Design, Construction and Testing of an Automotive Brake Pad Test Rig

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Abstract— This paper describes the design and construction of an automotive brake pad testing equipment that can be fitted into an existing diesel engine output rotor. The functionality of the design was tested by using the test equipment to evaluate the performance of three types of commercially available brake pads (i.e. asbestos, semi-metallic and ceramic). The wear rate of each brake pad was determined at different brake disc speed and the applied force on the brake pedal. The braking effectiveness of each brake pad was evaluated in terms of stopping time. The effect of brake disc temperature rise on wear rate was also evaluated for each of the brake pads. The results show that the wear rates of the three brake pads are satisfactory and are comparable with standard values. The ceramic brake pad is the most effective from the viewpoint of braking time and hence stopping distance. This is followed by the asbestos type while the semi-metallic brake pad is the least effective. The ceramic brake pad was observed to wear faster than either the asbestos or the semi-metallic brake pads.

Key words: Design, Brake Pad Test Rig, Wear Testing, Asbestos, Semi-Metallic and Ceramic Brake Pads

I. Introduction

The use of automobile vehicles as a means of transportation on roads and other adaptable surfaces are now an integral part of everyday activities. An important consideration for the safe, effective operation and control of these vehicles is the braking system which must be able to decelerate the vehicle at a faster rate that the engine can accelerate it [1]. There are two types of braking systems: the brake drum and the brake disc systems. Automobiles use either drum brakes, disc brakes or a combination of the two. The main components of a disc brake are the friction brake pads, the caliper, and the rotor. The friction brake material is an important part of the braking system.

The performance of the friction brake material must meet minimum requirements for wear, noise and durability. The brake pad is the friction material in the disc braking system that must be replaced periodically. The brake performance is affected not only by the material and vehicle hardware design, but also significantly by driver behavior, the vehicle usage, the state of adjustment of the brake hardware, and the overall environment in which the vehicle is driven [2].

When replacing the brake pads, there are many different types of friction materials from which to choose in the market. However, it is expected that the brake pads should function the same or better than the original linings in terms of performance. In an unregulated country where there are no specified standards for the friction brake pad in terms of quality and performance, the consumer (vehicle user) is exposed to the risk of getting sub-standard brake pads as replacement brake pads. This may ultimately result in the unexpected failure of the braking system in service.

The important physical properties of the brake pad that is of interest to the vehicle users include [1] the wear rate and its effectiveness. Other consumer demands include durability, safety and low cost which are functions of the above mentioned physical properties [3]. It is also observed [2] that even when a number of materials tests (compression tests, thermal conductivity measurements etc.) are employed during the development of friction brake materials and additives, the final qualification test for brake materials involves extensive, on-vehicle tests with full-sized components. Several types of testing machines have been developed [4] which were aimed at making brake systems safe, predictable in performance and reliable in service. Some of these machines include a variety of laboratory-scale testing machines ranging from massive inertial dynamometer with electronic controls and sensors [5] to small rub-shoe [6] and fly-wheel type machines [7,8,9]. Others are Gould recording instruments, Euro type test equipment, FAST (Friction Assessment and Screening Test) machine, Chase machine, etc.

The various types of available friction brake-materials testing facilities are summarized [2] as follow:

1) Vehicle road tests
2) Vehicle skid-pad tests
3) Vehicle-Drive-on Dynamometers (in-ground or portable)
4) Inertial Dynamometers (full size hardware)
5) Inertial Dynamometers (sub-scale hardware)
6) Laboratory Tribometers

We would however like to note that majority of the available equipment for evaluating and testing the performance of brake pads are very costly and scarce in developing countries such as Nigeria.

II. Objective

This paper focuses on the design, construction and testing of an experimental laboratory brake pad test rig equipment that can be fitted to an existing Diesel engine. The test rig was then used to determine the performance and quality of automotive friction brake pad by simulating the braking system and conditions of a vehicle on which the brake pads are to be installed.

The present work utilizes an existing high power 150hp Gardner Diesel engine (speed range of 4000 to 7500 rpm), available in the laboratory at the University of Lagos, to drive the disc brake (rotor) of the test rig. The speed of the Diesel engine is controlled by a hydraulic governor provided with the fuel injection system. This allowed the speed of the brake disc in the test rig to be varied between 500rpm and 1500rpm. The primary aim of this project is to develop an experimental laboratory brake pad test rig that can be used to investigate:

- The effect of speed and contact pressure on the wear rate of locally available automotive friction brake pad materials
- The average stopping time and hence the effectiveness of the brake pad materials at different speed
- The effect of applied pedal force and disc contact pressure on disc temperature rise.

The results obtained from the brake pad tests are used to demonstrate the functionality of the test rig and compare the wear rates and effectiveness of the three types of commercially available automotive brake pads (asbestos, semi-metallic and ceramic) in the Nigerian market.

III. DESIGN

A. *Design Philosophy and Description*

The idea behind the construction of the test rig is to utilize the high speed or high power output, 150hp (4000 to 7500rpm) of the Gardner diesel engine to drive the shaft of the test rig in order to wear the brake pads being tested. The machine assembly is mounted on a cast concrete base with the test rig sitting on an adjustable wood that is used to align its height so that the rotor can be fitted to the flange of the diesel engine. The wood also dampens the vibrations experienced during the experiment. Fig.1 shows the isometric view of the Diesel engine and friction brake pad test rig assembly. The test rig machine assembly consists of the following components: a 5.5hp$(1600 \pm 5rpm)$ gasoline engine, compressor, a servo-mechanism, air and hydraulic pressure gauges, braking system and a Peugeot 406 automobile disc and caliper brake unit. The gasoline engine drives the compressor via a power transmission belt.

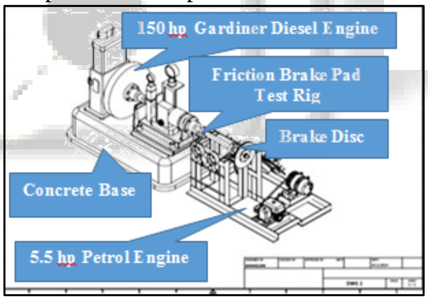

Fig. 1: Isometric view of the Diesel Engine and Brake Pad Test Rig Assembly

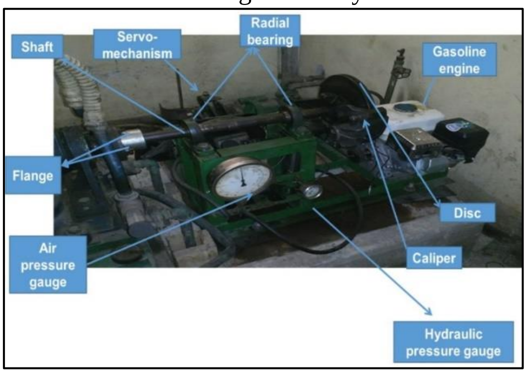

Fig. 2: Picture of the Friction Brake Pad Test Rig Assembly

The suction part of the compressor provides the servo-mechanism with the sub-atmospheric pressure that it needs for its operation while the compressed air is released in a controlled manner via a pressure regulating valve to the atmosphere. The servo-mechanism amplifies the force that is being exerted on the brake pedal so as to make braking easier. A disc brake system is also incorporated into the machine. It consists of a brake disc rotor, two brake pads and a caliper which houses the brake pads. An air pressure gauge is connected to the compressor to ensure the pressure in the servo-mechanism is within allowed limits. A fluid pressure gauge (range 0.00 to 2.06 MPa) is also connected to the hydraulic fluid line of the disc brake system to measure the pressure corresponding to the force exerted on the pedal. The flange of the shaft for the rotor of the brake pad test rig assembly is connected to the diesel engine by means of M19 bolts and nuts. Fig. 2 shows the picture of the friction brake pad test rig. Ref. [14] has the details of the design with calculations.

B. *Mode of Operation*

First, the brake pad to be tested is inserted into the caliper of the brake assembly. The gasoline engine is then run to power the compressor. Both are linked through a v-belt via two pulleys on the adjacent sides of the units (see Fig. 3).

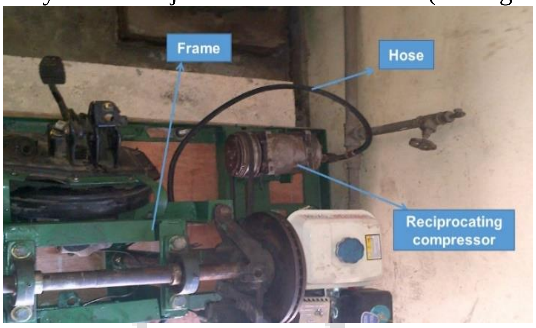

Fig. 3: Picture of the Compressor side of the Test Rig Assembly

The petrol engine is started by turning the engine switch to the "ON" position while moving the throttle lever away from the slow position about one-third of the way toward its initial position. The throttle lever is then positioned for the desired engine speed (e.g. 1500 rpm) The air pressure gauge connected to the suction nozzle of the compressor via a rubber hose (13mmØ) records the pressure (0.058MPa (0.57atm)) to ensure that it is enough to power the servo mechanism. The diesel engine is then turned on by rotating the starting lever. The speed of the diesel engine which is read on a speedometer is controlled by a hydraulic governor provided with the fuel injection system. A typical test involves switching off the diesel engine at the desired speed (say 500 rpm) and simultaneously applying a force (say 22.24 N) on the brake pedal. The corresponding contact pressure of 0.34 MPa on the brake disc is recorded by the hydraulic pressure gauge until the brake disc comes to rest. This process is repeated for other brake disc speed of 750, 1000, 1250 and 1500 rpm respectively.

IV. TEST METHODOLOGY

Three types of commercially available brake pads were purchased from auto dealers and labelled: Pad A (Asbestos type), Pad B (Semi-metallic type) and Pad C (Ceramic type). At a given speed of rotation of the diesel engine, the brake pad test rig assembly is set in operation by depressing the clutch lever and gently withdrawing the starter key on the diesel engine to allow the rotating brake disc to gradually come to a rest. A stopwatch is used to determine the stopping time. By putting different weights on the pedal plate, appropriate force can be applied on the brake pad while test measurements such as stopping time and other parameters are recorded. The brake pad is then removed from the caliper. Measurements are taken with the aid of a micrometer screw gauge to account for decrease in thickness and hence the wear rate of each of the three types of brake pads.

A micrometer screw gauge is used to measure the reduction in thickness after 20 brake applications. The choice of 20 brake applications is to allow for appreciable and measurable reduction in thickness of the brake pad. Thereafter, the average of the values is taken to give the reduction in thickness per brake application. A thermocouple connected to a multi-meter is used to measure the rise in temperature of the disc. The contact pressure applied on the brake pad is read from the hydraulic pressure gauge connected to the fluid line of the brake disc system. In order to ensure reproducibility of the test data, each test on a brake pad at a given speed is repeated three times and the average of the readings is taken as the test result.

V. PERFORMANCE EVALUATION TESTS

The performance test on each brake pad was carried out using the brake pad test rig described above to determine the effect of speed and contact pressure on the wear of brake pad, average stopping time and also account for the disc temperature rise. The test was carried out in two stages:

- keeping brake pedal force and brake pad contact pressure constant while varying the rotating speed of the diesel engine (between 500 and 1500rpm),
- keeping rotating speed constant while varying the contact pressure on the brake pad (from 0.38 to 0.50 MPa) and the applied force on the brake pedal (between 17.78 and 35.59N).

The wear rates, average stopping times and the disc temperature rise of the three types of brake pads under test were measured and recorded.

VI. RESULTS AND DISCUSSIONS

A. Effect of Speed on Brake Pad Wear

Table 1 shows the experimental data from the effect of brake disc speed on brake pad wear (in terms of reduction in thickness of the three types of brake pads). From the table, it can be deduced that the average wear rate of pad A at a constant pressure of $0.34MPa$, constant force of $22.24N$ and at a brake disc speed of 750rpm is $2.72\text{x}10^{-3}$mm per brake application and that of pad B is $2.77x10^{-3}mm$ per brake application, while that of pad C is 3.22 x 10^{-3}mm. These values are slightly higher than the average wear rate of a typical automotive brake pad. Material of $5x10^{-4}mm$ per brake application [2].

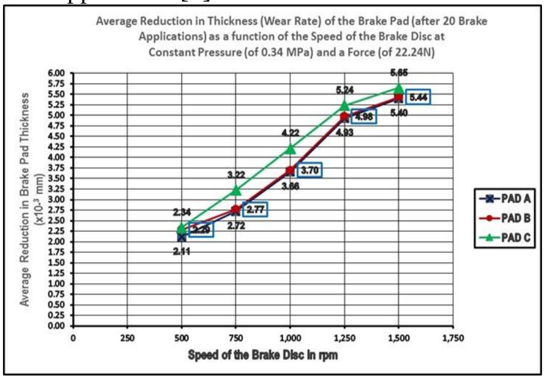

Fig. 4: Wear Rate of the Brake Pad as a function of the Speed of the Brake Disc

For the three brake pads, Fig. 4 shows that the Ceramic Brake Pad C wears more than either Pad A (asbestos) or Pad B (semi-metallic). This is not surprising because of the brittle nature of ceramic material compared to either semi-metallic or asbestos brake pads.

B. Effect of Pedal Force and Brake Disc Contact Pressure on Brake Pad Wear

Table 2 illustrates the data from the effect of applied pedal force and contact pressure on brake pad wear (in terms of reduction in thickness) for the three types of brake pads at at constant brake disc speed of $750rpm$. From the table, it can be deduced that the average wear rate of pad A at $750rpm$ with an applied force of $31.14N$ is $3.43x10^{-3}mm$ per brake application. The corresponding values for pad B and pad C, are $3.64x10^{-3}mm$ and $3.72x10^{-3}mm$ respectively. Since these values are slightly higher than the reported [2] typical automotive brake pad wear rate of $5x10^{-4}mm$, it can be concluded that the three brake pads used in the test have acceptable wear rate.

Speed of Brake Disc (rpm)	Reduction in thickness after twenty(20) brake applications ($\text{x}10^{-3}$mm)				Reduction in thickness after twenty (20) brake applications (x 10^{-3} mm)				Reduction in thickness after twenty (20) brake applications ($\text{x}10^{-3}$mm)			
	PAD A				PAD B				PAD C			
	sample1	**sample2**	**sample3**	**Average**	**sample1**	**sample2**	**sample3**	**Average**	**sample1**	**sample2**	**sample3**	**Average**
500	2.10	2.11	2.12	2.11	2.27	2.29	2.30	2.29	2.32	2.34	2.35	2.34
750	2.71	2.72	2.73	2.72	2.76	2.77	2.78	2.77	2.87	2.89	3.90	3.22
1000	3.64	3.66	3.67	3.66	3.69	3.70	3.72	3.70	3.87	3.88	4.90	4.22
1250	4.92	4.93	4.95	4.93	4.96	4.98	4.99	4.98	5.23	5.24	5.25	5.24
1500	5.39	5.40	5.41	5.40	5.42	5.44	5.45	5.44	5.64	5.65	5.67	5.65

Table 1: Effect of Speed on Brake Pad Wear at Constant Pressure (0.34MPa) and Constant Force (22.24N)

Brake Pedal Force (N) at 750rpm	Average Reduction in Brake Pad Thickness (x 10^{-3}mm)			Brake Disc Contact Pressure(MPa) at 750 rpm
	PAD A	PAD B	PAD C	
17.78	2.43	2.67	2.74	0.38
22.24	2.72	2.77	2.92	0.41
26.69	2.93	2.99	3.30	0.44
31.14	3.43	3.64	3.73	0.49
35.59	4.73	4.86	5.23	0.50

Table 2: Effect of Applied Force and Contact Pressure on the Wear of Brake Pad

C. *Braking Effectiveness of Brake Pad*

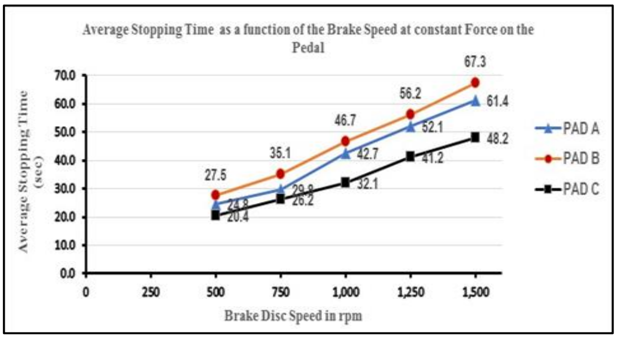

Fig. 5: Average Stopping Time as a function of the Brake Speed at constant Force on the Pedal

The braking effectiveness is generally determined by vehicle deceleration or stopping distance, pedal travel and pedal force [10,11]. Stopping distance is extremely important for emergency braking. Fig. 5 shows the plot of average stopping time of the three types of brake pads under conditions of varying speed at constant force of 22.24 N on the pedal and contact pressure of 0.41 MPa. From the graph, it is evident that at any given speed of the brake disc, the brake pad B (semi-metallic) takes a longer time to stop than brake pad A (asbestos) while brake pad C has the least stopping time. For all the brake Pads and under the application of constant force on the brake pedal, the stopping time increases with increasing speed of the brake disc.

The plot of the average stopping time of the brake pads under conditions of constant speed (750 rpm) and different applied force on the pedal is shown in Fig.6. Here, it is seen that Brake Pad B (semi-metallic) takes a longer time to stop than Brake Pad A (asbestos), while Brake Pad C (ceramic) shows the least stopping time. Similarly, it is seen that at any brake pedal force, the Brake Pad C shows the least stopping time and hence is the most effective brake pad any brake pedal force, the Brake Pad C shows the least stopping time and hence is the most effective brake pad

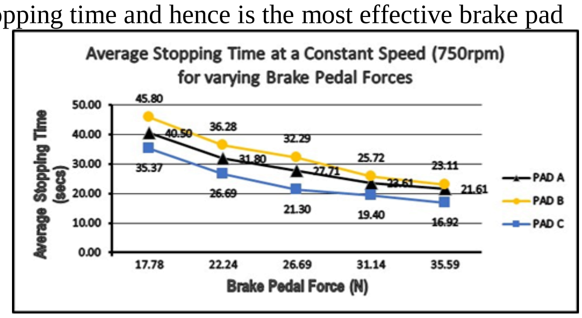

Fig. 6: Average Stopping Time of Brake Pad at constant speed (750 rpm) and for varying Brake Pedal forces.

D. *Effect of Disc Temperature Rise on Brake Pad Wear*

Modern automotive disc brake systems can generate extremely high temperatures under high but short duration braking loads or under relatively light but continuous braking [12]. The result is the temperature rise emanating from the thermal resistance between the pad and the disk and which prevents the brake disc from absorbing the generated heat at the contact surface of the pad [13]. One possible consequence of this temperature rise is the gradual heating of the brake hydraulic fluid which can lead to boiling of absorbed water and loss of braking effectiveness. Fig.7 shows the graph of brake pad wear rate (in terms of reduction in thickness) as a function of brake disc temperature rise. From this plot, it is seen that Brake Pad B (semi-metallic) has a higher disc temperature rise.

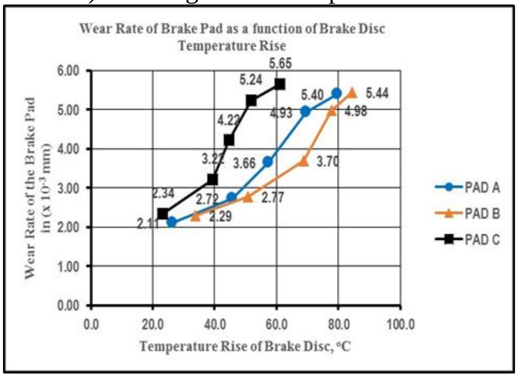

Fig. 7: Wear Rate of Brake Pad as a function of Brake Disc Temperature Rise

VII. CONCLUSION

An experimental brake pad friction material test rig that can be fitted to an existing Diesel engine has been successfully designed and constructed. Using this equipment, it has been demonstrated that the brake pad test rig can be used to rank and evaluate the performance and quality of three types of commercially available automotive friction brake pads. (i.e. asbestos, semi-metallic and ceramic) by simulating the braking system and conditions of a vehicle on which the brake pads are to be used. On the basis of the results of the brake pad performance tests the following conclusions may be reached:

- The wear rate of the three types of commercially available brake pads in the Nigerian market is satisfactory and compare favorably with standard values.
- The ceramic brake pad C is the most effective brake pad from the viewpoint of braking time and hence stopping distance. This is followed by the asbestos type while the semi-metallic is the least effective.
- At all speed of the brake disc and for any applied force on the brake pedal, the ceramic brake pad C wears faster than either the asbestos or the semi-metallic brake pads.

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