PERFORMANCE CHARACTERISTICS OF A WOOD BY-PRODUCT AS BASE FRICTION LINING MATERIAL

A.N. Enetanya
Department of Mechanical Engineering
University of Nigeria, Nsukka

L.E.S. Akpanisi
Department of Pure and Industrial Chemistry
University of Nigeria, Nsukka

ABSTRACT

Material mix and composition as well as detailed production processes using saw-dust as base friction lining material have been studied. The resulting friction brake lining materials were additionally subjected to thermal cycles and associated baking and curing. The final products were thereafter subjected to laboratory and road performance tests which included investigations of the effects of temperature and pressure on the friction lining coefficients, the response to immersion in water, lining surface hardness values and the average rate of wear during actual performance on the road. Other physical and mechanical properties were also investigated. The results show that these products possess acceptable properties for commercial applications.

Key Words*: Friction coefficients, temperature/pressure effects*

1. INTRODUCTION

Friction materials for clutches, moulded brake pads and brake shoes are produced by blending heterogeneous mixtures of organic and inorganic materials which are subsequently subjected to a combination of cold-pressing, sintering and hot-pressing. The ingredients are required to provide a range of properties, which must be possessed by friction clutch or brake linings. These properties include: adequate mechanical strength, high and uniform friction coefficients over a wide range of conditions such as pressures, temperatures and sliding velocities, heat resistance and good thermal conductivity, low wear rate, no abrasive action on brake drum (for shoe brakes) or brake plate (for disc brakes) low moisture sensitivity and rapid recovery following immersion in water. Other recommended properties include high bonding strength to the brake plate or brake shoe, low shrinkage or swelling and, most important, low cost.

Equally significant are the necessary production processes, from the preparation of the various constituents of the powder mix to the blending, compaction and curing of the final product. Important parameters in these production processes include the sieve size range of the base powder materials, percentage contents of the mix, the compaction pressure and heating sequence, the actual pressures, temperatures and durations of these processes.

Until recently asbestos was the most common base friction lining material [1] as it possesses a good number of the necessary properties. However asbestos is now banned in all developed countries on account of its cancer related health hazards. Alternative base friction lining materials are continually being developed and tested. Iloeje et al [2] have developed and successfully produced and tested asbestos-free blend of mixtures using a locally sourced organic base material for commercial applications. A typical base material imparts mechanical strength and bulk; other constituents in smaller proportions are friction particles, vulcanizing agents, bonding agents, additives (as carbon black to improve the tensile strength, and brass chips to increase wear resistance and reduce drum or plate scoring).

The final products - friction linings - are subjected to tests, to determine the effects of temperature, pressure, sliding speed and moisture on the coefficients of friction. Road performance tests on the friction linings are necessary to confirm simulated laboratory tests and to monitor the wear rate during normal operations of vehicles using these friction linings. In normal use, the rubbing action of the mating surfaces generates heat, resulting in increases in the temperature of the brake plate or drum. High sliding speeds and large pressure loads tend to generate enormous amounts of heat and increased wear rate [3, 4]. Moreover wear rate and lining life are very dependent on plate and drum temperatures as well as on sliding speed and pressure. Thus, the effects of these three factors of pressure, temperature and sliding speed are interrelated [5]. The increase in temperature tends to reduce the coefficient of friction. On the other hand the wear of the friction lining tends to restore friction so that some small amount of wear is required for a balanced performance and to keep clean the lining and drum or plate surface. Very high plate or drum temperatures can result in degradation of friction lining surfaces, and possible abnormally high coefficient of friction with subsequent brake squeal [6]. It can alternatively result in brake fading, which is the abrupt drop in friction coefficient at high plate or drum temperatures.

This paper is a summary of recent investigations, on production and performance of moulded brake linings, using a particularly abundant organic base friction lining material -saw dust, a by-product of wood.

2. PRODUCTION PROCEDURE

The production involved preparation of the base powder, mixing the constituents, and preparation of the mould and brake pad backing plates for powder compaction, sintering and hot-pressing. Base powder particle size distribution and quality significantly affect the sintering rate [7].

2.1. **Powder Mix and Mould Preparation**

The powder mix consisted of saw-dust as the base material (about 45% wt) to provide bulk and mechanical strength and varying smaller quantities of urea and phenolformaldehyde (20% wt) resins and latex (8.5% wt) as bonding agents, clay (9.5% wt) (for heat resistance, fire retardation and as friction particles), carbon black (5.0% wt) to improve mechanical strength and add colour, sulphur and zinc oxide (1.8% wt) as vulcanizing agents, and brass chips (10.2% wt) for wear resistance and to reduce brake plate scoring. The mixture was thoroughly ground, blended and measured out to determine the sieve size range, bulk density and tap density.

The particle mix was sieved to establish particle size distribution using the Endcott Mechanical Sieve Shaker. The result is shown in Table 2.1. The bulk density was determined by gradually filling a dry cylindrical container 100mm in diameter and 43mm deep. This was weighed and the mass of the content was obtained by subtracting the mass of the container, to compute the bulk density of the powder mix. The tap density was determined by measuring out the mass of the powder mix within the above cylindrical container after tapping twenty five times. Each tapping consisted of dropping a 2.5 kg tap-rod in a guided gravitational fall through an 87mm travel on a larger container enclosing the cylinder and the mix. The results indicate powder mix bulk density of 77. *88kg/m3* and tap density equal to *98.90kg/m*^{3}

The mould was next prepared and set for the introduction of the powder mix. For convenient road performance tests of the final products the mould was designed and produced with the shape and cross-section of the 504 Peugeot car disc brake pad.

The brake pad back plate was carefully smoothened with a file and finally with an emery cloth which was also used to prepare the mould surfaces. A single compaction plunger was next assembled in readiness for the introduction of the powder mix (Fig 2.1).

2.2 Establishment of Optimum Cold-pressing, Sintering and Hot-Pressing Parameters

From earlier investigations (8) the quality of the final brake pad had been found to be very dependent on the following production process parameters

(a) Cold-Pressing (Application of Pressure without Heating) Pressure and Duration
(b) Sintering (Application of Heat without Pressure) Temperature and Duration
(c) Hot-Pressing (Simultaneous Applications

of Heat and Pressure) Temperature, Pressure and Duration

Approximately 80g of the powder mix was poured in the mould cavity for each brake pad sample and then subjected to sequences of cold-pressing, sintering and hot-pressing. The temperatures, pressures and durations of these processes were established as indicated in Table 2.2, for six sample specimens.

3. PRELIMINARY LABORATORY TESTS

Laboratory tests and visual inspections were conducted on the six specimens to establish the best combinations of cold-pressing, sintering, and hot-pressing durations, temperatures and pressures.

3.1 The Scratch Hardness Test

Scratch hardness values, based on Mohs' Scale (Table 3.1) were established for each of the six sample specimens. The results are shown in Table 3.2.

3.2 Low Load Static Coefficients of Friction

A steel plate was polished and prepared to represent the rubbing plate on which the final brake pad would act when mounted on the automobile. The steel plate, in surface to surface contact with the brake pad, was next fixed on a flat board and the inclined plane method was used to determine the low load static coefficients of friction between the brake pads and the steel plate (Fig. 3.1). This consisted of gradually increasing the slope of the inclined plane, using the wedge in Fig. 3.1, until the brake pad began to slide down the steel plate. The static coefficient of friction,.μ_s is given by

$$\mu_s = \tan\theta \qquad (3.1)$$

where θ is the angle of the inclined plane in Fig. 3.1. This was performed several times for each brake pad specimen to establish and average value for μ_s. The results are summarized in Table 3.3.

3.3 Comparative Wear Test

A test rig, similar to the rig used by Iloeje et al [2] was devised using a centre lathe (Fig.3.2). This consisted of a wheel disc mounted in the lathe chuck against which the brake pad, inside a special holder, was made to press, with a measured force of about to 60 kg. For brake pad surface area of approximately 38.5cm^2 or 3.85 x 10^{-3}m^2 this gives a pressure loading of approximately 156 kPa[1]) A fine emery cloth was bonded to the face of the disc plate in order to accelerate the brake pad wear rate. Before each test, the emery cloth was dulled by rotating against a used brake pad (inside the brake pad holder) through thirty revolutions. The thickness of each brake pad specimen was measured before running against the disc plate for a fixed duration of 20 minutes. Thereafter, it was again measured to determine the amount of wear. The resulting wear for each brake pad specimen is shown in Table 3.3. This gives the relative wear resistance for each set of production process parameters

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[1] An approximate value of 10.0m/s^2 is used here for g in converting Kgf to Newtons reflecting the approximate nature of values of coefficients- of friction.

Table 2.1 Powder Mix Particle Size Distribution and Densities

Sieve No.	Mesh Diameter (mm)	% Retained	% Passed	Mass of Retained Sample (g)
16	1.000	2	98	1
22	0.699	4	94	2
30	0.500	6	88	3
44	0.350	8	80	4
60	0.250	10	70	5
85	0.178	10	60	5
120	0.124	8	52	4
150	0.104	8	44	4
170	0.089	4	40	2
240	0.064	8	32	4
300	0.053	4	28	2
PAN		28	0	14
TOTAL		100	100	50g

Bulk density = 0.07788g/cm^3=77.88kg/cm^3
Tap density = 0.09890 g/cm^3 = 98.9kg/m^3

Table 2.2 Initial Powder Compaction, Heating and Pressing Temperatures, Pressure and Durations

Sample No.	Production Process	Process Temp. (^{o}C)	Process Pressure (Mpa)	Duration (Mins)
	Cold-Pressing	Room Temp. (30°C)	6.75 - 7.0	20
1	Sintering Hot-Pressing	190 205	Atm. Pressure 6.75 - 70	20 40
2	Cold-Pressing Sintering Hot-Pressing	Room Temp. (30°C) 185 205	6.75 - 70 Atm. Pressure 6.75 - 70	15 15 25
3	Cold-Pressing Sintering Hot-Pressing	Room Temp. (30°C) 170 200	6.75 - 70 Atm. - Pressure 6.75 – 70	10 10 20
4	Cold-Pressing Sintering Hot-Pressing	Room Temp. (30°C) 200 220	6.75 - 70 Atm. Pressure 6.75 – 70	30 15 35
5	Cold-Pressing Sintering Hot-Pressing	Room Temp. (30°C) 180 200	6.75 - 70 Atm. Pressure 6.75 – 70	15 15 25
6	Cold-Pressing Sintering Hot-Pressing	Room Temp. (30°C) 160 170	6.75 - 70 Atm. Pressure 6.75 - 70	10 15 20

Table 3.1: Mohs' Scale of Relative Hardness Numbers for Minerals

Mineral	Hardness number	Mineral	Hardness number
Talc	1	Feldspar	6
Guypsun	2	Quartz	7
Calcite	3	Topas	8
Flaurite	4	Corundum	9
Apatite	5	Diamond	10-42

Table 3.2: Scratch Hardness Test Results for Brake Pad Samples

Specimen Number	Relative Scratch Hardness Number
1	4/5(Flaurite/Apatite)
2	4/5(Flaurite/Apatite)
3	4 (Flaurite)
4	4/5(Flaurite/Apatite)
5	4 (Flaurite)
6	3/4(Flaurite/Apatite)

Table 3.3: Low Load Static Friction Coefficients and Comparative Wear Test Results

Specimen number	Low load static friction coefficient $\mu_s = \tan\theta$	Wear (mm) (at 15kPa)
1	0.44	0.16
2	0.45	0.17
3	0.47	0.20
4	0.44	0.15
5	0.44	0.20
6	0.48	0.21
mean	$\mu_{sav} = 0.45$	0.18

Table 3.4. Recommended Quantity Production Process Parameters for the Brake Pads

Production Process	Process Temp. (^{0}C)	Process pressure (Mpa)	Process Duration (Mins)
Single Compaction Plunger Cold Pressing	Room Temperature (30)	6.75 -700	10-15
Sintering	205 -210	Atm. Press	15 -20
Single compaction plunger Hot pressing	205 - 210	6.75 -7.00	15 - 30

3.4: Effects of the Production Process Parameters

The choice of the process pressure range of 6.75 to 7.00 Mpa was partly based on earlier investigations [2,8]. At this production pressure range the resulting brake pads possess good wear resistance with virtually no voids or cavities. The above test results on the preliminary brake pad samples suggested that this pressure range was adequate; additional pressure increase was unnecessary. The combination of this pressure range with the higher process temperatures of 205°C to 210°C also gave the products the necessary hardness range for good performance. The tests therefore suggested that the best products were those involving hot-pressing and sintering temperatures of 205 to 210°C. The above pressure and temperature ranges together with process durations of 10 to 30 minutes were therefore recommended for the mass- production of the brake pads. These are shown in Table 3.4.

4. BRAKE PAD SAMPLES FOR MASS PRODUCTION

The production process parameters in Table 3.4 were used to produce more samples that were in addition subjected to four thermal cycles between 60^0C and 250^0C at a constant brake lining pressure of 208 kPa. This gave the final brake pads additional baking and curing on the lining outer layers for improvements in wear resistance, hardness, and other properties. These steps represent the mass production processes for brake pads for commercial applications. These samples were again subjected to laboratory tests and finally to road performance tests.

4.1 Additional Laboratory Tests on Mass Production Brake Pad Samples

Those laboratory tests in Section 3 were repeated on the sample brake pads that were produced using the process parameters recommended in Table 3.4. These tests included the scratch hardness test and the determination of the low-load static coefficients of friction. The results are presented in Table 4.1, which has a summary of the average properties of the final brake pad samples. In order to determine the mechanical and other properties of the friction brake - linings, twenty-five samples were produced using the above recommended production process parameters, without the backing plates. The resulting products were weighed and measured to determine the average density and specific gravity. Other samples were cut, measured and subjected to standard tests for compressive and tensile strengths. The results are summarized in Table 4.1.

4.2 Effects of Pressure and Temperature on Static and Low-speed Dynamic Coefficients of Friction

The arrangement in Fig. 4.1 was used to investigate the effects of pressure and temperature on the static and low-speed dynamic coefficients of friction between the brake pad samples and the steel plate. Values of the horizontal forces F_s and F_{1d}, respectively to start, and move the friction pad, subjected to vertical forces W from a hydraulic press, along the horizontal steel plate were measured. As the pad stated to move slowly along the steel plate the force F_s would be expected to change to F_{1d}, For each value of W, the static coefficient of friction μ_s is given by

$$\mu_s = \frac{F_S}{W} \qquad (4.1)$$

The corresponding low speed dynamic coefficient of friction μ_{1d} is given by:

$$\mu_1 = \frac{F_{1d}}{W} \qquad (4.2)$$

The pressure, P, on the pad is given by

$$P = \frac{W}{A_P} \qquad (4.3)$$

Where A_p is the brake pad apparent contact surface area, approximately equal to 3.85 x $10\text{-}^3 m^2$

Equations (4.1) through (4.3) were evaluated for W = 200N, 400N, 600N and 800N for steel plate temperatures between 60°C and 300°C. The low-speed dynamic coefficients of friction for this particular brake material were more or less the same as the static coefficients of friction for a given temperature and pressure. The results are shown in Fig. 4.2. Average properties of the friction pad samples are shown in Table 4.1.

4.3 Water Absorption Tendencies and Rate of Recovery After Immersion

Sample friction brake pads were soaked in water for 60 minutes. Therefore, the static coefficients of friction on the steel plate were measured every five minutes at room temperature (30°C) and 130kP_a pressure. The results are shown in Fig. 4.3.

4.4 Road Tests to Establish Operational Rate of Wear and General performance

Sample brake pads were ground down to about 12mm friction lining thickness and prepared for installation on Peugeot 504 passenger car front wheels. The brake pads were cleaned with a fine emery cloth and measured to determine actual friction lining thicknesses. The car brake plates were also cleaned with an emery cloth; following this. the brake pads were installed on the front wheels of the car.

No peculiar noise, smell or performance problem was observed as the car was used for routine operations for 14000 km. The brake pads were subsequently removed, checked and measured to determine the amount of wear. The brake pads showed an average wear of 0.90 mm over the 14000 km distance.

5. RESULTS AND DISCUSSION

The low-load friction coefficients of the brake pads at room temperature (about 30°C) ranged from 0.44 to 0.48 with an average value of 0.45. More significantly temperatures and pressures were shown to have profound effects on these friction coefficients (Fig. 4-2). Generally, the effects of high sliding speeds and pressures on friction linings are the generation of high local temperatures due to frictional heating at points of actual contact of surface asperities, and increased wear rates. At a given pressure the static coefficients of friction showed some increase with temperature; this was followed by a steady drop to some minimum value, and finally a gradual increase with temperature. The low-speed friction coefficients were in general, approximately the same as the static coefficients of friction for these brake pads.

Following immersion in water for 60 minutes, the static coefficient of friction dropped to a very low value, somewhat below 0.20 immediately after removal from water. It then rose rapidly to a value above 0.55 in the next five minutes. Subsequently, it fell to below 0.50 some thirty minutes after removal from water. Gradually, it returned to normal values in the next twenty minutes (Fig.4.3). These friction coefficients were measured at room temperature (about 30°C) and 130 kPa friction lining pressure. A more rapid return to normal values after immersion would be expected in normal operation on an automobile, above room temperatures.

Table 4.1 Average Prosperities of the Mass Production Samples of the Brake Pad Friction Linings

	symbol	
Compression Strength (Mpa)	S_{uc}	50-60
Tensile Strength (Mpa)	S_{ut}	15-20
Scratch Hardness Number (Mohs' Scale)	-	4/5
Specific Gravity	S.G.	1.20
Wear rate on Brake Plate(mm/1000km)	-	0.064
Low Load Static Friction Coefficient	μ_s	0.45
Low Speed Dynamic Friction Coeff.	μ_{1d}	0.45
Average Static Friction Coeff. (120^0C,136 kPa)	μ_{sav}	0.45

Although the tests have not included those involving actual variations of sliding speeds, these were implicit in those tests involving combinations of elevated temperatures and relatively high pressures. The main effect of high sliding speed is the generation of high local temperatures due to frictional heating at the points of real contact. This is accompanied by wear and related wear transfers [3, 4].

The recorded rate of recovery (Fig. 4.3), after immersion in water, expectedly is average for these lining materials because they are dry-mix linings.

Other physical and mechanical properties of the friction brake linings, including the wear rate, tensile and compressive strengths and hardness confirm the suitability of the blending, mixing, cold-pressing, sintering, hot-pressing and other related production processes.

6. CONCLUSION AND RECOMMENDATIONS

Material mix, composition and production processes for friction brake lining using saw-dust as the base friction .material have been studied in this report. The post-production thermal cycles with the accompanying baking and curing of the friction lining surfaces are especially important for improved physical and mechanical properties of the final products. The final products were subjected to laboratory and road performance tests. The results have shown that these brake lining materials possess acceptable properties for commercial applications. Design and production of suitable mass-production equipment and machines for these products are hereby recommended.

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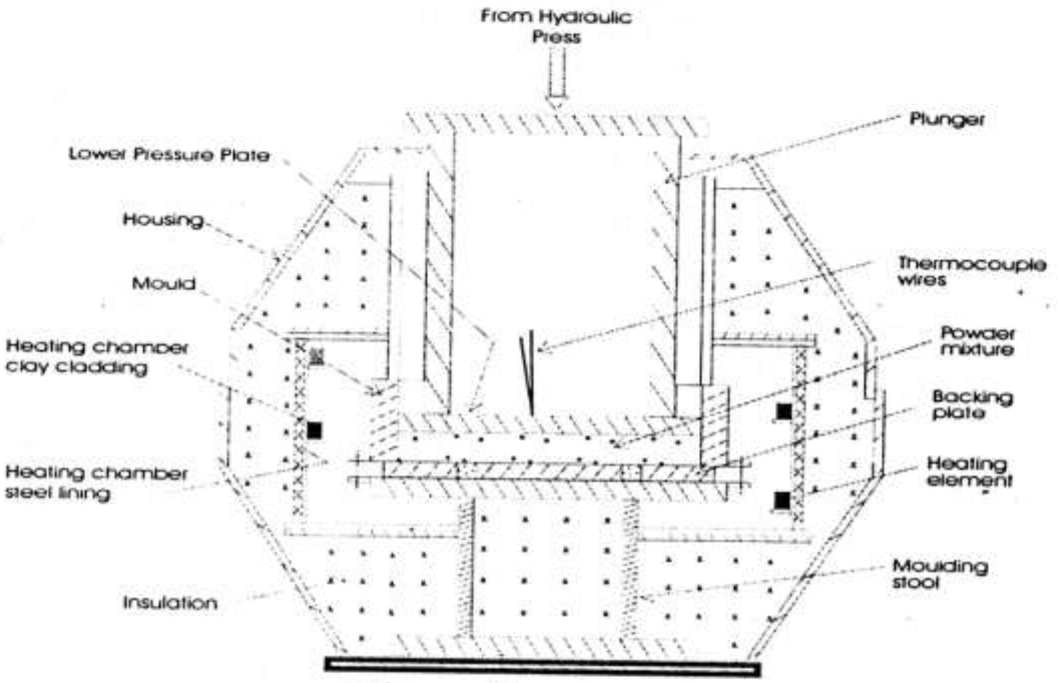
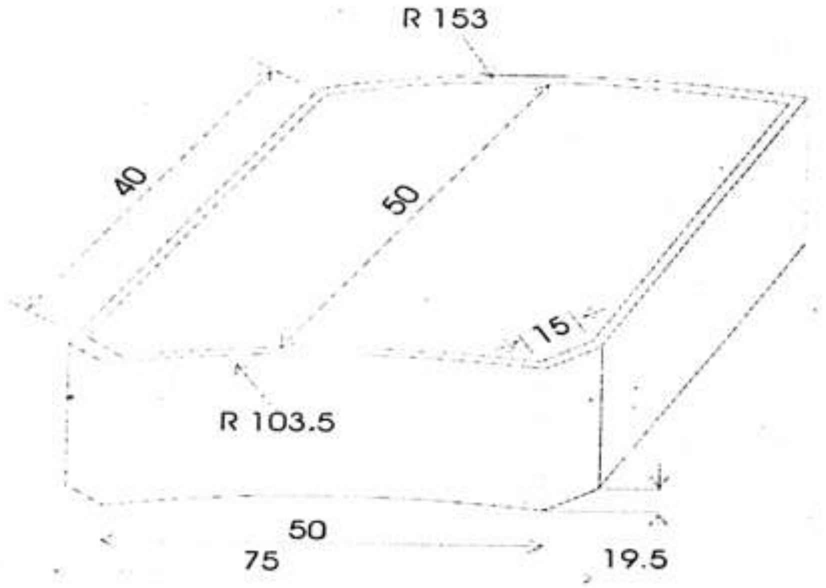
NOTATION

A = actual brake pad contact surface area in the frictional force equation
A_P = brake pad apparent contact surface area
F_{1d} = value of horizontal force to maintain the motion of weight W against friction
F = total frictional force
F_s = value of horizontal force to start the motion of the weight W against friction
P = Static pressure on brake pad surface
W = Total weight on friction pad surface
S_{ut} = tensile strength of friction lining
S_{uc} = compressive strength of friction lining
μ_S = static friction coeffiction of friction lining on steel surface
μ_{1d} = low speed dynamic friction coefficient of friction lining on steel surface
μ_{sav} = average static coefficient of friction lining on steel plate
θ = angle of inclined plane of steel plate in friction pad static friction test.



a) Compaction and Heating Rig



b) Brake Pad Mould

Dimensions in mm

Fig 2.1: Powder Mix Compaction and Heating

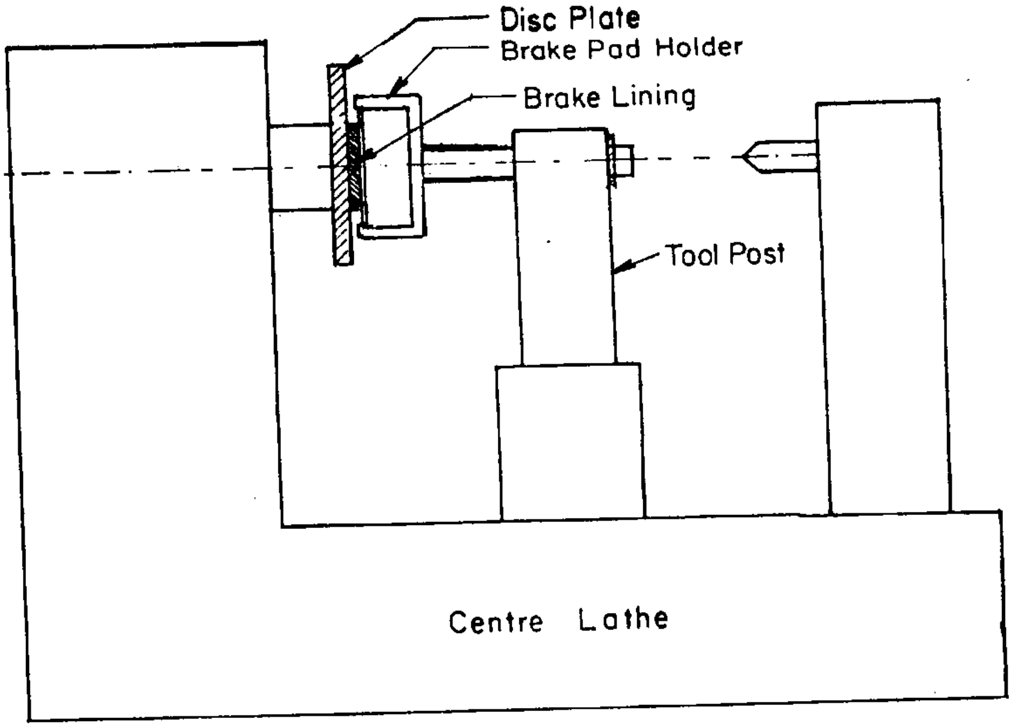


Fig.3.2 Wear Test Rig.

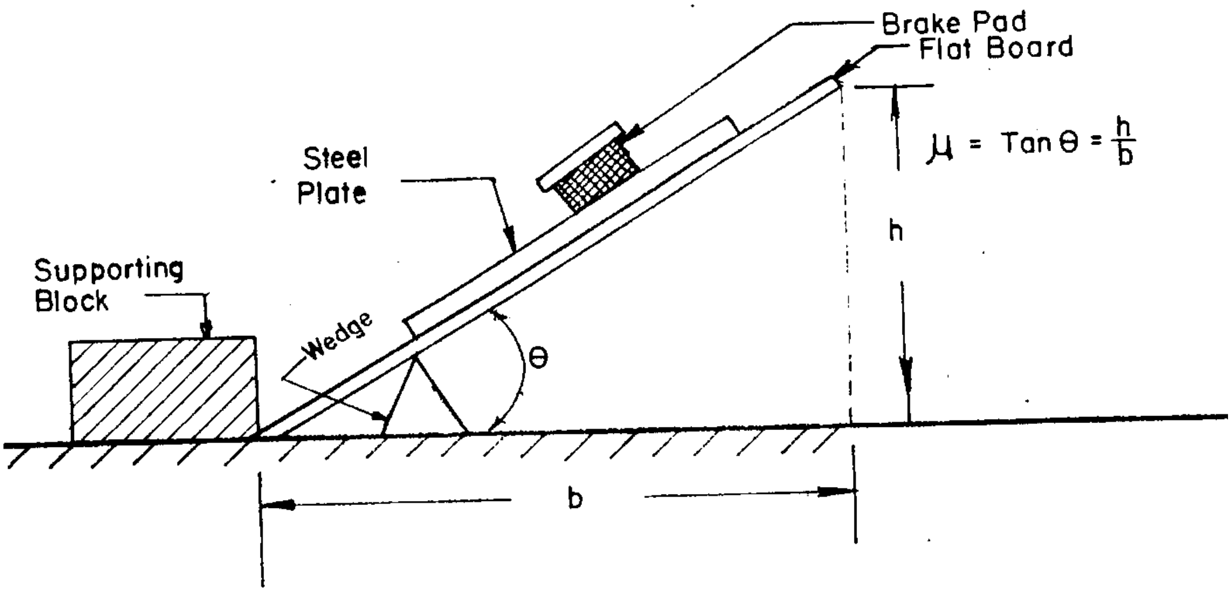


Fig.3.1 Determination of Low Load Coefficient of Friction

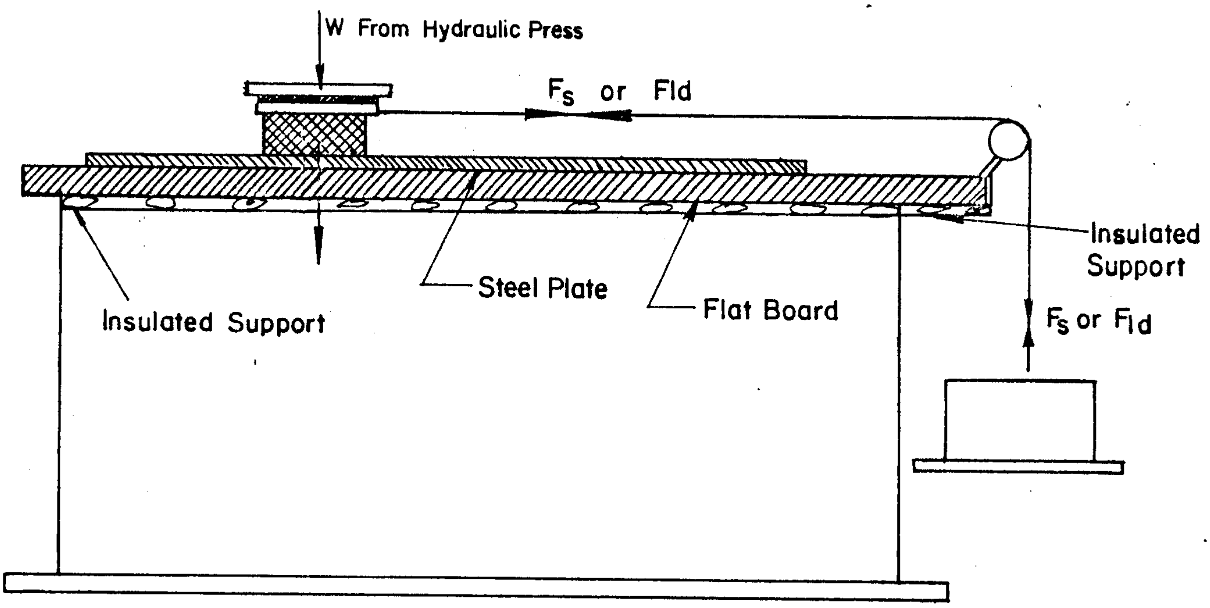


Fig. 4.1: Effects of Pressure and Steel Plate Temperature on the Static and Low Speed Coefficients of Friction.

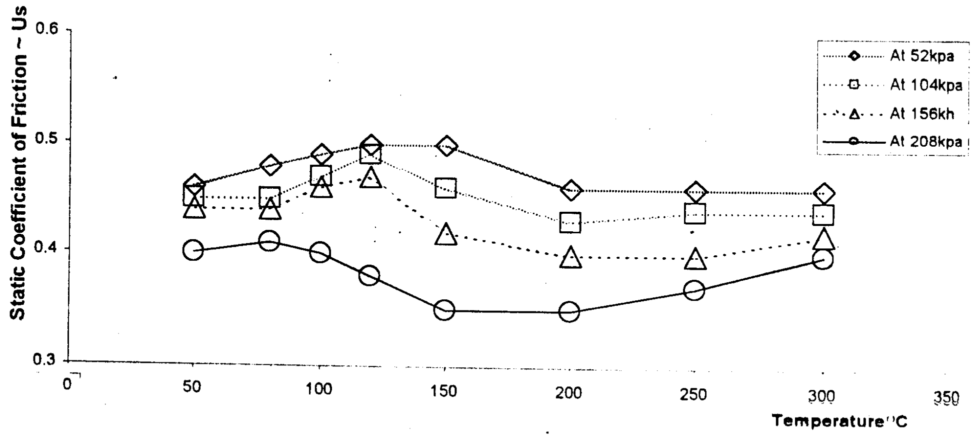


Fig. 4.2 Effects of Pressure and Temperature on Static Coefficient Friction.

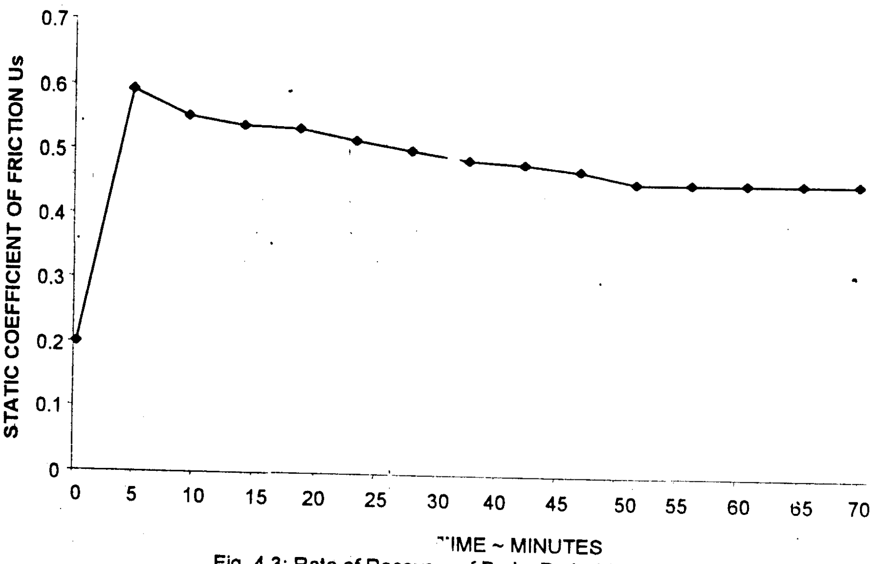


Fig. 4.3: Rate of Recovery of Brake Pads After Immersion in Water.