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Some physical and mechanical properties of asbestos–free experimental brake pad

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ABSTRACT
This paper highlights the physical and mechanical properties of asbestos-free laboratory automobile disk brake pad. Using standard tests and experimental methods, the properties of the new asbestos-free brake pad were determined. These properties include compressive strength, shear strength, Brinell hardness, impact strength, tensile strength, specific gravity, thermal conductivity, specific heat capacity, porosity, average wear (mg/application), coefficient of friction, thickness swell in water after 24 hours, thickness swell in oil (SAE40) after 24 hours, and flame resistance test after 10 minutes. The results show that the new brake pad has Brinell hardness (at 3000kgf) of 92, coefficient of friction, 0.43; specific gravity of 1.65; compressive strength of 103MPa and the average wear of 4.4mg/brake application. The results compared favourably with the commercial brake pad.

Keywords: *Physical properties, Mechanical properties, Asbestos-free experimental brake pad.*

INTRODUCTION

A brake pad is a vital component of automobile disk brake system. It is a friction material which when pressed against the brake disk will dissipate the heat energy, which is generated during braking application. The brake pad is more efficient when it is compared with the brake lining used in drum brake system [1]. There are three basic types of brake pads viz: metallic, semi-metallic and organic brake pad. And there are also several requirements of good friction materials properties as reported elsewhere [2]. For over 80 years now asbestos has dominated the industry as the best friction material [3]. Its content in vehicle brakes varies from about 30% - 70%.

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The positive characteristics of asbestos are its thermal stability, its good frictional properties and it insulate thermally, it processes well, it wears well, and it is strong yet flexible [3]. Due to the aforementioned characteristics, it has been the most prominent candidate for use as friction material. However, medical results show that prolonged exposure to asbestos dust is carcinogenic [3,4]. Hence, efforts have been in progress towards developing asbestos-free friction materials. There has been increasing interest in developing asbestos-free brake pad. Subsequently, there have been significant changes in the formulations of friction materials for the brake lining systems of automobiles [5]. A new asbestos-free automobile disk brake pad has been developed using Palm Kernel Shell (PKS) as base materials, which was sourced locally [6]. The development of new environmentally friendly brake pad materials was to solve the problem of environmental pollution due to the wear of asbestos, when used as a brake friction material.

The focus of this study is to evaluate the physical and mechanical properties of the laboratory brake pad by using standard laboratory tests and experiment methods. For newly developed brake pads it is important to determine their properties so as to ensure the safety of the vehicle users.

MATERIALS AND METHODS

Materials

The raw materials used in the production of friction materials such as brake pad may be classified into three major categories: filler materials, binders and additives.

Typical composition of brake pad is as presented in Table1

Table 1: **Composition of ingredients used for the brake pad manufactured in this work**

Ingredient	Volume (%)
Fillers, Reinforcement & Miscellaneous (PKS, iron powder, etc)	56
Abrasives (*qucer*)	14
Friction producers/Modifiers (Brass chips, etc)	6
Thermosetting resin	24

Source: Dagwa and Ibhadode [2]

Methods

The following physical and mechanical tests were carried out on the brake pad material specimens:

Specimen preparation

The specimens were made from the laboratory type brake pad with the composition as shown in Table 1. The optimal manufacturing parameters for this experimental formulation were as obtained else-where [2] moulding pressure (16.74MPa), moulding temperature (160°C), curing time (8 minutes), and heat treatment (2 hours).

The specimens were carefully moulded or cut to size using hacksaw blade and some were ground to dimension using pedestal-grinding machine.

Thermal Conductivity Test

The Lees' Disk Method [7] was used in determining the thermal conductivity of specimen prepared in disk form (ϕ85.5 x 11.23mm thickness).

Impact Test

Charpy impact test was carried out on the brake pad material as described in literature [8].

A WOLPERT Impact pendulum- type PW5 machine according to DIN 51 222 was used for the impact test. It has impact energy of 50 joule.

The consumed impact energy A_v is equal to the difference between potential energy A_P and the redundant energy A_u (the energy of the pendulum after breaking the specimen, which can be measured by knowing the angle through which the pendulum rose).

$$A_v = A_p - A_u$$
$$= F.L\,(\cos\lambda - \cos\phi) \text{--------}(1)$$

Where F = supporting force

L = length of the pendulum

λ = uplift (rise) angle of pendulum

ϕ = drop angle of the pendulum.

The uplift and drop angles were read on the analogue indicating instrument. A resettable drag pointer indicated the impact energy consumed. During the test with only the pendulum hammer, tests of 0-150 joules can be carried out.

Specific Heat Capacity Test

A method described by Tyler [7] for determining specific heat capacity using a copper calorimeter was used. Specimens were prepared and were cut from laboratory and commercial brake pads.

Hardness Test

A Brinell hardness tester was used for the hardness tests of the brake pads. The test method was in accordance with ASTM Standard E 10 and BS 240 (1986)

Tensile Test

The axial tensile testing of brittle materials is difficult because of the problem of preparing suitable shape test-pieces and those of effectively holding them within the testing machine. It is therefore customary to determine the tensile strength from a three-point bend test known as modulus of rupture (M.O.R). This mode of testing was also used to determine the fracture strength of rigid thermo set materials such as phenol – formaldehyde resin laminated with either cloth or paper as reported by John [9].

The MOR value for a material is approximately double the true tensile strength. This is covered in BS 2782, Part 3 Method 335 A (1989).

Compressive Strength Test

Compression test was carried out on a compression-testing machine and the force needed to crush the specimen (10mm(W) x10mm(T) x30mm(L)) was recorded for each specimen as in BS 1881 part 116 (1983). Surface dimension of 30 x 10mm was used for the compression test.

Shear Strength Test

The shear strength value is obtained as ultimate load at fracture divided by the cross sectional area of the specimen. The direct shear test method was adopted for the shear test on 10mm x 10mm cross-section specimen. Hence, specimens were carefully clamped in a G-clamp and dead loads were applied near the point of shear on the short over-hung side until they snapped off. The shear strength (S) was determined as follows:

$$S = \frac{Ultimate\ load\ at\ fracture}{Cross\ \text{sectional}\ area}\ \frac{N}{mm^2}$$

Flame Resistance Test

To test for the flame resistance of the brake pad material, the specimens were placed on wire gauze positioned directly on the blue flame of a Bunsen burner. The specimen weighing 3.54g and 3.55g for laboratory- made and commercial types respectively were left for 10 minutes on the flame.

Coefficient of Friction (COF) Test

The coefficient of static friction (COF) for the brake pad was measured by sliding it over a cast iron surface [7]. For friction linings the COF ranges from 0.3 to 0.6.

And they are classified in codes[3] as shown in Table 2.

Table 2 **Society of Automobile Engineers (SAE) Recommended Practice J866a Lists the following codes for Brake lining/Pads and associated friction Coefficients** [3]:

Code	Friction Coefficient
C	<0.15
D	0.15-0.25
E	0.25-0.35
F	0.35-0.45
G	0.45-0.55
H	>0.55
Z	Under classified

Apparent Porosity Test

Porosity is the measure of pore – spaces contained in a material. Immersion technique was used in this work[10].

Water and Oil Soak Test:

The 24-hour water and oil soak tests determine the water and oil absorption behaviour of the asbestos-free experimental brake pad and the effects of the absorbed water and oil on its dimensions. After the oven drying of the specimen in MIM type electric oven (0-250°C), its weight was measured. Subsequently, the dimensions (thickness) of the specimen were measured at four different points by using a digital vernier caliper.

After 24 hours of submersion in water and engine oil SEA 20/50 at 28°C ± 2°C the specimens were weighed after the excess water and oil had drained off. The thickness was measured at the same four positions and the average was calculated.

The following formulae were used:

$$\text{Water absorption (\%)} = \frac{W_w - W_i}{W_i} x100 \text{-------(2)}$$

Where:

W_w – wet weight

W_i – initial weight of oven dry specimen

$$\text{Thickness swelling (\%)} = \frac{T_w - T_i}{T_i} x100 \text{-------(3)}$$

Where:

T_w – wet thickness

T_i – initial thickness of oven dry specimen.

Specific Gravity:

The true density of the brake pad materials were determined by weighing the samples on a digital weighing machine with an accuracy of 0.01g – model XP 300 and measuring their volumes by liquid displacement method. Subsequently their specific gravities were determined by dividing the unit weight of the brake pad by the unit weight of water [7].

Brake Pad Wear Test

The brake pad test rig designed and constructed as reported by Dagwa and Ibhadode [11] was used to determine the wear of the brake pads.

Preliminary performance test for wear:

A set of asbestos –free laboratory brake pad was obtained and another set of commercial brake pad of Toyota Carina II model was purchased from Mubi market.

For the determination of the effect of speed on wear of the brake pads, the brake pads were first of all weighed on the digital scale. The flywheel weight chosen for this test was 30kg weight, and a constant brake line pressure of 2 bars (0.2MPa) was used throughout.

Arranging the appropriate pulley and belt assembly varied the sliding speeds. Speeds were therefore varied between 530rpm and 1100rpm, which are equivalent to 6.66m/s and 13.82m/s respectively. The brake pads were fixed one on each side of the disk in the caliper unit. After choosing a particular speed, the electric motor was switched-on and the flywheel was first driven up to a constant angular velocity in its bearings. Subsequently, the brake was operated at 0.2MPa, which forced the pads against the surface of the disk. The timer recorded the stopping time from the time of brake application to when the flywheel was brought to rest. Five (5)-braking applications were performed before measuring the material loss of the friction pad, which was by re-weighing the brake pad on a digital scale.

RESULTS AND DISCUSSION

Physical and Mechanical Properties of the Optimum Formulation Brake Pad

Table 3 shows the physical and mechanical properties of the optimum formulation brake pad and an equivalent commercial brake pad. The table also summarises the test results for the laboratory made brake pads and compares these results with those of the control commercial brake pad.

Standard deviation in parenthesis Based on the laboratory tests carried out, the following results and observations were made:

Hardness

The average hardness for the laboratory specimens was 92 Brinell hardness, while the organic commercial brake pad had 101 Brinell hardness. The results suggest that the laboratory brake pad was only slightly less harder than the commercial brake pad. Hence, the laboratory brake pads would not have adverse effect on the brake disk.

Table 3 Physical and Mechanical Properties of Optimum Formulation and Commercial Brake Pads [6]

Property	Optimum formulation Laboratory brake pad (PKS based)	Commercial brake pad (asbestos based)
Compressive strength (MPa)	103.5(4.350)	110
Hardness, Brinell (at 3000kgf)	92(7.288)	101(2.770)
Modulus of rupture (MPa)	11.36	–
Tensile strength (MPa)	6.8	–
Impact strength (J/mm^2)	0.077(0.031)	0.11(0.019)
Specific gravity	1.65(0.090)	1.89(0.04)
Thermal conductivity (W/mK)	1.46	0.539
Specific heat capacity (J/kgK)	1907(403.340)	1344(166.960)
Average wear (mg/application)	4.4(1.630)	3.8(1.020)
Porosity (%)	21.7(1.709)	–
Coefficient of friction	0.43	0.4
Thickness swell in water after 24hrs (%)	5.03(1.460)	0.9(0.060)
Thickness swell in oil (SEA 40) after 24 hrs (%)	0.44(0.290)	0.30
Flame resistance test after 10 minutes	Charred with 46% ash	Charred with 9% ash.
Shear strength (MPa)	2.45	5.46

Standard deviation in perantesis

Impact

Table 3 shows the impact test results. The impact strength for the laboratory type was 0.07696J/mm^2 while that of the commercial type was 0.1069J/mm^2. It is reported[12] that the Izod impact strength of friction materials ranges from 0.0115 – 0.0154 J/mm^2. This shows that the commercial and laboratory types have acceptable impact strength, that is, they have better shock resistance.

Specific Heat Capacity

The specific heat capacities of the laboratory-made pad and the commercial type are presented in Table 3. These values are 1907 J/kgK and 1344J/kgK respectively.

From the results, the laboratory pad requires more energy to heat its unit mass by 1°C compared to the commercial type. The results show that the commercially made brake pad is more readily heated up than the laboratory pad this is because it has lower specific heat capacity.

Specific Gravity

The specific gravity for the laboratory made brake pad was 1.646 while that of the commercial type had 1.89 as shown in Table 3. This suggests that the laboratory type was lighter in weight compared to the commercial type, whose specific gravity generally varies from 1.99 to 2.25. Lightweight with acceptable strength properties are most desirous for automobile parts.

Porosity

The porosity for five specimens of the laboratory type brake pad was 21.66 ± 1.709% as compared to the work done by Kim et al[13], which varies between 13.32 to 23.91% and commercial brake pad had 7.6%. Friction materials with high porosity have a tendency to decrease noise propensity during brake applications (*ibid*).

Flame Resistance

Both the laboratory specimens and the commercial type specimens did not burn after 7 minutes in the Bunsen burner flame. The flame resistance test showed that 3.54g of laboratory pad did not burst into flame after 10 minutes but charred and after it was weighed it recorded 1.71g (45.7% volatile materials). 3.55g of commercial type did not burst into flame also after 10 minutes but it also charred and when weighed, it was 3.15g (8.77% volatile materials). The laboratory type lost more volatile materials perhaps because of the presence of PKS, which contains pyrolysates. The presence of *qucer* and $CaCO_3$ acted as flame retardant in the formulation. Virtually the same results were obtained when the tests were conducted in a muffle furnace (45.70% and 8.66% for laboratory and commercial pads respectively).

Water and Oil Soak

The test results for water and oil soak tests are also shown in Table 3. The absorption of water by the laboratory and commercial was higher than the samples in oil. This was because water has smaller viscosity and surface tension compared to the SAE 40 engine oil. After 24 hours of soaking, the laboratory made pad absorbed 12.38% and 1.32 % of water and oil respectively, while that of commercial type absorbed 4.29% and 1.3% respectively.

Thermal Conductivity

Using the Lees' Disk Method, the thermal conductivity for the laboratory type was

1.462W/mK. The commercial brake pad could not be obtained in a standard Lees' disk size of 85mm diameter; however attempt was made to determine its thermal conductivity by peeling a commercial brake pad and 50% of the Lees' disk surface area was achieved. With this, the thermal conductivity value was found to be 0.58W/m K.

Generally, the standard thermal conductivities of friction materials range from 0.47 to 0.804 W/mK

When brake associates have improved thermal conductivity they tend to improve the braking efficiency. Therefore from the foregoing the laboratory type was better.

Compression Strength

The compression strength test results are also presented in Table 3. The laboratory type had an average value of 103.55 MPa compression strength, while that of commercial type had an average of 110.07 MPa. In the literature the recommended compression strength for brake materials ranges from 70 – 125 MPa[14]. Hence, both values are within the recommended values.

Coefficient of Friction

This is a dimensionless indication of the friction qualities of one material sliding over another. When the coefficient of friction (COF) is high, there is severe friction on the surface. From the test results shown in Table 3 the laboratory brake pad has an average COF of 0.43 when measured at room temperature while the commercial type had 0.4. Both values are within standard values (0.3 – 0.6) recommended for vehicle brake pads [3].

Tensile Strength

The tensile test result for the laboratory brake pad material was obtained by using the 3-point loading system [3], which determines the modulus of rupture (MOR). For thermosets the MOR is approximately twice the true tensile strength of the material [9]. The tensile test result as shown in Table 3 is 6.8 MPa for the laboratory made pad. This is less than the standard value of 20 MPa [15]. Several efforts to test the prepared tensile test specimens using tensile test machine did not yield a reasonable result because they fractured prematurely.

Tensile test could not be performed on the commercial pads because standard specimens for tensile test could not be prepared from the commercial brake pads that could be accommodated on the tensile test equipment available in the laboratory.

Shear Strength

The shear strength results are presented in Table 3. The laboratory type had an average value of 2.54 MPa while the commercial pad material had 5.46MPa. Both types of brake pads appear to have acceptable shear strength as they were above the standard value (2.10 MPa at room temperature) [16].

Wear

The average wear of the experimental brake pad and the commercial brake pad were 4.4 mg/application and 3.8 mg/application respectively. This indicates that the experimental brake pad wore more than the commercial brake pad.

Comparison between Laboratory Brake Pads and NIS Specifications

The comparison between the laboratory brake pad with that of NIS (1997) [17] specifications for friction materials for road vehicles brake lining and pads reveals that:

(i) the coefficient of static friction for the laboratory brake pads (0.43) is higher than that of the NIS (0.3 – 0.38) specifications, This suggests that the laboratory type may be more effective than that specified by NIS,

(ii) the specific gravity/relative density of the brake pad by NIS is 1.99-2.25 while that of the laboratory type was 1.65. It is important also to note that the relative density of the commercial pad was 1.89 which is less than the NIS recommended range. These therefore indicate that the laboratory type and commercial pads were lighter in weight than the NIS specification.

CONCLUSION AND RECOMMENDATION:

In this work effort has been made to determine some physical and mechanical properties of an asbestos-free experimental brake pad. These properties indicate the measure of reliability of the experimental brake pad when it is compared with the commercial brake pads.

The results of the properties studied for the experimental brake pad were: compression strength (103MPa), shear strength (2.45MPa), tensile strength (6.8MPa), Brinell hardness at 3000kgf (92), specific gravity (1.65), thermal conductivity (1.46W/mK), coefficient of friction (0.43), porosity (21.7%), thickness swell in water and oil after 24-hour (5.03% and 0.44% respectively).

Flame resistance test after 10 minutes (charred with 46% ash), impact test (0.077J/mm^2). Other characteristic studied was the brake pad wear 4.4mg/brake application.

From the foregoing, this work has scientifically shown that the laboratory brake pad has compared favourably well with the commercial brake pad. Thus, Nigeria has good prospects in developing its friction materials industry using locally available materials. This should be encouraged since the advanced countries are making effort to produce asbestos-free materials that are environmentally friendly Nigeria should also be in this race to develop her asbestos – free friction materials. This non-asbestos friction material could be exploited in other friction lining applications too.

It is hereby recommended that there is need for the Standard Organisation of Nigeria (SON) to give specifications for the following properties of friction lining: porosity, moisture content, compressive strength, tensile strength, or modulus of rupture, thermal conductivity and specific heat capacity and flame resistance tests to serve as control to local manufacturers of brake pads.

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