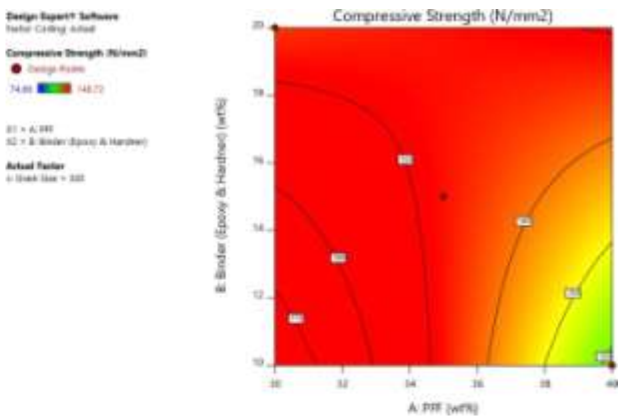

Figure 6: 3D surface plot of relationship between three variables to theCompressiveStrenghoftheSamplesdevelopedofthebrakepad.

Again,fromtheresultgeneratedshowingthecontourdiagramofrelationshipbetweentwovariables,i.e.,PalmFruitFiber (A) and Binder (Epoxy Resin) (B), to the Hardness Value ofthe samples developed for the brake pad (Figure 7), it can beinferredthatthevalueofthecorrelationcoefficient(r)isabout 0.29 for A while it is 0.80 at B. This shows that Binder (i.e.,Epoxy Resin) contribute more in terms of Hardness value forthe material developed. Figure 7 shows the 3D surface plot ofrelationship between three variables to the Hardness Value oftheSamplesdevelopedofthebrake pad.

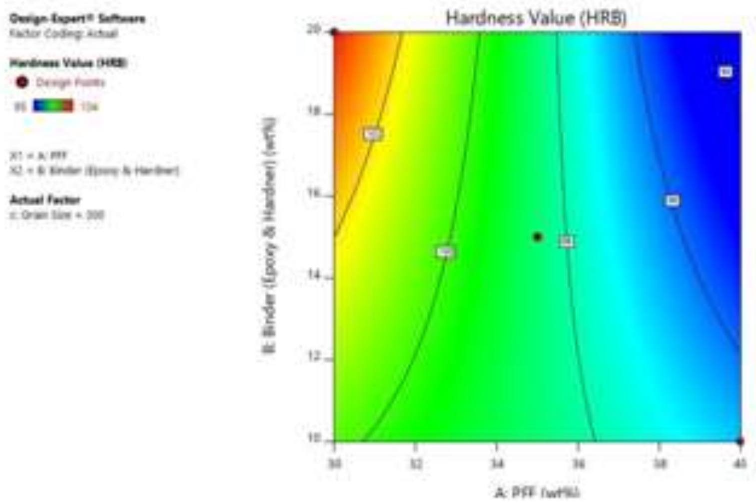

Figure 7: 3D surface plot of relationship between three variables to theHardnessValueofthe Samplesdevelopedofthebrakepad.

V. CONCLUSION

A non-asbestos brake pad material using palm fruit Fiber asbase material was developed. Various mechanical Tests wereconductedontheproducedsamplesandtheirresultsanalyzed.The results related how the samples performed during testing.Thefollowingwerededucedfromthisstudy:

- TheHardnessvaluesresultshowedthattheHardnessvaluesofthesampleswhichrangesfrom94HRBto104HRBareincloseproximitywiththecommercialbrakepad.
- ThecompressiveStrengthvariesfrom74.66MPato148MPa,withSampleBhavingtheleaststrength,while sample C has the highest compressive strength. The wearresultsrangefrom3.21mg/mto3.96mg/mwhichconformswith that ofcommercial brakepad(3.8mg/m).
- The optimal sample for the brake pad material is sample F(30wt%ofPFF,600µm)whichistheclosesttothepredicted value.
- The best particle size of Palm Fruit fiber for brake padproduction is600µm.
- The pad samples were thermally stable with no loss inweightupto250^{0}Cto550^{0}C
- The relationship between the formulated Palm Fruit Fiber(PFF)brakepadandcommercialbrakepadhasacorrelation coefficientR= 0.80.

REFERENCES

[1] Adebisi,A.A.,Maleque,M.A.&Shah,Q.H.(2011).Surfacetemperaturedistributioninacompositebrakerotor,InternationalJournalofMechanicalandMaterialsEngineering6 (3):356-361.
[2] Aigbodion, V.S., Akadike, U., Hassan, S.B., Asuke, F., Agunsoye, J.O.(2010). Development of Asbestos - Free Brake Pad Using Bagasse.Tribologyinindustry, Volume32,No. 1,pp12-18.
[3] Akramifard,H.R.andGhasemi,Z.(2016).FrictionandWearPropertiesof a New Semi-Metallic Brake Pad According to SAE J 661: A CaseStudy in PARSLENT Complex (Iran). International Journal of NewTechnologyandResearch(IJNTR),Volume-2,Issue-3,Pages96-99.
[4] Bashar,D.A.,Peter,B.M.,andJoseph,M.(2012).MaterialSelectionandProductionofaCold-WorkedCompositeBrakePad.WorldJofEngineeringandPureandApplied Sci.2(3):92
[5] Blau, P.J. (2001). Compositions, Functions, and Testing of FrictionBrake Materials and Their Additives. Tennessee: Oak Ridge NationalLaboratory.
[6] Dagwa, I.M. and Ibhadode, A.O.A. (2005). Design and Manufacture ofExperimental Brake Pad Test Rig. Nigerian Journal of EngineeringResearchandDevelopment,BasadePublishingPressOndo,Nigeria,Vol.4, No.3.15-24
[7] Elzey,D.M,Vancheeswaran,R,Myers,SW,McLellan,RG,(2000),Theintelligent selection of materials for brake Lining. Proceedings of the18th Annual brake Colloquium & Engineering Display, P-358: pp, 181-192.
[8] Filip, P., Weiss, Z., &Rafaja, D. (2002). On friction layer formation inpolymermatrixcompositematerialsforbrakeapplications.Wear,252(3-4),189-198.
[9] Gachoki, J. J. and Kathenya, M. D. (2011). Design of brake pad frictionmaterial.Finalyearproject.DepartmentofMechanicalandManufacturing Engineering. UniversityofNairobi.
[10] JaafarTR,SelamatMS,KasiranR,(2012).Selectionofbestformulationforsemi-metallicbrakefrictionmaterialsdevelopment.J.PowderMetall.,1-30.
[11] Kim, S. J., & Jang, H. (2000). Friction and wear of friction materialscontaining two different phenolic resins reinforced with aramid pulp.Tribologyinternational,33(7),477-484.
[12] Kumark.&Bijwe,J.(2010),"NAOfrictionmaterialswithvariousmetalpowders: tribological evaluation on full-scale inertia dynamometer,"Wear,vol.269,no.11-12,pp.826–837.

[13] Leman Z., Sapuan, S.M. Saifol, A.M. Maleque M.A. and Ahmad, M.M.(2008 Moisture absorption behaviour of sugar palm fibre reinforcedepoxycomposites'ShortCommunication,InternationalJournalofMaterialsandDesign29(8):1666-1670.
[14] Mohanty, S., & Chugh, Y. P. (2007). Development of fly ash-basedautomotivebrakelining.TribologyInternational,40(7),1217-1224.
[15] Nicholson, G. (1995). Facts about Friction.Croydon, PA: P&W PriceEnterprises
[16] Vijay, R., Janesh, M.J., Sai Balaji, M.A and Thiyagarajanm V. (2013).Optimization of Tribological Properties of Nonasbestos Brake PadMaterialbyUsingSteelWool.AdvancesinTribology,volume2013,pp1-9.
[17] Wanniketal.,2012;Wannik,W.B.,Ayob,A.F.,Syahrullail,S.,Masjuki,H.H., Ahmad, M.F., 2012. The effect of boron friction modifier on theperformanceofbrakepads. Int.J.Mech.Mater. Eng.7,31