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IMPROVING AUTOMOTIVE BRAKE LINING CHARACTERISTICS

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ABSTRACT

The use of asbestos in brake lining gives a satisfactory friction characteristics from point of view of vehicle dynamics. However; the existence of asbestos is considered a probable cause of some carcinogenic effects. Accordingly; the objective of this work is to improve the brake lining characteristics both from point of view of health hazards by minimizing the asbestos content and from point of view of automobile brake stability requirements by using the most suitable processing conditions.

To achieve this goal an experimental work has been carried out through which 92 different samples of brake lining were tested and analyzed. These samples were prepared with different percentages of asbestos content at different processing conditions. The samples were then examined using the Friction Assessment and Screening Test machine (FAST) which gives the change of friction coefficient, temperature, and wear rate during a test period of 90 minutes for each sample.

Analysis of the experimental results shows that it is possible to decrease the asbestos content in the brake lining by 30% (from 50% to 35%) while obtaining improved lining friction and wear characteristics under suitable processing conditions: hot molding (pressure of 160 bar, temperature of 150°C, and molding time of 1.0 min./mm. thickness) and post curing (temperature of 150°C and time of 2 hrs.).

Application of these results to produce an actual disk brake lining and testing it using a dynamometer that simulates the different regimes of automotive braking shows a satisfactory stable performance.

1. INTRODUCTION

Brake lining materials used in automobile braking system are complex composites consisting of asbestos as reinforcement, organic resin as binder and different fillers and additives to satisfy high stable braking performance. A satisfactory brake material must operate efficiently over a wide range of operating speeds, pressures and temperatures. The quality of brake linings depends on a number of factors that are related to safety, endurance, economy , pollution and production technology . The brake lining must, therefore, satisfy a number of physico – chemical, mechanical and tribological requirements such as the resistance to frictional heating, appropriate and stable value of friction coefficient and low wear rate [1-6].

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Asbestos – free friction lining were introduced to avoid the claimed health hazard effect caused by asbestos. However, the carcinogenic effect of asbestos is started by a direct inhalation of asbestos dusts for at least (13-25) years [7].

Molding and post curing conditions affect the frictional characteristics of the final product. Temperature, pressure and time chosen during each stage of processing are important factors to be considered according to the type of the used binding agent and the final product size.

The brake lining characteristics have a great effect on the vehicle braking performance. For the front wheels locked first; loss of controllability of the vehicle takes place and for the rear wheels locked first loss of stability of the vehicle takes place. The locking of all wheels at the same time gives optimum braking performance condition keeping in mind that the kinetic energy of the moving vehicle must be dissipated in the form of frictional heat by the braking system.

In this study an experimental work has been carried out through which 92 different samples of brake lining were tested and analyzed. These samples were prepared with different percentages of asbestos contents at different processing conditions. The samples were then examined using the Friction Assessment and Screening Test machine (FAST) which gives the change of friction coefficient, temperature, and wear rate during a test period of 90 minutes for each sample. For testing under conditions similar to the real automobile braking conditions; an actual disk brake lining has been produced and tested using a dynamometer that simulates the different regimes of automotive braking.

2: EXPERIMENTAL WORK

The present experimental investigation aims at studying the effect of asbestos content and the manufacturing process conditions on the brake linings characteristics. The asbestos contents considered were: 50 % , 45 % , 40 % , 35 % , 30 % and 20 %; while to study the effect of the manufacturing process; different samples are prepared using different combinations of molding conditions (pressure, temperature and time) in addition to different post curing conditions (temperature and time). The molding pressures considered were: (150, 160, 170, and 180) bars while the molding temperatures were: (140,150, 160, and 170) °C and the different molding times were: (1, 0.75, and 0.5) min/mm thickness. The post curing temperatures were: (150,155, 165, and 170) °C and the time for post curing was: (2, 2.5, 3, 3.5, and 4) hours. It should be noted that during the study of the effect of process conditions; the different test samples were of the same chemical constituents (35% Asbestos, 20% Phenolic resin; 30% Barium sulphate, 5% Copper, 5% Rubber, and 5% Oxides).

The FAST machine was used to obtain the lining characteristics for each sample while only one general performance test was performed on a produced actual disk brake lining using a dynamometer that simulates the different regimes of automotive braking. The results were averaged for at least 3 test samples for each condition.

2.1: Samples Preparation

A total of 92 samples were prepared. Table 1 shows the distribution and the main constituents of these samples [8]. The sample (C) with 35 % asbestos content is prepared using different combinations of hot molding and post curing conditions . The procedure of preparing the samples is as follows:

*(1)- **Weighing different constituents***: This is done using an electric balance of 0.1 mg accuracy.

*(2)- **Mixing***: This is carried out using a mixer of capacity 4 kg, the mixing time is nearly (15- 20) min.

*(3)- **Molding:*** The different samples are cold molded in a special die under pressure of (4-5) bar for 10 seconds then hot molded according to the different combinations of molding conditions (pressure, temperature and time). Gases produced during hot molding process are released through appropriate ventilation periods. Different combinations of molding pressure, temperature, and time are considered.

*(4)- **Post curing***: is carried out in order to improve the friction characteristics. It should be noted that to study the effect of post curing conditions; seventy five samples were prepared with the following conditions :

- Asbestos content (35%)
- Molding pressure 160 bar.
- Molding temperature 150°C .
- Molding time (1-0.75-0.5) min/ mm thickness.
- Post curing time (2, 2.5, 3, 3.5, and 4) hours .
- Post curing temperature (150, 155 , 160, 165 and 170) °C.

An electric furnace with timer was used to get the required post curing conditions for the considered samples.

Table 1 . Samples Distribution and Main constituents.

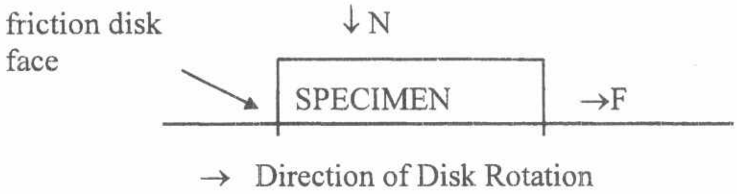
Sample	**Number of samples**	**Asbestos**	**Phenolic resin**	**Barium sulphate**	**Copper**	**Rubber**	**Oxides**
A	1	20	20	45	5	5	5
B	1	30	20	35	5	5	5
C	87	35	20	30	5	5	5
D	1	40	20	25	5	5	5
E	1	45	20	20	5	5	5
F	1	50	20	15	5	5	5
Total	**92**						

2.2:Test Machine

The FAST machine; Fig.1 is conceived and developed for evaluation of brake and clutch lining materials. It consists of three basic components: the XY recorder with time base, the signal conditioner and the test machine. The major elements of the machine are the drive motor and friction disk, the pivot and load arm, the clamping assembly, the control valve assembly, the base or oil reservoir, the hydraulic components and the pressure transducer. Specimen loading as well as self-generation of temperature may be correlated to conditions occurring in automotive use. The constant friction force test mode is used in this study.

Constant friction force test mode

The constant friction force mode of operation maintains both friction force and sliding velocity at constant values. The elementary friction principle indicated below is used :



N = Normal force (referred to as clamping force)
F = Friction force acting on the specimen
μ = Dynamic coefficient of friction (referred to as coefficient of friction).

Since $F = \mu N$ or $\mu = F/N$, and F is held constant, the values of μ relative to changes in the clamping force (N) vary in a reciprocal relationship. If the test cycle time is kept identical, and the velocity is maintained at the same level, then the distance traveled by the specimen must be equal in each test. The work (W) performed in opposing the friction force (F) for a distance (S) traveled is stated as:

$$W = F * S \qquad (1)$$

Therefore, with force (F) and distance (S) at the same values, the same amount of work (W) is absorbed in each test. For a given test, this work is dissipated in the form of heat, almost entirely by the friction disk. If the disks are of the same material and mass with ambient initial temperatures, nearly identical temperature histories are experienced with every test run, which therefore may also be identified with time.

2.3:Test Procedure

Before conducting the test the friction surface of the disc is cleaned. The test specimen is cut with the dimensions 12.7mm X 12.7mm X 3.175mm, then weighed and the thickness is measured. The sample is mounted in the sample arm. The drive and pump motors are started and the clamping load is applied (producing 7.89 kg friction force) for 90 min. The clamping force is recorded as a function of the time during the test. At the completion of the test, the sample is removed, weighed, and re-measured. These measurements are used to calculate wear.

2.4:General Performance Test

The purpose of this test is to measure the general performance of the friction material of brake shoes of passenger cars. A dynamometer that simulates the different regimes of automotive braking is used for this purpose. Fig. 2 shows a schematic diagram of the two wheel dynamometer. Table 2 shows the sequence of the general performance test.

Table 2. Sequence of General Performance Test

	Test Item & Sequence	Test Conditions: Initial Speed (km/h)	Interval (s)	Initial Temp. (°C)	Braking Decel. (g)	No. of Applic. (Times)	Remarks
1	Initial Measurement						
2	Preburnish Check	50	120		0.3	10	
3	1st Effectiveness Check	80		80	0.8	5	
4	Burnish	65		120	0.35	200	
5	2nd Effectiveness Check	80		80	0.8	5	
6	1st Reburnish	Repeat (4) Burnish, excepet 35 applications					
7	(Emergency Brake Test)	80		80	0.25	4	
8	First Fade & Recovery Test (a) Beseline Check	50		80	0.3	3	After 8 (b) Fade test cool the brake for 120 sec. until 1st brake application at 8(c) Recovery test
	(b) Fade Test	80	45	60	0.45	10	
	(c) Recovery Test	50	120		0.3	12	
	(d) Effectiveness spot check	80		60	0.45	2	
9	2nd Reburnish	Repeat (6) 1st Reburnish					
10	2nd Fade Recover Test	Repeat (8) 1st Fade Recovery Test, except 15 Applications in (b) Fade Test					
11	3rd Reburnish	Repeat (6) 1st Reburnish					
12	3rd Effectiveness Check	Repeat (5) second Effectiveness Check					
13	4th Reburnish	Repeat (6) 1st Reburnish					
14	Second Recovery Test (a) Base line Check	50		80	0.3	3	
	(c) Recovery	50		60	0.3	15	
15	Final Measurement & Inspection						Inspection of brakes & Measurments of shoes thickness, etc

3: ANALYSIS OF TEST RESULTS

The following characteristic values are considered in the analysis of the results obtained :

- Maximum value for the coefficient of friction , F_{max},
- Minimum value for the coefficient of friction F_{min} ,
- $\Delta F = F_{max} - F_{min}$, The value, ΔF, gives indication of the stability of the lining friction, as ΔF increases, the stability of the lining friction decreases,
- Wear in gm ,ΔW,
- Wear rate in (cm^3/N.m)
- Mean value of the friction coefficient

$$F_{MEAN} = \frac{\sum f_i}{n} \quad (2)$$

where;

F_i is the instantaneous coefficient of friction and ,

n .: is the number of the discrete points considered.

3.1: Effect of Asbestos Content (%)

Table 3 along with Fig. 3 show the effect of the asbestos content on the characteristic values at molding temperature 150 °C, molding pressure 160 bar and the molding time 1 min/ mm thickness. It can be seen that the maximum value for F_{max}, (0.57) is obtained at the maximum value of the asbestos content (50%). However; the minimum wear rate (0.381 x 10^{-7} cm^3/N.m) , the minimum difference between the maximum and minimum friction coefficient, f (0.15) (giving stable performance) and the maximum mean friction coefficient (0.363) (giving suitable braking effort) are obtained at 35 % asbestos content. For asbestos content lower than 30 % there exists a glazed surface layer which has relatively low coefficient of friction and low wear rate.

Table 3: Effect of Asbestos Content

(!60 bar, 150 °C, 1min./mm molding pressure, temp. & time- No post curing)

As %	F_{max}	F_{min}	F_{mean}	Δ F	$\Delta F/F_{mean}$	Wear rate (10^{-7}) (cm^3/Nm)
20	0.35	0	0.099	0.53	3.535	0.969
30	0.5	0.16	0.326	0.34	1.043	0.742
35	0.45	0.3	0.363	0.15	0.413	0.381
40	0.55	0.16	0.32	0.39	1.218	0.557
45	0.55	0.16	0.354	0.39	1.101	0.706
50	0.57	0.17	0.344	0.4	1.162	0.754

3.2: Effect of Molding Pressure

Table 4 along with Fig. 4 & 5 show the effect of molding pressure on the characteristic values at molding temperature 150 °C, molding time 1 min/ mm thickness and 35 % asbestos content. It can be seen that the maximum value for F_{max}, (0.5) is obtained at the molding pressures of 150 and 170 bars. However; the minimum wear rate (0.381 x 10^{-7} cm^3/N.m) , the minimum difference between the maximum and minimum friction coefficient, f (0.15) and the maximum mean friction coefficient (0.363) are obtained at molding pressure of 160 bar.

Table 4 . Effect of Molding Pressure

(35% Asb.- 150 °C, 1min./mm molding temp. & time- No post curing)

Pressure (bar)	F_{max}	F_{min}	F_{mean}	ΔF	$\Delta f/F_{mean}$	Wear rate to $10^{-7} cm^3/Nm$
140	0.42	0	0.157	0.42	2.675	0.993
150	0.5	0.2	0.343	0.3	0.874	0.595
160	0.45	0.3	0.363	0.15	0.413	0.381
170	0.5	0.25	0.359	0.25	0.696	0.536
180	0.35	0.15	0.258	0.2	0.775	0.374

3.3: Effect of Molding Temperature

Table 5 along with Fig. 6 & 7 show the effect of molding temperature on the characteristic values at molding pressure 160 bar , molding time 1 min/ mm thickness and 35 % asbestos content . It can be seen that the maximum value for F_{max} , (0.47) is obtained at the molding temperature of 160°C. However; the minimum wear rate (0.381×10^{-7} $cm^3/N.m$) , the minimum difference between the maximum and minimum friction coefficient, f (0.15) and the maximum mean friction coefficient (0.363) are obtained at molding temperature 150 °C.

Table 5. Effect of Molding Temperature

(35% Asb.- 160 bar, 1min./mm molding pressure & time- No post curing)

Temp (°C)	F_{max}	F_{min}	F_{mean}	ΔF	$\Delta F/F_{mean}$	Wear rate 10^{-7} ($cm^3/N.m$)
130	0.37	0	0.183	0.37	2.021	0.905
140	0.35	0.16	0.273	0.19	0.695	0.573
150	0.45	0.3	0.363	0.15	0.413	0.381
160	0.47	0	0.292	0.47	1.609	0.441
170	0.42	0	0.226	0.42	1.858	0.168

3.4: Effect of Molding Time:

Table 6 summarizes the effect of molding time on the characteristic values at molding pressure 160 bar , molding temperature of 150 °C, and 35 % asbestos content . It can be seen that as molding time increases; the lining characteristics is improved (the wear rate and the difference between the maximum and minimum friction coefficient, f, are decreased while the mean friction coefficient is increased.). However; it should be noted that the increase of molding time is expected to decrease the productivity, so an optimization of the cost and the resulting improvement should be considered.

Table 6. Effect of Molding Time

(35% Asb.- 160 bar, 150 °C molding pressure & temp.- No post curing)

Molding Time (min./mm)	F_{max}	F_{min}	F_{mean}	ΔF	$\Delta F/F_{mean}$	Wear rate 10^{-7} ($cm^3/N.m$)
0.5	0.35	0.16	0.25	0.19	.76	1.571
0.75	0.42	0.2	0.326	0.22	0.67	0.911
1.0	0.45	0.3	0.363	0.15	0.413	0.381

3.5: Effect of Post Curing :

Post curing is carried out in order to improve the friction characteristics. To study the effect of post curing conditions; seventy five samples were prepared with the following conditions: Asbestos content (35%), Molding pressure (160 bar), Molding temperature (150°C), Molding time (1, 0.75, and 0.5 min/ mm thickness), Post curing time (2, 2.5, 3, 3.5, and 4 hours), Post curing temperature (150, 155 , 160, 165 and 170 °C). An electric furnace with timer was used to get the required post curing conditions for the considered samples. Analysis of the test results shows that an improvement of the lining characteristics could be only obtained when the post curing conditions are carefully determined. Based on an exhaustive search of the test results for the samples considered; the most suitable conditions for post curing are: 150°C for 2 hours when the molding time rate is 1 min./mm thickness and 155°C for 3 hours when the molding time rate is 0.75 min./mm thickness. On the other hand, when the molding time rate was 0.5 min./mm thickness; the test could not be completed due to the friction drop resulting from the high rate of wear. Table 7 summarizes the improvement due to post curing in the first two cases. As it is clear from the table, a remarkable improvement can be seen in the sample produced with molding time 1min./mm thickness. For the sample produced with molding time 0.75min./mm thickness; (F_{mean}) and ($\Delta F/F_{mean}$) are decreased by about (16-17)% but the gain obtained with the decrease of the wear rate by 27% is a considerable improvement.

Table 7: Possible Improvements Due to Post Curing.

	Molding Time: 1 min./mm thickness (Post curing @ 150°C for 2 hours)				Molding Time : 0.75 min./mm thickness (Post curing @ 155°C for 3 hours)			
	F_{mean}	ΔF	$\Delta F/F_{mean}$	Wear rate (10^{-7} cm^3/N.m)	F_{mean}	ΔF	$\Delta F/F_{mean}$	Wear rate 10^{-7} (cm^3/N.m)
Without Post cur.	0.363	0.15	0.413	0.381	0.326	0.22	0.67	0.911
With. Post cur.	0.362	0.12	0.33	0.378	0.269	0.21	0.78	0.661
% Improve.	No impro.	20	20	0.8	-17	4.5	-16	27

3.6: The General Performance Test:

A disk brake lining having 35% asbestos and produced with the most suitable conditions (molding conditions: 160 bars, 150°C, and molding time rate is 1 min./mm thickness, and post curing conditions: 150°C for 2 hours) has been tested using a dynamometer that simulates the different automobile braking regimes. Fig,8 illustrates the results of this test from which it is evident that a satisfactory stable performance is obtained.

4:CONCLUSIONS:

From the foregoing experimental results and analysis , the following conclusions can be drawn:

1. There is a definite dependency of the brake lining characteristics on the hot molding processing conditions (pressure-temperature- time). Optimization of these conditions can improve the brake lining characteristics.

2. The brake lining characteristics can be further improved by post curing only when careful determination of its conditions (temperature & time).

3. For the samples tested; it is possible to decrease the asbestos content in the brake lining by 30% (from 50% to 35%) while obtaining improved lining friction and wear characteristics under suitable processing conditions: hot molding (pressure of 160 bar, temperature of 150°C, and molding time of 1.0 min./mm. thickness) and post curing (temperature of 150°C and time of 2 hrs.).

4. Application of these results to produce an actual disk brake lining and testing it using a dynamometer that simulates the different regimes of automotive braking shows a satisfactory stable performance.

5. The vehicle braking performance can be improved by the choice of suitable friction characteristics of the brake lining material according to the load distribution on different axles.

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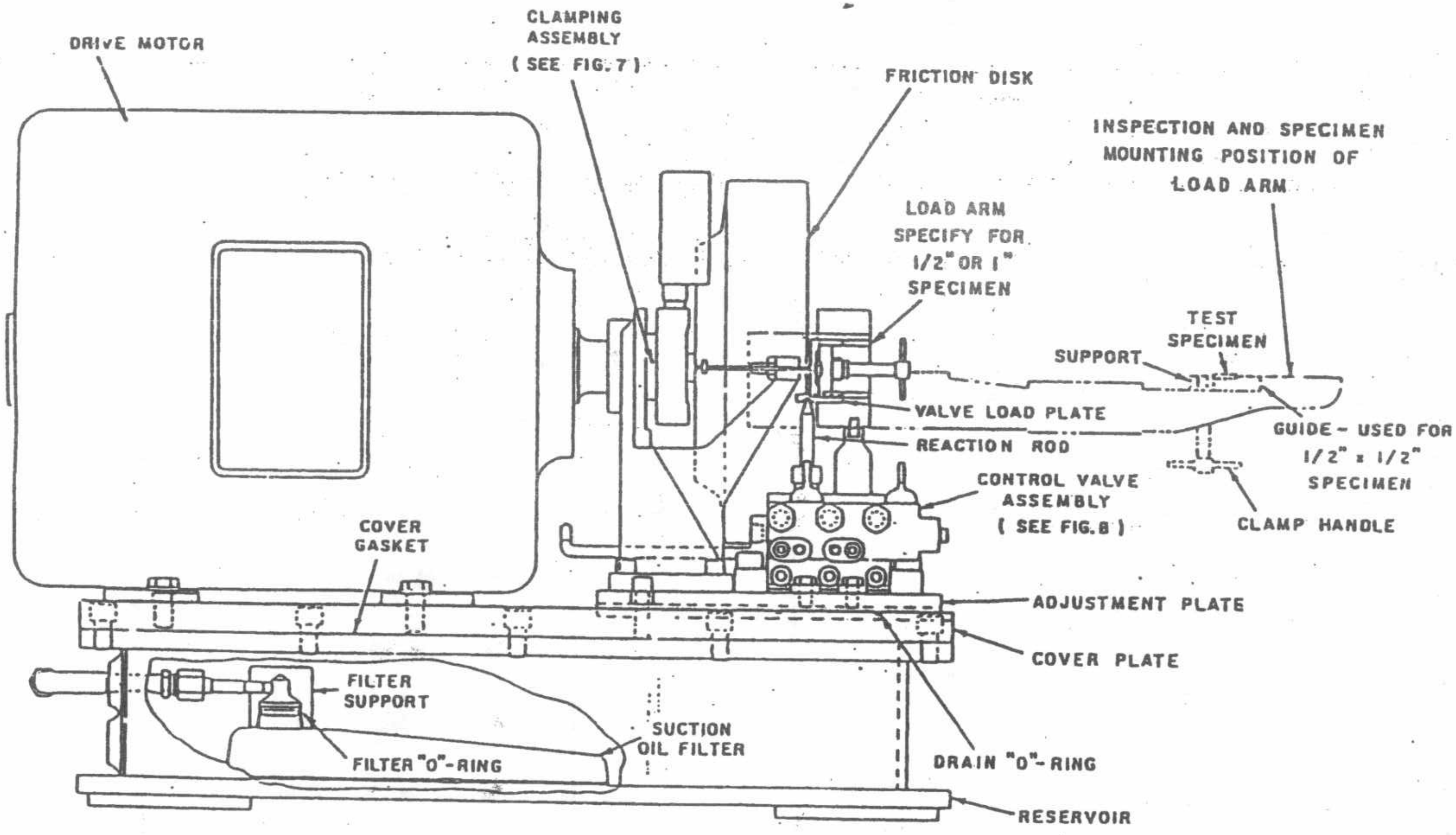

Fig. (1) FAST machine.

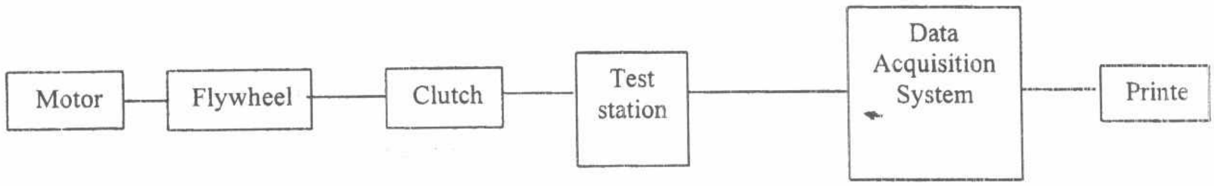

Fig. 2. Schematic drawing of the two wheel dynamometer.

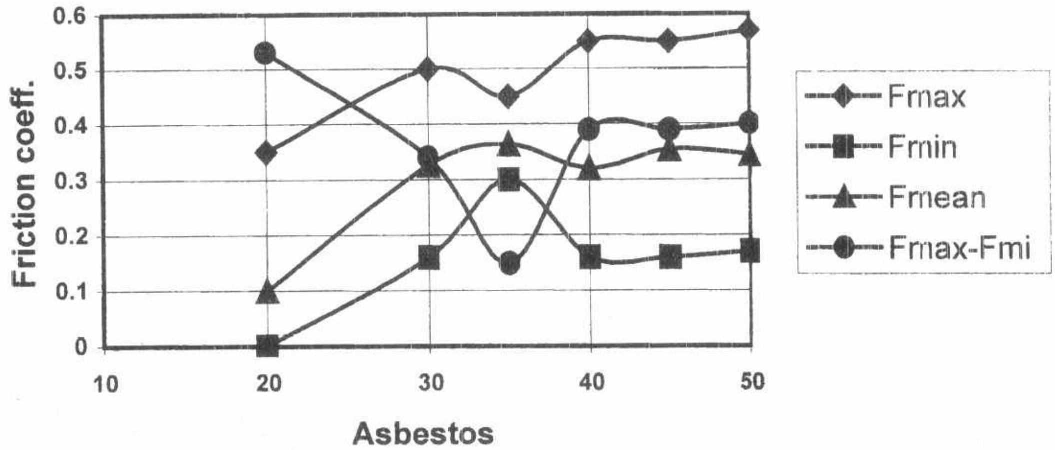

Fig. 3. Effect of Asbestos % on the characteristic values.

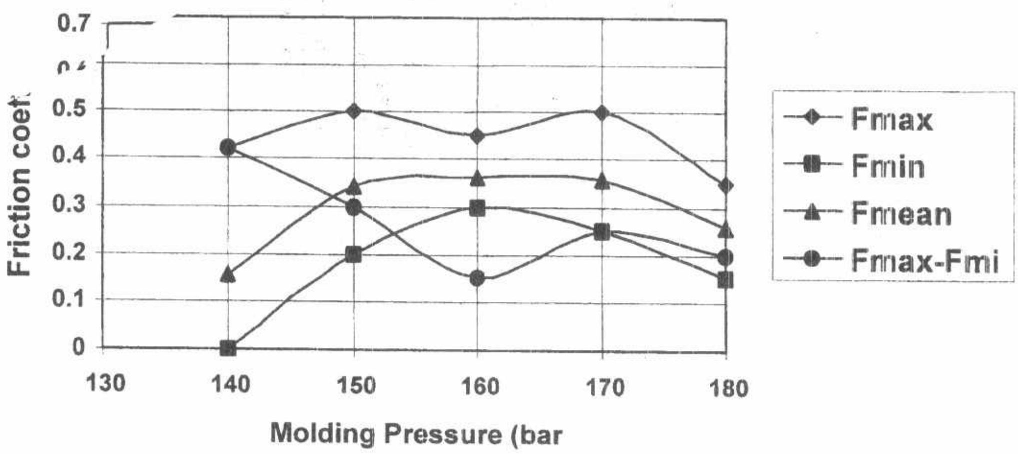

Fig. 4. Effect of molding Pressure on the characteristic values.

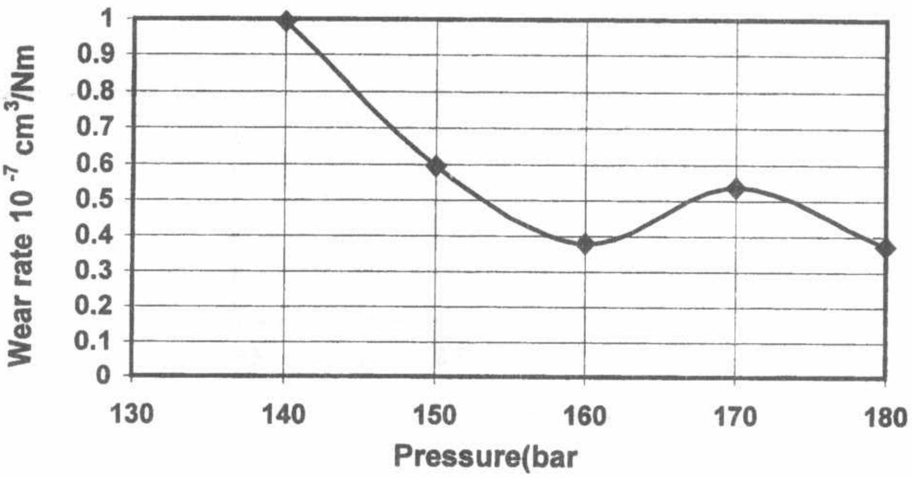

Fig. 5. Effect of molding pressure on wear rate.

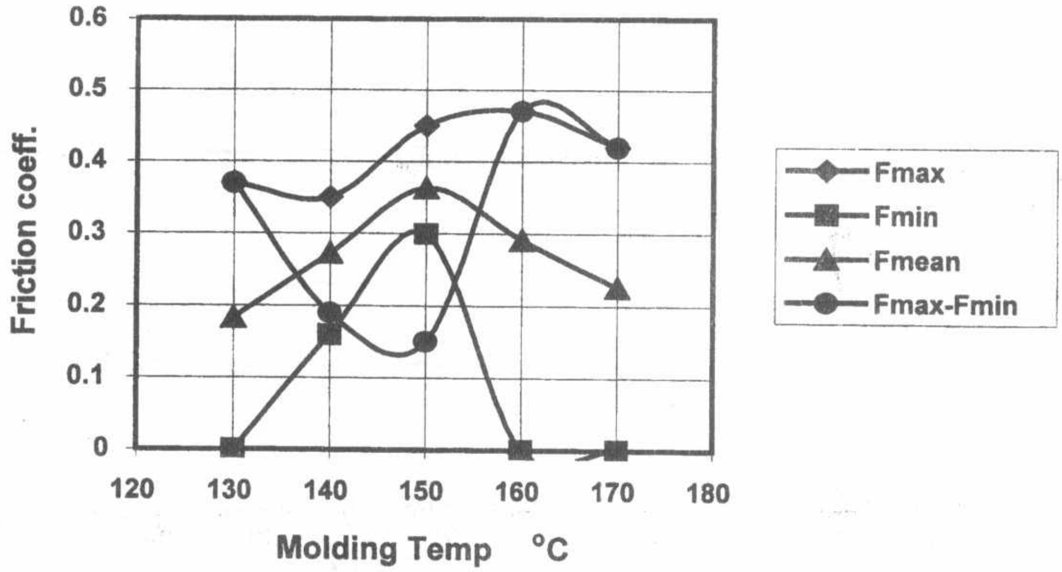

Fig. 6. Effect of molding temperature on the characteristic values.

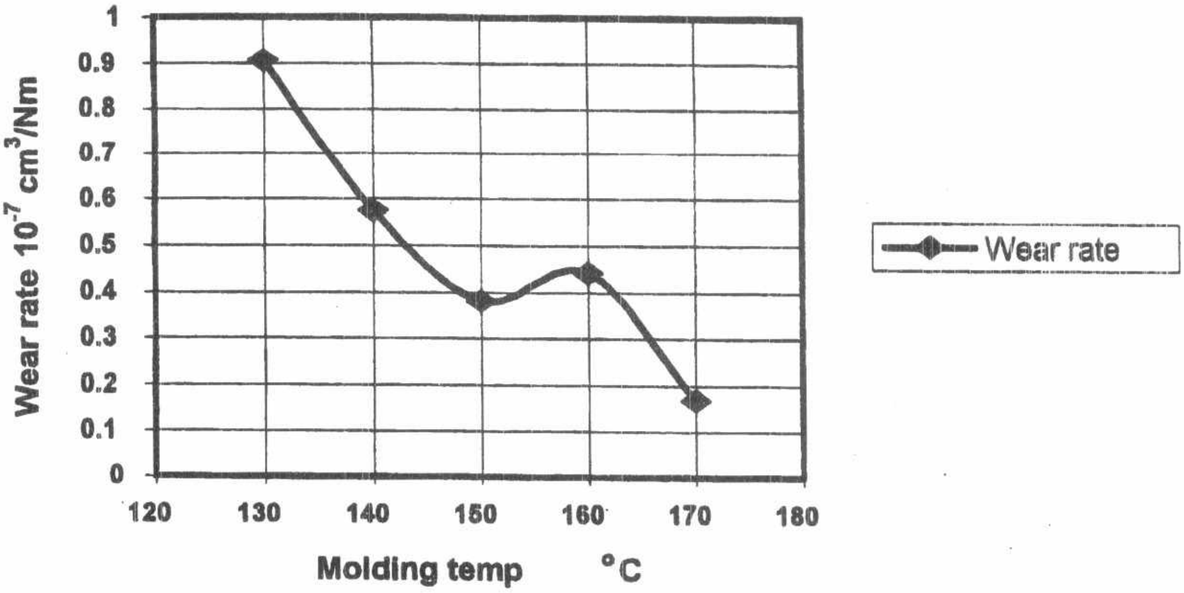

Fig. (7) Effect of molding temp on wear rate.

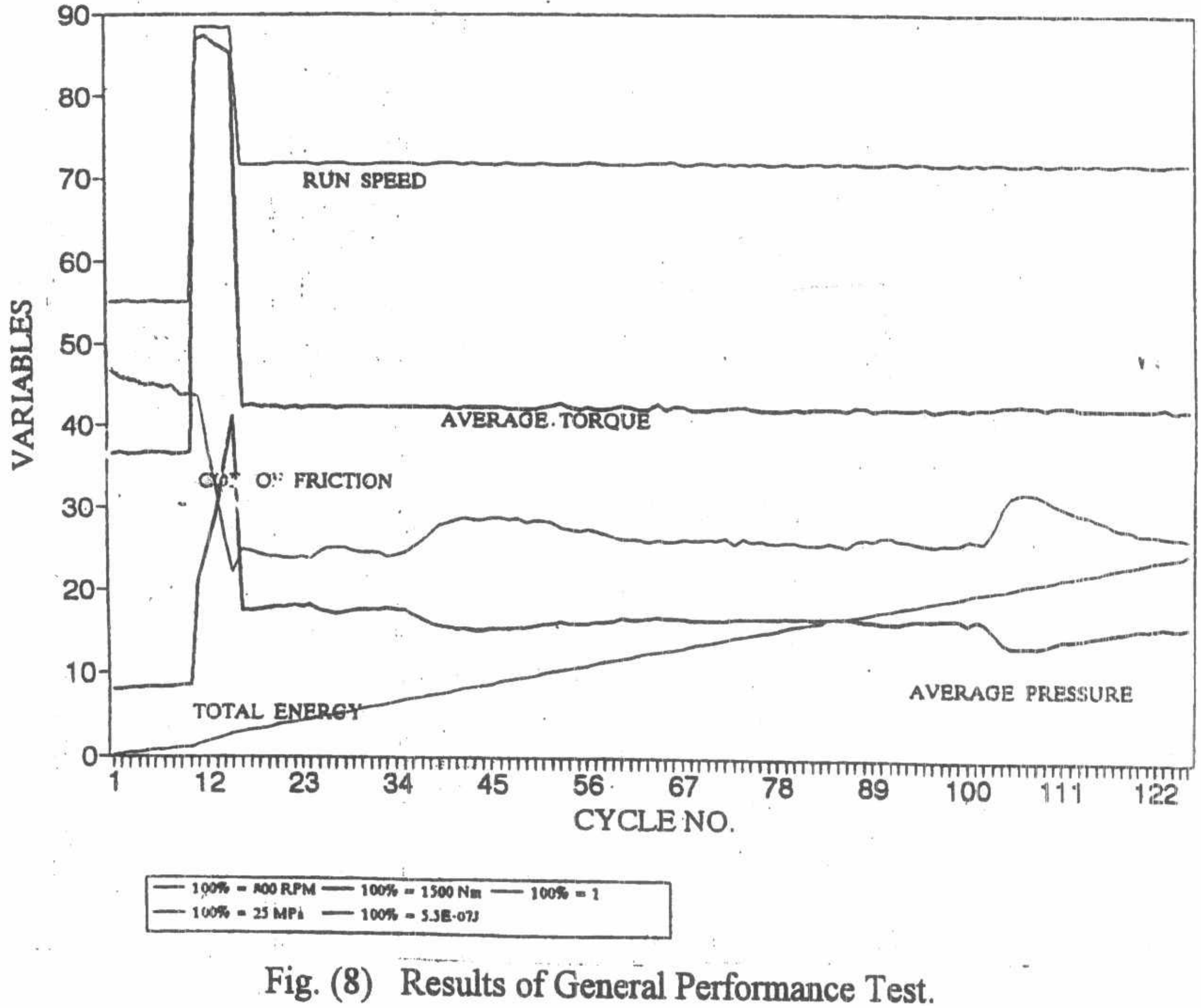

Fig. (8) Results of General Performance Test.