Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P) Vol.1 No.1, 2012, pp.25-34

DOI: https://doi.org/10.51983/arme-2012.1.1.2821

Development and Testing of Asbestos Free Brake Pad Material

R. Vijay, S. Rajesh Kumar, V. Satish and V. Thiyagarajan
Department Mechanical Engineering, Sree Sastha Institute of Engineering & Technology, Chennai - 600 123, Tamil Nadu, India.
Email : vimyr2010@gmail.com, srajesh2604@gmail.com, satz0891@gmail.com, vijilu84@gmail.com
(Received on 17 January 2012 and accepted on March 2012)

***Abstract* - An attempt is made through this project to incorpate 20% alumina fiber in automotive brake pad friction composites. Ingredients such as glass fiber, steel wool, rock wool, phenolic resin, barite, graphite, chalk powder and friction dust are added with alumina fiber to make up the composition. The developed brake pad composites have exhibited consistent coefficients of friction in the range of 0.3-0.4 and wear resistances are 1.2 times greater than asbestos frictional materials.**

Keywords: **Composites, Brake Pad, Alumina, Filler, Friction, Wear**

1. Introduction

The friction material in the automotive brake system has been considered as one of the key components for overall performance of a vehicle. This is because it plays crucial roles in various aspects of the brake performance such as a stopping distance, pedal feel, counter disk wear and brake induced vibrations [1]. A great deal of effort has been given to improve the performance of the friction material and multiphase composites have been used as a brake friction material from the early stage of vehicle development since a monolithic material has never been successful for commercial brake friction materials. More than 10 ingredients have been used to produce commercial brake friction materials, expecting that each ingredient provides beneficial roles for brake performance under different braking conditions. Brake pads typically comprise the following sub-components [1].

a) Frictional additives, which determine the frictional properties of the brake pads and comprise a mixture of abrasives and lubricants;
b) Fillers, which reduce the cost and improve the manufacturability of the brake pads;
c) A binder, which holds components of a brake pad together
d) Reinforcing fibers, which provide mechanical strength.

Before the ban on usage of asbestos in brake linings was imposed in 1989, Asbestos was the most preferred filler material as it is thermally stable up to 500^{0}C, helps regenerate friction surface during use, insulates thermally, strong and flexible and mostly, it is available cheap. Since the ban on asbestos, researchers have struggled to come up with an equally efficient alternative. Barites, mica and cashew dust are amongst some of the materials that have been considered for use as fillers [1].

II. Material And Methods

A. Physical-Thermal Characterstics of Aluminia Particles

As a trial a base formulation containing nine ingredients was developed to replace asbestos friction materials. It consist of reinforced fibers such as alumina fiber, steel wool, glass wool and rock wool, phenolic resin as binder, barite and chalk powder as fillers while friction dust and graphite as friction modifiers. To study influence of alumina fiber on physical, thermal, mechanical and tribological properties, its content is varied from 0wt% to 20wt% in steps to formulate five composites. When a new formulation is evolved, it has to satisfy the basic requirements of an automobile that it should have stable friction and lower wear rate. The sample received were subjected to thermo-gravimetric analyzer (TGA) in the Fig. 2.1 (A) thermo gravimetric analysis graph is shown. It consists of heating ('igniting') a sample of the material for the temperature range of 0 - 1000^{0}C allowing volatile substance to escape, until its mass ceases to change [4]. The process is repeated to show that mass-change is complete. Argon was used as the inert gas during all the experiments.

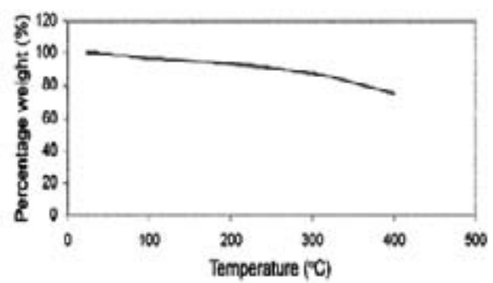


Fig. 2.1 (A) Plot of thermo gravimetric analysis carried out to determine the temperature resistance of the sample

B. Sample Preparation

In development of friction materials, a base composition with 20 wt% steel wool to impart good thermal conductivity and strength [2], 5 wt% each glass and rock wool to further improve the strength, 5 wt% of graphite to obliterate any seizing tendency of the friction material. steel wool are often used in the friction material industry [3] since steel fibres provide good wear resistance and maintain friction effectiveness at elevated temperature (fade resistance with fast recovery), 10 wt% of friction dust to stabilize the friction, 25 wt% chalk powder as filler materials and 25 wt% of phenolic resin as bonding material [5]. The developed friction material satisfied the requisite strength properties. Hence for the study alumina fiber (length 0.1mm and diameter 3µm) was added to the base composition in steps of 5wt% to 20wt% and barite correspondingly the content was reduced in the base composition. The details of the five grades of NAO friction material developed are given in the Table I.

Table I formulation of five non-asbestos organic friction materials

Ingredient	Content in wt% Samples				
	1	**2**	**3**	**4**	**5**
Alumina fiber	0	5	10	15	20
Glass fiber	5	5	5	5	5
Rockwool	5	5	5	5	5
Steel wool	20	20	20	20	20
Phenolic resin	25	25	25	25	25
Barite	25	20	15	10	5
Graphite	5	5	5	5	5
Chalk powder	5	5	5	5	5
Friction dust	10	10	10	10	10

The friction materials were fabricated in three steps which are mixing of the ingredients, moulding in hydraulic press (curing), and post curing which is explained below in Table II.

Table II A Fabrication Methodology of the Friction Composite

stage	Ingredient	Mixing time (min)
1	Alumina fibers, Rockwool	6
2	Phenolic resin	5
3	Steel wool, barite, graphite, $CaCO_3$,friction dust	15
4	Glass fiber	4

Procedure & Conditions : 1 Sequential Mixing Total duration – 30min, feeder rpm – 150, chopper rpm -3000,

Sequence: 2 150 ton compression moulding machine Preforming (figure 2.2)

3 Curing 165^{0}C, 165 kg/cm^2, 10 min (figure 2.3a, 2.3b)

4 Post curing 150^{0}C, 8 hrs (figure2.4)

Fig. 2.2 Job After Preforming

Fig 2.3A Curing Apparatus

Fig 2.4 Post Curing Oven.
The Cured components haveto be kept inside For 8 Hrs

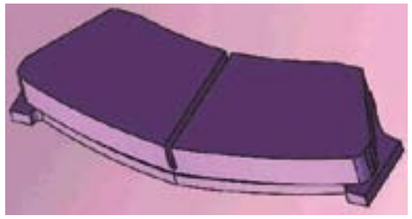


Fig. 2.5 Finished Pad View with Centre Cut

III. Physical, Thermal And Mechanical Characterization

The composites were characterized for their density and void content. Acetone extraction of the cured powdered mix has also been carried out to estimate the amount of uncured resin or any other organic fraction to define the composites more accurately. The ash content was determined by carrying out roasting at very high temperature (above 500^0C) in a muffle furnace following gravimetric methods.

The mechanical properties such as hardness as a measure of resistance to indentation under loads, cross-breaking/ shear strength for the characterization of composite integrity throughout the bulk and compressibility characteristics have been determined following standards conforming to industrial practice. Hardness was measured using Rockwell hardness tester while shear strength with the back plate was measured with a separate test rig in house.

The various properties are listed below namely

A. Specific Gravity

Using the specification given in IS2742 part 3. The specific gravity was measured using the equation 4.1

Specific gravity $S= W_A /W_A-W_W \longrightarrow (3.1)$

W_A is the weight of sample in air and W_W is the weight of sample in water. The average S of various composites is shown in figure 4.1.

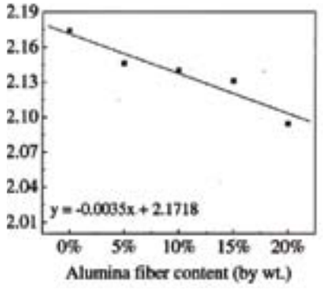


Fig. 3.1 Specific gravity of various compositions

This graph specifies that specific gravity of the material decreased linearly with increase in alumina content. This is because replacing heavier barite. The reduction in specific gravity is advantageous as it reduces the un-sprung mass of the vehicle.

2. Thermal Analysis

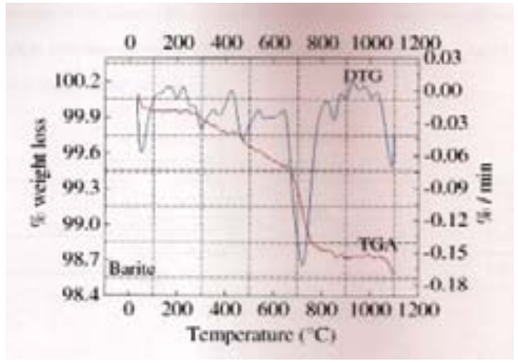


Fig. 3.2 (a)

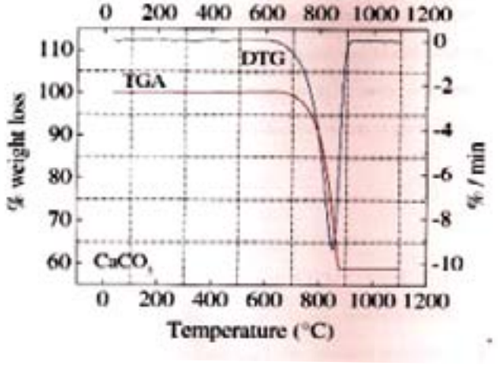


Fig. 3.2 (b)

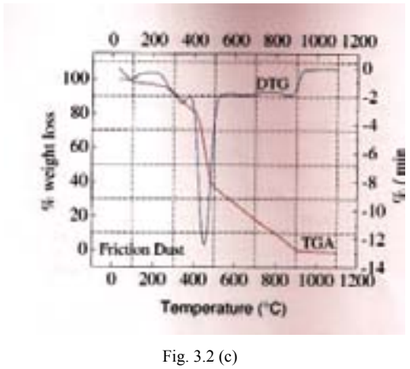


Fig. 3.2 (c)

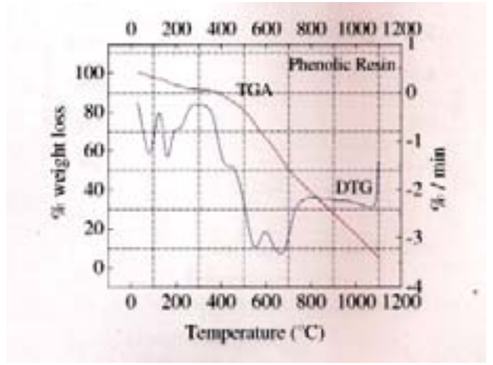


Fig. 3.2 (d)

In working of brakes the frictional materials are subjected to high temperature this will lead the decomposition of the friction materials. To know about the thermal behavior and stability of the various materials. TGA Thermo Gravimetric analysis and DTG (Differential Thermal Gravimetry) thermo grams figure 3.2a, b, c and d for various ingredients. The Thermal analysis result for sample 5 is shown in figure 3.2 e.

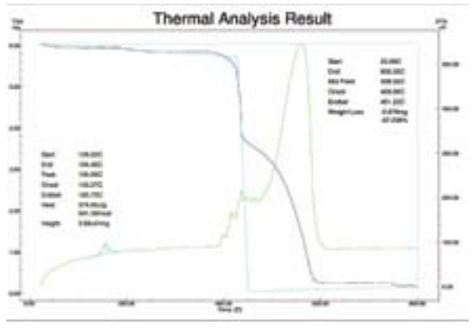


Fig. 3.2 TGA analysis result for sample 5(figure 3.2 (e))

From the graph it is clear that decomposition of resin starts after 350°c. While that the friction dust occurs after 400°c .thus the TGA study, it is speculated that degeneration of friction materials begins with decomposition of phenolic resin.

C. Mechanical Properties

The various mechanical properties are shown in Table III. These tests are conducted based on the IS2742 (Part3). Here K scale is used because these harder materials so these scale having ball indenter of 3.85mm dia and load of 1500N are used.

Table III Various Mechanical Properties for different compositions

Property	Alumina content (by wt.) in material				
	0%	5%	10%	15%	20%
Density (g/cc)	2.174	2.146	2.140	2.131	2.095
Tensile strength (MPa)	30.414	32.65	33.42	36.28	37.291
Compressive strength (MPa)	118.68	126.67	134.40	146.80	176.90
Shear strength (MPa)	22.439	24.85	27.09	29.02	32.474
Hardness (K scale)	92	89	87	86	82

IV. Friction And Wear Test

A. PIN on Disk Test

Friction tests were performed on Friction Coefficient Test rig as per IS 2742 /SAE J661. It is fully computerized and is programmable to study friction reaction against speed, load, temperature and wear. New rotor discs and brake pad composite samples were used for each test. Each composition was tested at least two times on the test rig to develop confidence in the data. The rig uses a pearlitic gray cast iron discs (diameter of 180 mm, thickness 38 mm) and a brake pad test sample in the form of pin 8mm dia x 60 mm length Fig. 4.1 (A). Each test sample was mounted on the load arm and pressed against the rotating disc [7]. The rotating cast iron disk has a constant sliding speed of 9m/s and the test duration was 15 min. The surfaces of the samples and the cast iron discs had to be ground with 320-grid sandpaper before beginning the test. The normal load was varied to achieve a constant friction force. The friction coefficient was calculated by measuring normal and shear forces every 5s over the entire duration of the test. The weight and thickness of the samples were noted before and after the friction test to calculate the total wear of each sample. An infrared sensor was used to record the temperature of the contact interface during the test and readings were recorded every second. The apparatus of pin on disc is shown in Fig. 4.1 (B).

Fig. 4.1 (A) Pin For Testing

Fig. 4.1 (B) Pin on disc apparatus

Fig. 4.1 (B) Pin on disc apparatus

Fig. 4.1 (B) Pin on disc apparatus

Thus by using the above test the various coefficient of friction and wear rate is obtained [7], which are shown in the figure 4.1 (c) and figure 4.1 (d)

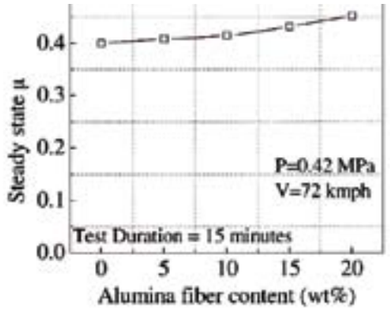


Fig. 4.1 (c) Alumina wt % Vs. steady state friction

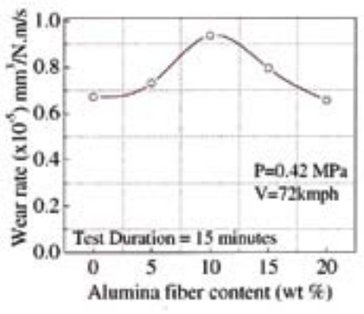
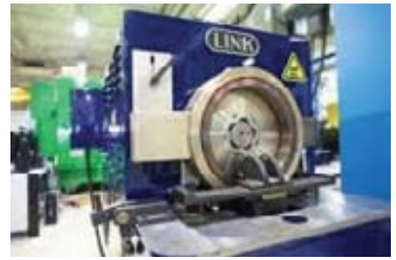


Fig. 4.1 (d) Alumina wt % vs. wear rate

B. Chase Test

Since pin on disc is a preliminary test next procedure of testing the specimen is the chase test which is meant to find out the fade, recovery, wear using various aspects [6]. It consists of a rotating drum with a 25.4 mm square pad [6] of friction material loaded against the inner diameter of the drum (279.4 mm ID) by an air pressure system. The wear is usually reported in terms of weight loss of the pad and thickness loss for the drum.The sequence of steps followed are the baseline or the burnish in which the brake pad tribological surface comes in contact with rotating drum, next step is the fade -1 in which the heater is made on the drum and the drum temperature reaches 289°c and the friction is noted down , next stage is the recovery-1 here the heater is switched off once it reaches 289°c and the blower is switched on where the temperature is slowly reduced to 93°c and the friction is noted next stage is wear where the rotation of disc causes the wear on the pad and it is recognized by the computer and the values are noted in computer. Then the hot friction and normal friction values are obtained. Next stage is the baseline-2 in which the specimen is again burnished and the fade-2 and recovery-2 is carried out in the fade-2 the temperature is raised up to 345°c using 2 heaters and as usual after fade recovery will take place up to 93°C in some cases the fade-3 is required in which additional heater is used which can produce the whole system temperature to be 400°c.The specimen size of this test is 1inch x 1inch fig. 4.2(C) .the various views of the chase testing machine is shown in the below figure 4.2(a).

Fig. 4.2 (a) Chase Testing Machine



The chase test results based on the IS2742 part 4 standards shown in the graph 4.2 b

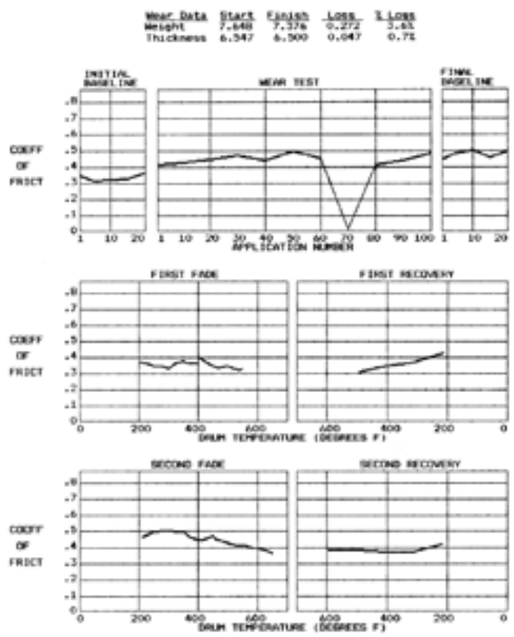


Fig. 4.2 B Chase Test Results

LINK-CHASE SAE J-661 FRICTION MATERIAL TEST REPORT

Manufacturer: SHRI KRISHNAN CHENNAI — Date: 08/07/11
Material: SAI BALAJI TRAIL 4 — Test Number: HCL6233
Test Pressure: 150 psi — Sample 1 of 1

Wear Data	Start	Finish	Loss	% Loss
Weight	7.648	7.376	0.272	3.6%
Thickness	6.547	6.500	0.047	0.7%

INITIAL BASELINE			FINAL BASELINE		WEAR		
Application	Fric Force	Coefficient	Fric Force	Coefficient	Application	Fric Force	Coefficient
1	32.4	0.344	67.4	0.441	1	62.2	0.410
5	47.1	0.309	74.1	0.484	10	66.2	0.429
10	48.1	0.315	76.2	0.501	20	68.0	0.446
15	50.2	0.327	70.1	0.458	30	71.2	0.466
20	55.6	0.364	75.0	0.493	40	67.6	0.438
					50	75.8	0.493
					60	69.8	0.451
					70	1.6	0.010
					80	63.8	0.415
					90	67.3	0.436
					100	74.1	0.483

FIRST FADE				SECOND FADE			
Time (min)	Fric Force	Coefficient	Temp (deg F)	Time (min)	Fric Force	Coefficient	Temp (deg F)
0.0	56.1	0.369	205	0.0	70.4	0.462	211
0.5	54.4	0.293	238	0.5	74.4	0.486	246
1.0	53.1	0.340	279	1.0	76.1	0.499	289
1.5	55.7	0.363	322	1.5	76.5	0.498	331
2.0	55.6	0.361	363	2.0	71.1	0.461	371
2.5	60.9	0.398	400	2.5	68.6	0.445	414
3.0	59.4	0.382	434	3.0	69.6	0.453	456
3.5	50.5	0.330	467	3.5	66.0	0.433	493
4.0	52.5	0.346	495	4.0	62.6	0.411	529
4.5	49.9	0.323	520	4.5	63.0	0.412	559
5.0	48.5	0.319	542	5.0	60.4	0.396	586
5.2	47.6	0.324	550	5.5	59.4	0.390	611
				6.0	57.9	0.377	633
				6.4	55.5	0.363	650

FIRST RECOVERY				SECOND RECOVERY			
Application	Fric Force	Coefficient	Temp (deg F)	Application	Fric Force	Coefficient	Temp (deg F)
1	46.0	0.307	495	1	58.4	0.370	596
2	52.2	0.342	402	2	57.6	0.380	503
3	56.5	0.368	309	3	56.2	0.368	408
4	64.8	0.424	213	4	56.3	0.367	313
				5	64.3	0.421	219

Fig. 4.2(C) Specimen For Chase Test

C. Inertial Dynamometer Test

The Inertial Dynamometer which evaluates a full size brake or a brake system and simulates vehicle braking well, but is time consuming and expensive the inertial dynamometer requires the proper number of the full-size pads, linings, segments or blocks together with the proper brake and rotor, and in addition it requires the proper inertial capacity. Inertial dynamometers fade and recovery performance test procedure based on IS11852: part 7 (Automotive vehicles –Brakes and Braking System –part 7 Inertia Dynamometer test method for Brake Lining), with additional effectiveness evaluations scattered throughout the test schedule. The set up of the Inertia brake dynamometer setup for testing brake pad is shown in fig 4.3(b) and the disc brake assembly and calliper is shown in fig 4.3(a).

The dynamometer results are plotted in a graph as shown in the Fig. 4.3 (a).

Fig 4.3(a). Disc Brake Assembly & Caliper

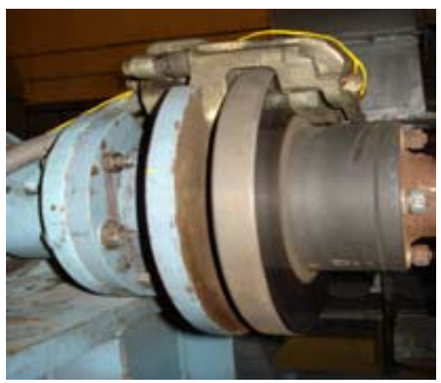


Fig 4.3(b) Inertia Brake Dynamometer Setup for testing Brake Performance

A Kelsey-Hayes disc brake used on a 1981 and Ford Escort was used (callipers with 54.0 mm (2.126 inch) cylinder diameter and pads with an area of 42.6cm^2 or 6.60 inch^2). The wheel load was 1042 lbf (473 kgf). The ventilated cast iron disc was 235 mm (9.25 in) in diameter, 24 mm (0.95 inch) thick and weighed 4.46 kgf (9.82 lbf). The rotor surfaces were finished to a 60 - 80 µ in range. The test may be summarized as follows.

(1) Preburnish effectiveness: at 200 ºF (93 ºC) and 483 rev/min (30 miles /hr or 50 km /hr); run stops at 150 - 750 lbf/in 2 in 100 lbf/ in 2 increments (10.3- 1.7 bar in 6.90 bar increments); repeat at 967 rev/min (60 miles/hr or 100 km /hr).

(2) Burnish: 200 stops at 644 rev /min (40 miles/ hr or 65 km/hr) at 3.66 m/s^2 (12 ft /sec^2) deceleration at 100 ºC (212ºF).

(3) Post-burnish effectiveness: same as above.

(4) First rebumish: 30 burnish stops.

(5) Recovery baseline: three stops at 644 rev/ min (40 miles/ hr or 65 km/ hr) at 3.05 m/s^2 (10 ft/ sec^2) from 66 ºC (150 ºF).

(6) First fade: ten stops from 967 rev/ mm (60 miles/hr or 96.7 km/hr) at 4.57 m/ s^2 (15 ft/ sec^2) deceleration with 35 s intervals, beginning at 66 ºC (150 ºF).

(7) First recovery: 12 stops at intervals of 120 s from 30 miles /hr (50 km/ hr) at 3.05 m/ s^2 (10 ft/ s^2).

(8) Second rebumish: 30 burnish stops.

(9) Recovery baseline: as above.

(10) Second fade: 15 stops from 967 rev/ min (60 miles/ hr or 96.7km/ hr) at 4.57 m/s (15 ft/s) deceleration with 35 s intervals, beginning at 66 ºC (150 ºF).

(11) Second recovery: same as first recovery.

(12) Third rebumish: 30 burnish stops.

(13) Final effectiveness: same as above.

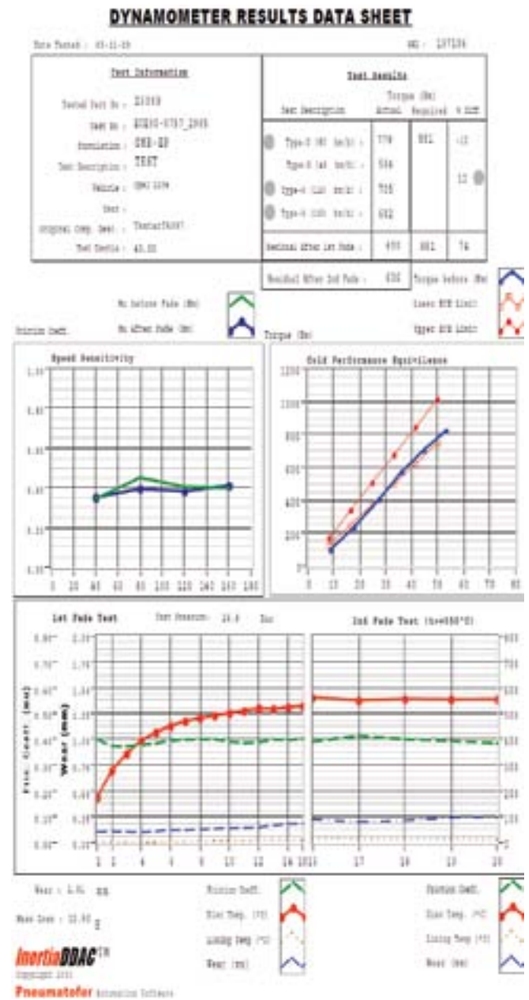


Fig. 4.3(a) Dynamometer Results

V. Results And Discussions

From the Fig. 4.1(a) and 4.1 (b) the steady state friction and wear rate is known. The steady state friction increases with the wt % of alumina increase and the wear resistance increases with alumina wt % increase.

The microscopic structure of the various compositions taken in the Scanning electron microscope after the pin on disc test to show the microstructure view of the materials. This is shown below in the figure 5 a, b, c.d, e.

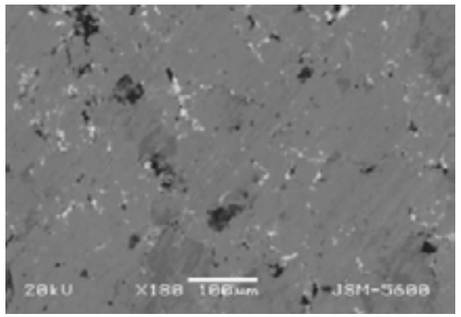


Fig. 5a 0wt% Alumina

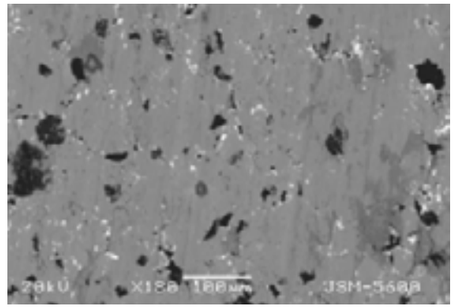


Fig. 5b 5wt% Alumina

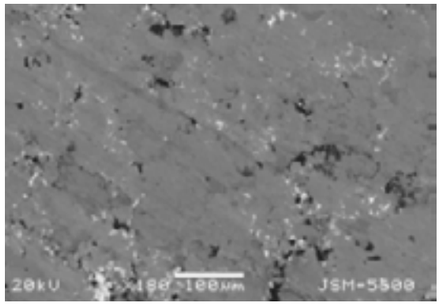


Fig. 5c 10wt% Alumina

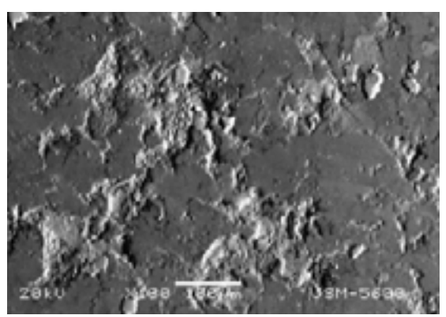


Fig. 5d 15wt% Alumina

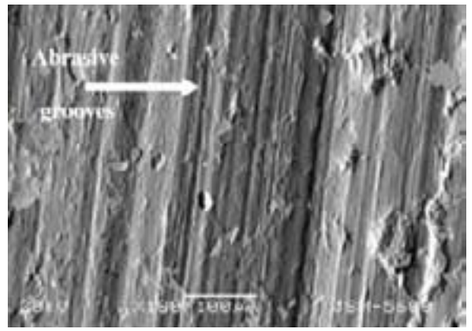


Fig. 5e 20wt% Alumina c

Fig. 5 Scanning Electron Microscope images for a) 0wt% alumina b) 5wt% alumina c) 10wt% alumina d) 15wt%alumina e) 20wt% alumina

Based on the wear resistance obtained on pin on disc test sample 20wt% of alumina and commercial frictional material is chosen. It is made to undergo five sliding wear test, each of 15minutes were carried out at normal pressure of 0.42Mpa and sliding speed of 72Kmph. After each test frictional material is cooled to room temperature and next test is carried out. The results are shown in graph 5b and 5c for commercial frictional material and 20wt% alumina fiber composition resp.

VI. Conclusions

The various conclusions made from present study are:

1. From the test we conclude that the increase in alumina wt% increases the wear resistance.
2. The physical and mechanical properties of the developed friction materials are in the range of commercial friction materials (OE standards).
3. For the brake applications the coefficient of friction should be between 0.3 to 0.6 which is satisfied by the composition.
4. In all the five formulations it is concluded that 20wt% has got good coefficient of friction, lower wear rate and it is also not harsh with the rotor disc.

When compared with the commercial brake pad the developed brake pad has 1.2 times more wear resistance shown in graph 6c. And the friction is also maintained at 0.4.

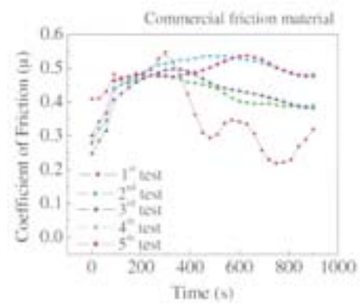


Fig. 5a. Commercial frictional material

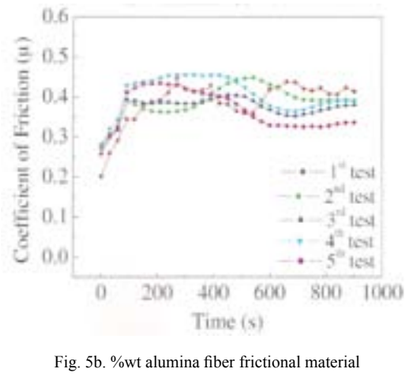


Fig. 5b. %wt alumina fiber frictional material

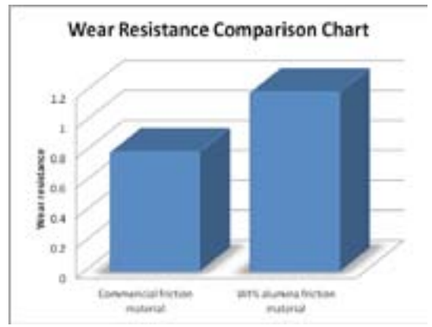


Fig. 5c. Comparison graph between commerical and alumina fibre frcition material in terms of wear rate

VII. Appendix - Measurement of Shear Strength

The value for Shear Strength is found out using the following procedure:

a. Place the specimen in the fixture and gradually increase the load in direction parallel to the direction of stress at normal service conditions.

b. The load shall not be applied in shocks and the rate of increase.

c. The test shall be carried up till the breaking up of the material occurs.

The specimen size is length 20mm width 20mm and thickness 5mm.

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