[1.]Tajudeen Kolawole AJIBOYE, [2.]Sulyman Age ABDULKAREEM,
[3.]Olusegun Samuel BALOGUN

ANALYSIS OF SLIDING PARAMETERS ON WEAR BEHAVIOUR OF BRAKE LINING MATERIALS

[1.] Department of Engineering, University of Ilorin, Ilorin, NIGERIA

Abstract: In this study, the effect of sliding parameters on the wear behaviour of brake pad lining materials was analyzed. The test samples were procured and coded as TY, HN and MZ respectively. The sliding parameters considered for this research were application load, sliding speed and application time. The application load considered are those of vehicles gross weights ranging between 1500 – 3500 Kg, the sliding speed was varied between 100 – 200 rpm while the application time was from 20 – 100 seconds at an interval of 20 seconds. Using standard equipment and test methods, the test samples were subjected to elemental composition analysis, wear characteristics and microstructural examination. The elemental composition test carried out revealed that the reinforcing fibre which gives an optimum performance in the formulation of these brake pads was carbon. The wear characteristics was conducted using the pin on disc test method and the results showed that wear rate of brake pads lining materials increased with increase in applied load and sliding speed but decreased with an increase in the application time.
Keywords: brake pads; elemental composition; lining materials; sliding parameter, wear behaviour

INTRODUCTION

Brake pad is a component part of automobiles that is essential for the purpose of safety and controlled performance. The presence of this component in automobiles provides a lot of assistance for safe reduction in the speed of automobile vehicles and apparently bringing it to a halt as the case may be [1]

The principle of operation of brake pad is based on the transformation of energy in which the kinetic energy of a moving vehicle is been transformed into thermal energy which results in either retardation of the vehicle or bringing the vehicle to a halt [2].

The materials used in the formulation of brake pads play significant role in deciding the suitability and their respective individual properties combine to determine the properties possessed by the brake pads [3]. Since brake pads lining material is a crucial component from the safety point of view, materials used for the brake systems should possess stable frictional and wear properties under varying conditions of load, speed and environment [4, 5].

Wear behaviour refers to how materials react under a specific service condition. The most useful method of characterization of wear behaviour is to classify the service condition of the material under investigation in terms of the broad types of wear and then examine the behaviour in terms of specific operational features. The characterization enables the sorting and identification of appropriate information on wear behavior, model development, and selection of wear data [6].

Due to the service condition brake pads are regularly exposed to in which they are opened to the activities of different sliding parameters that contribute to wear and consequently may serve as a contributory factor to vehicle brake failure, this research work was embarked on to provide useful information on the cause of wear of vehicle brake pads lining materials through analysis of the wear effect contributed by application pressure and other associated sliding parameters on the brake pad lining materials as well as the effect of the application environment(dry).So the focus of this study is to analyse the effect of sliding parameters such as load, speed and environmental conditions on the wear behaviour of brake pad lining materials.

MATERIALS AND METHODS

The brake pads employed for this research are those used in light weight vehicles with gross weight ratings between 1500 – 3500 Kg [7, 8] and the specification is as stated [9]. The materials used for this experiment were procured from the local market in Nigeria and were subjected to composition analysis using ARL 4460 Optical Emission Spectrometry equipment and the result is presented in Table 1

Table 1: Elemental composition of brake pads lining materials used for the experiment

S/N	Test Specimen	% Composition					
		Fe	C	Si	V	W	Sn
1	SA	26.45	>59.39	0.39	0.48	9.83	9.83
2	SB	0.41	>94.054	>4.65	0.00	0.12	0.01
3	SC	0.87	>89.20	>9.25	0.00	0.11	0.04

SAMPLE PREPARATION

The brake pad was carefully mounted on a bench vice and the metallic back plate was removed using hacksaw. Afterwards, the brake pad lining material was prepared for the property tests according to the standard dimensions required.

— Brinell Hardness

Brinell hardness testing equipment with model number EEDB00006/13 was used to test for the resistance of the specimen to indentation. A hardened steel ball of 10mm indentation diameter was pressed into the test specimen under a constant load of 3000 Kgf for a dwell time of 15 secs. The indentation created was measured using a micrometer screw gauge across two different directions with the mean value substituted for in the formula for Brinell hardness number (BHN) [1].

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad (1)$$

where: P= Applied load (Kgf)
D= Diameter of hardened steel ball (mm)
D= Diameter of indentation created (mm)

Figure 1: Brinell hardness test of test material

— **Izod impact test**

Avery Denilson Impact testing equipment with a capacity of 150 J and an impact velocity of 3.65 m/s was employed for the test. According to ASTM E23-2013 test standard, the test samples were prepared into 64 x 12 x 3.2 mm dimension with a 2 mm deep notch at the centre. Each of the test specimens was firmly fixed with the notched area positioned in the opposite direction of the falling hammer. The hammer was released at maximum load of 150 J to create an impact on the test specimen and the result of the impact was read on the equipment scale.

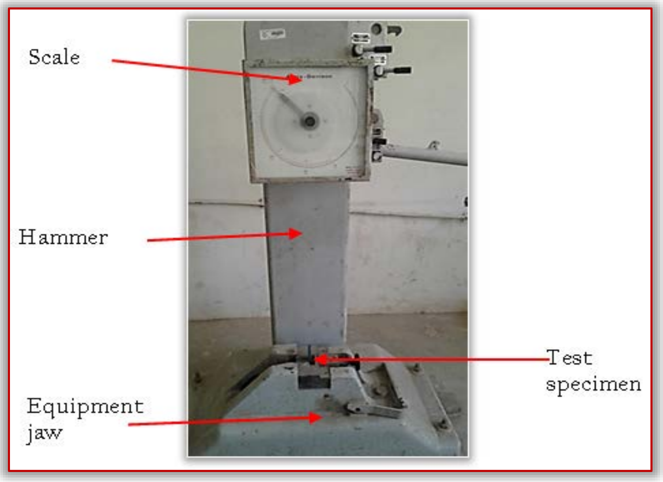

Figure 2: Izod impact test on test specimen

— **Tensile strength**

A Testometric Universal Testing Machine (UTM) FS was used for this test. The test specimen was prepared into a dimension of 120 x 10 x 5 mm according to ASTM E8-2013 standard. The test piece was fixed into the jaw of the equipment and an initial load of 5,000 N which was gradually varied was applied until samples SA, SB and SC fractured at 520.87 N, 426.51 N and 815.03 N respectively.

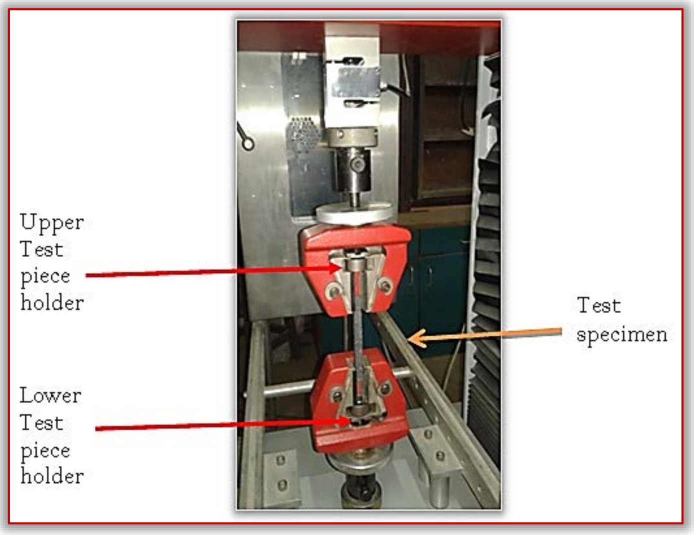

Figure 3: Tensile test of test specimen

— **Compressive strength**

The test specimens were prepared into a determined shape of 10 mm x 10 mm x 30 mm according to ASTM E9-2013 test standard after which it was placed between the jaws of the testometric Universal Testing Machine with a capacity of 50 kN. An initial force of 5 kN was applied on the specimen and was gradually increased until the material finally yielded under load.Samples SA, SB and SB yielded at 17.68 kN, 32.46 kN and 14.59 kN load respectively.

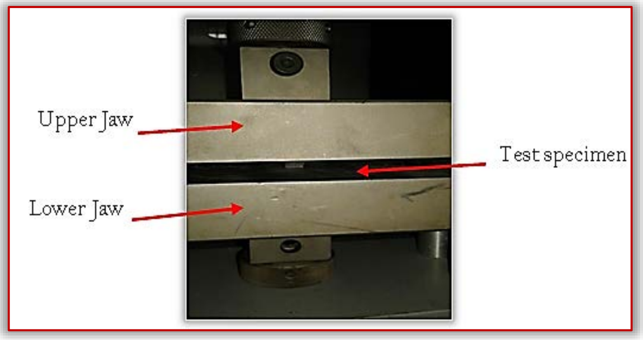

Figure 4: Compression test of test specimen

— **Coefficient of friction**

The co-efficient of friction (COF) of the test specimens were carried out using simple inclined plane method in which the specimen was allowed to freely slide down over the cast iron plane.

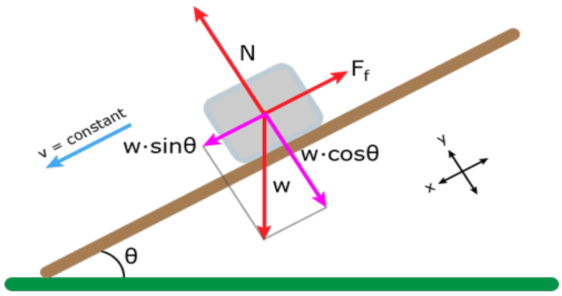

Figure 5: Free Body Diagram of a Simple Inclined Plane

At the point of sliding, the plane was clamped and the angle of inclination (θ) was measured after which the coefficient of friction (μ) was calculated using equation 2 [10, 11].

$$COF(\mu) = \tan\theta \quad (2)$$

— Wear Characteristics

The test sample was firmly held in the specimen holder which has a combined weight of 1174.28 Kg with the handle. The weight of the samples were measured before and after each test time with a measuring electronic scale with 0.001 mg precision as the test time were varied between 20 to 100 seconds at an interval of 20 seconds. Prior to weighing, the worn out samples were cleaned with wool soaked in acetone and wear particles debris on the emery paper were intermittently removed by compressed dry air blower.

— Microstructural Examination

The microstructural examination of the test specimens were carried out by polishing the surface of the samples with an emery cloth of 600grit on a polishing machine after which it was viewed under the computerized metallurgical microscope.

Figure 6: Test specimen under wear test

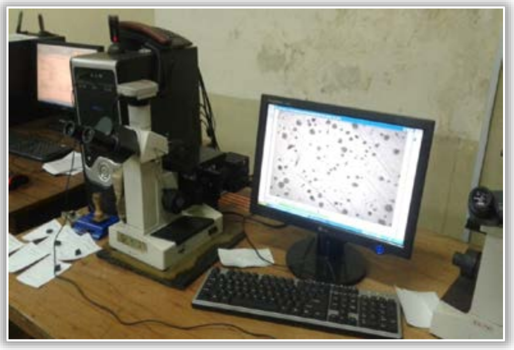

Figure 7: Metallurgical microscope for examination

RESULTS

The results obtained for each of the test were detailed in Tables 2 to 6 and Figures 8 to 13 which clearly shows the behavior of the material under the application of the designed load

Table 2: Brinell Hardness Test Results

S/N	Test Specimen	Test No	Load (Kgf)	Steel ball diameter, D (mm)
1	SA	SA_1	3000	10
		SA_2	3000	10
		SA_3	3000	10
2	SB	SB_1	3000	10
		SB_2	3000	10
		SB_3	3000	10
3	SC	SC_1	3000	10
		SC_2	3000	10
		SC_3	3000	10

S/N	Test Specimen	Indentation diameter,d (mm)	Mean Value,d (mm)	BHN
1	SA	5.46	5.46	117.15
		5.44		
		5.47		
2	SB	5.70	5.71	106.68
		5.71		
		5.71		
3	SC	5.79	5.78	103.22
		5.78		
		5.78		

Table 3: Result of Izod Impact Test

S/n	Test Specimen	Test No	Impact Strength(J)	Avg. Impact Strength(J)
1	SA	SA_1	69.50	69.08
		SA_2	68.75	
		SA_3	69.00	
2	SB	SB_1	69.00	69.17
		SB_2	69.50	
		SB_3	69.50	
3	SC	SC_1	69.50	69.00
		SC_2	68.50	
		SC_3	69.00	

Table 4: Results of Tensile Test

S/N	Test Specimen	Test No	Yield Force(N)	Avg.Yield force (N)
	SA	SA_1	520.10	
1		SA_2	520.90	520.87
		SA_3	521.60	
	SB	SB_1	426.05	
2		SB_2	429.90	426.51
		SB_3	423.58	
	SC	SC_1	816.10	
3		SC_2	813.22	815.03
		SC_3	815.76	

S/N	Time to failure (Secs)	Avg. time to failure (Secs)	Elong. at Yield(mm)	AverageElong. at yield (mm)
	9.43		0.61	
1	9.42	9.44	0.62	0.61
	9.48		0.61	
	6.80		0.42	
2	6.82	6.76	0.42	0.42
	6.67		0.41	
	10.82		0.71	
3	10.72	10.79	0.72	0.72
	10.83		0.73	

Table 5. Result of Compressive Test

S/N	Test Specimen	Test No	Yield force (kN)	Avg. Yield force (kN)
1	SA	SA_1	17.57	17.68
		SA_2	17.65	
		SA_3	17.83	
2	SB	SB_1	32.44	32.46
		SB_2	32.45	
		SB_3	32.49	
3	SC	SC_1	14.57	14.59
		SC_2	14.56	
		SC_3	14.63	

S/N	Time to failure (Secs)	Avg. time to failure (Secs)	Def. At Yield (mm)	Avg. def. At yield (mm)
1	15.99	16.09	2.57	2.62
	16.21		2.61	
	16.06		2.68	
2	13.37	13.41	2.30	2.24
	13.52		2.18	
	13.33		2.24	
3	7.77	7.73	1.30	1.29
	7.66		1.29	
	7.75		1.29	

Table 6. Co-efficient of Friction of the Brake Pads

S/N	Test specimen	Test No	Inclination Angle, θ(°)	Calc. Coefficient of Friction (μ)	Average COF(μ)
1	SA	SA_1	18.78	0.34	0.34
2		SA_2	18.78	0.34	
3		SA_3	18.26	0.33	
1	SB	SB_1	18.51	0.33	0.32
2		SB_2	17.99	0.32	
3		SB_3	17.86	0.32	
1	SC	SC_1	18.95	0.34	0.33
2		SC_2	17.55	0.32	
3		SC_3	18.40	0.33	

Table 2 shows the results obtained for the Brinell Hardness Test for each of the sample specimens under the same loading and experimental conditions. Tables 3, 4, 5 and 6 indicate the results obtained for Impact, Tensile, Compressive, and Coefficient of friction tests in that order.

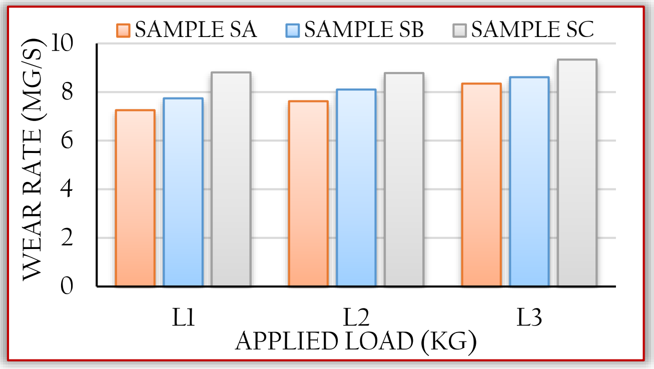

Figure 8: Variation of wear rate with the variation of applied load at 100 rpm; (L1 = 1569.05g, L2=1583.72g and L3 = 1603.83g)

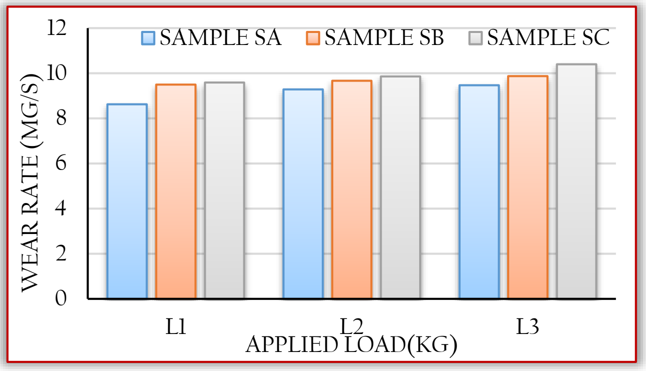

Figure 9: Variation of wear rate with the variation of applied load at 150 rpm(L1 = 1569.05g, L2=1583.72g and L3 = 1603.83g)

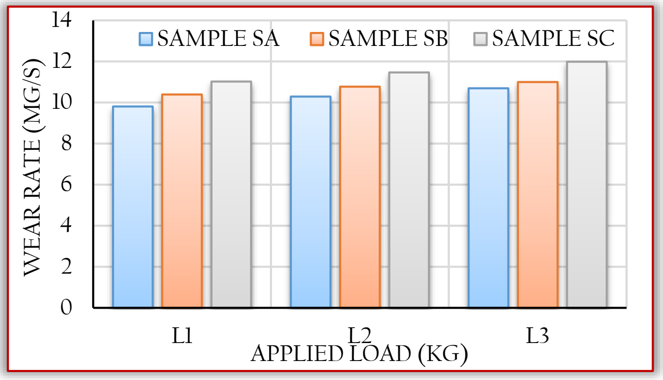

Figure 10: Variation of wear rate with the variation of applied load at 200 rpm (L1 = 1569.05g, L2=1583.72g and L3 = 1603.83g)

Figures 8, 9 and 10 shows the variation of the wear rate with load at 100 rpm, 150 rpm and 200 rpm respectively for the three samples under consideration.

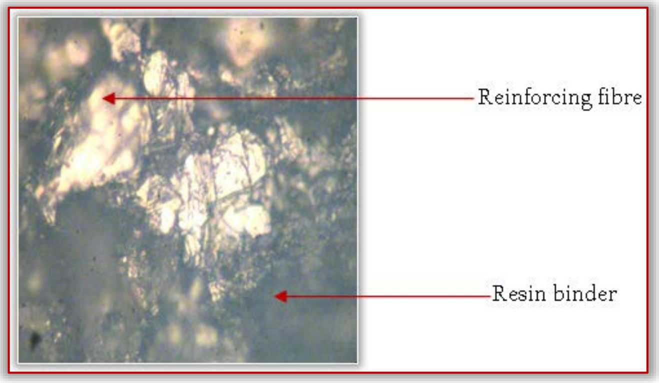

Figure 11: Microstructure of Sample SA at x400

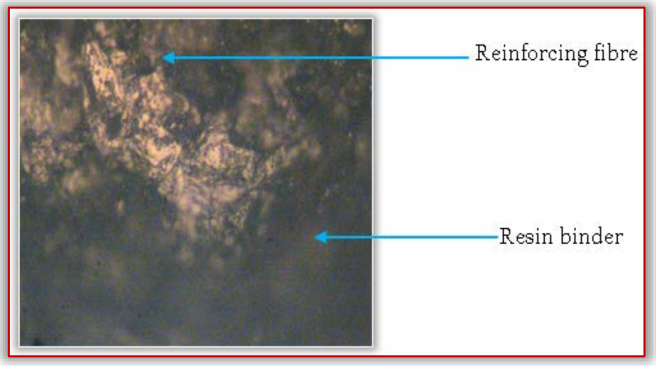

Figure 12: Microstructure of Sample SB at X400

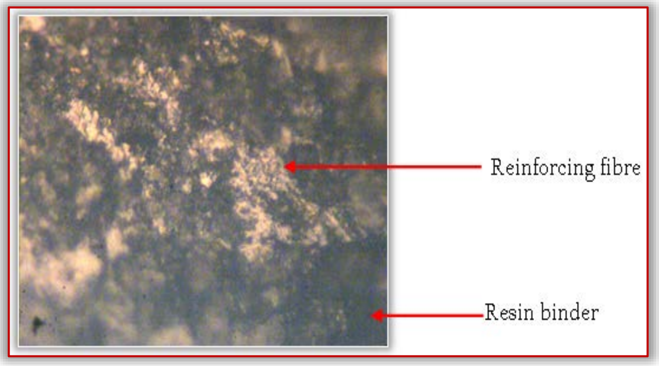

Figure 13: Microstructure of Sample SC at X400

Figures 11, 12 and 13 show the microstructure of each of the test sample. These depict the structural arrangement of the constituents which is an indication of the behaviour of the samples under the application of loads.

DISCUSSIONS

— Brinell hardness

From the result table, it can be inferred that SA possesses the best hardness property when compared with SB and SC respectively under the same load condition of 3000 Kgf while that of SB is slightly higher than that of SC. The high brinell hardness number indicated by SA is as result of its high tungsten content which stands at an average of 9.83% when compared with the respective average values of tungsten contents in SB (0.12%) and SC (0.11%) as indicated by the elemental composition results for each of the test specimen.

— Izod impact strength

The three test specimens tend to have an approximately same value of impact strength when subjected to the same hammer drop at a maximum load of 150 J with the average izod impact strength of SA, SB and SC at 69.08 J, 69.17 J and 69.0 J respectively. This could be as a result of their respective high carbon content with that of SA supplemented with the high iron content.

— Tensile strength

Generally, the test results indicated that the brake pad lining materials are highly brittle in nature, a condition that could be associated to the high carbon contents. Due to the very high carbon content of SB, it has the earliest average yield time to failure and the lowest average yield force respectively when compared with the corresponding parameters for both SA and SC respectively. Also, the average elongation at yield point for SB is the lowest of the three samples which is also as a result of the high carbon content while that of SC is slightly higher than the corresponding obtained values for SA.

The test result showed that SC possesses the highest average yield force which stands at 815.03 N with SA and SB having a value of 520.87 N and 426.51 N, respectively. The average time to failure for SA is 9.44 seconds, SB is 6.76 secs and SC is 10.79 secs while the average elongation at yield for Samples SA, SB and SC are 0.61 mm, 0.42 mm and 0.72 mm respectively.

— Compressive strength

From the above test results obtained for each of the test specimen, SA shows an average compressive strength value of 17.68 kN which is slightly higher than that of SC at 14.59 kN despite the higher carbon content of SC though it is lower than that of SB. One of the factors that could be responsible for this variation is the higher tungsten percentage in SA (9.83%) when compared with that of SC (0.11%).

The high average yield force indicated by SB is as a result of its extremely high carbon content though its tungsten percentage is at 0.12%. Comparatively, SA has the longest average time to failure due to its higher tungsten and iron contents though with a higher deflection while SC has the lowest average time to failure and deflection respectively.

— Coefficient of friction

The calculated coefficient of friction for the three test specimens were virtually the same and they all fall within the range of coefficient of friction for brake pad lining materials as stipulated by NIS 323(1997) which is between 0.3 and 0.4 as obtained by other researcher in a similar research [8].

— Wear Characteristics

In general, from the various results obtained at varying application time, applied loads and sliding speed conditions, it was observed under each load applications that the wear rates of samples SA, SB and SC respectively were decreasing as the application time was increasing and the average wear rates increased with each sliding speed and applied loads. That is, the wear rate of brake pads lining materials increase as the sliding speed and applied loads increase but it decreases as the application time increases.

Under each test condition, it was observed that the average wear rate values of both sample B and sample C were consistently higher than that of sample A with that of sample C slightly higher than that of sample B, a condition that could be related to the amount of resin binder inclusion in the brake pads. The results clearly showed that wear rate is at maximum at the shortest time of application.

— Microstructural Examination

In general, the graphite which is the reinforcing fibre, is martensic in nature, a condition that is responsible for the brittle nature of the brake pads used for the purpose of this research and the distribution of particles in the friction materials are different for each test samples.

CONCLUSIONS

≡ The brake pads have carbon as the reinforcing fibres and it is in larger percentage than other constituent elements used in the brake pads formulation

≡ The high carbon element present in these brake pads makes it highly brittle in nature consequently resulting in their respective low tensile strength capacity.

≡ The brake pads displayed a good co-efficient of friction that it falls within the range of results obtained by Dagwa and Fono-tamo on similar vehicle size.

≡ The wear rates of the brake pads decreased with increased application time but it increased with increased applied load and sliding speed.

≡ The amount and distribution of binder in the brake pads affects the wear characteristics as it determines the structural stability of material under mechanical stress and thermal stresses and also prevents it from crumbling

Acknowledgement

The authors which to acknowledge the Technical team of the Mechanical Engineering Workshop, University of Ilorin for their contributions towards the successful completion of the research work.

References

[1] 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 and Engineering Research, 5(10), pp. 726-742.

[2] Surojo E., Jamasri, Malau V.,Ilman N., (2014) “Effects of phenolic Resin and Fly Ash on Coefficient of Friction of Brake

Shoe Composite" ARPN Journal of Engineering and Applied Sciences, 9(11),pp. 2234-2238.
[3] Darius G., Solomon, Mohamad N.B., (2007) "Characterization of Friction Material Formulations for Brake Pads" Proceedings of the World Congress on Engineering, London Uk.,2, pp. 234.
[4] Maleque M.A., Dyuti S.,Rahman M.M.,(2010) "Material Selection Method in Design of Automotive Brake Disc" Proceedings of the World Congress on Engineering.
[5] Riyadh A.,Al-Samarai, Haftirman, Khairel R. A.,Al-Douri Y.,(2012) "Effect of Load and Sliding Speed on Wear and Friction of aluminium-Silicon Casting Alloy" International Journal of Scientific and Research Publications, 2(3), pp. 1-4.
[6] Bayer R.G, (2002) "Wear Analysis for Engineers" HNB Publishing, New York, USA.
[7] Blau J.P., (2001) "Compositions, Functions and Testing of Friction Brake Materials and their Additives", Oak Ridge National Laboratory, USA Department of Energy, pp. 1-29.
[8] Miller-Wilson K. (2016) "List of Car Weights" Available at "http://cars.lovetoknow.com/List_of_Car_Weights" accessed 08/09/2017 10:40am
[9] Nigeria Industrial Standard (1997), Specification for Friction Materials for Road Vehicles Brake Lining and Pads, NIS 323: 1997,Standard Organization of Nigeria.
[10] Fono-Tamo .R.S, Olufemi A.K, (2015) "Weibull Approach to Brake Pad Wear Analysis in the Nigerian Market", 3(10),Tsinghua University Press, pp 228-233.
[11] Nagesh S.N., Siddarju C., Prakash S. V.,Ramesh M.R., (2014) "Characterization of Brake Pads by Variation in Composition of Friction Materials" International Conference on Advances in Manufacturing and Materials Engineering, Procedia Materials Science 5, pp. 295-302.

ISSN: 2067-3809