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Research Paper

EFFECT OF INGREDIENTS ON MECHANICAL AND TRIBOLOGICAL CHARACTERISTICS OF DIFFERENT BRAKE LINER MATERIALS

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Asbestos possesses properties that are ideally suitable for use as a friction material in automotive and a number of other applications. Animal and human studies carried out since the early 1900s have established that asbestos is carcinogenic and that exposure to especially asbestos dust causes a large number of diseases. The search is, therefore, still on to find suitable substitutes for asbestos. A brake lining containing 14 ingredients was investigated to study the effect of ingredients on various aspects of friction properties. The composite was developed for a non-asbestos organic based friction material for an automotive brake system and contained typical ingredients for commercial brake friction materials. Two types of friction materials with different combinations were developed: (1) flyash range (10%-60%), and (2) without flyash based friction materials were investigated to study the effect of ingredients on the friction characteristics and wear. The main focus on the average normal coefficient, hot coefficient (Fade and recovery), wear loss, mechanical, as the function of the relative amount of the ingredient. The results also showed that the friction coefficient of fly-ash was better in the range of 0.35 to 0.48 when compared barites based brake linings and asbestos based brake linings. The materials such as potassium titanate (terraces), wollastonite, friction dust powder have strongly influence on friction coefficient. Wear resistance of the friction material was strongly affected by the relative amounts of ceramic wool, rockwool, calcium hydroxide, and zircon. The presence of glass fiber, twaron fiber, has increased the strength of the friction material. All these samples were tested on chase type friction tester at automobile ancillary unit.

Keywords: Flyash, Braking lining material, Chase type friction tester, Mechanical, Friction, Wear

INTRODUCTION

Flyash is a by-product of thermal power stations. Much of the flyash is presently treated as a waste product for uses such as land fill although a small quantity is utilized as fillers in concrete, bricks and other materials.

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Nowadays attempts has been made to utilize flyash in manufacturing sectors where large volume usage of the same could be exploited will prove substantially beneficial in techno-commercial and environmental terms Flyash is composed of fine size particles (mean size 10-30 mm), with uniform physical and engineering characteristics. Flyash possesses low specific gravity in the range of 2-3, as compared to ingredients used in contemporary brake linings (Samrat and Chugh, 2007). Flyash particles are typically generated at very high temperatures, i.e., 100 °C upwards. Hence, they should provide a thermally stable bulk for high-temperature environments that a friction composite experiences. Also, majority of flyashes contain substantial amounts of silica, alumina, calcium sulfate and un-burnt carbon in them, which are already being used in many of current commercial brake linings. The specific heat of flyash particles is also high (800 kJ/kg K). The successful incorporation of flyash or flyash derivatives into friction material formulations could greatly reduce the cost of the friction material, i.e., 50-60% assuming all the fillers are substituted (Samrat and Chugh, 2007; and Nandan *et al.*, 2009). Hence, incorporation of flyash would possibly cater to various functional roles which otherwise are expected from a set of fillers as ingredients. The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat, via friction and dissipating that heat to the surroundings. The temperature sensitivity of friction materials has always been a critical aspect while ensuring their smooth and reliable functioning of the brakes. High friction materials have applications in automotive, aerospace and industrial brake systems. High friction compositions are a three-element composition consisting of a matrix of polymeric blends, reinforcing material, friction and anti-wear material. Among the most well known polymeric systems known, the phenolic resins or modified phenolic resins are the well known thermo sets with good thermal stability. Friction materials for a brake system should be designed to maintain stable and reliable friction force at wide ranges of pressure, vehicle speed, drum temperature, humidity and others. No single material has met the performance related criteria such as safety, noise propensity, durability and comfort under various braking conditions. In general, more than 14 ingredients have been used for commercial brake friction material to accomplish above mentioned requirements. The friction materials have been formulated based on application such as light motor vehicle, light commercial vehicle and heavy duty vehicle and the ingredients comprise of fillers, binders, fibers, solid lubricants and friction modifiers and abrasive (Seong and Ho, 2000; Min and Seong, 2005; and Yun and Min, 2008). In this study an attempt has been made to incorporate flyash in the brake liner for the effective brake application for the light motor vehicle.

EXPERIMENTS

Friction Materials

Friction materials investigated in this study were Non-Asbestos Organic (NAO) type materials containing 14 different ingredients as shown in the Table 1. Figure 1 shows conventional compression molding machine used for making friction material. Figure 2 shows the procedure for making non asbestos

Table 1: Material Composition for Flyash Based Brake Liner

Description (%) wt	Composition %
Flyash	10-60
Filles	5-15
Friction Modifiers	15-25
Fibers	5-15
Binder	15
Lubricant	3-9

Figure 1: Compression Molding Machine with a Steel Die

friction material. The ingredients in the friction material comprise binder resin, reinforcing fibers, friction modifiers, solid lubricants as graphite (Kato, 2000). These ingredients were weighed in given proportions, blended well, molded in a steel die and then heat treatment process was carried out with the given parameters. The each quantity of ingredients was measured in the electronic scale and poured into the mixer for mixing. The mixing time was 15 min. After mixing, the mixture was taken out of the mixer and required quantity of mixture of 220 gm was measured and kept in the die for pressing. The die was preheated to 145 °C and pressure of 160 kg/cm^2 was applied over a powder for a molding time of 6 min (Table 2). The Friction material sample of size 105 mm × 130 mm × 30 mm was made.

Figure 2: Procedure for Making Non Asbestos Organic Brake Lining

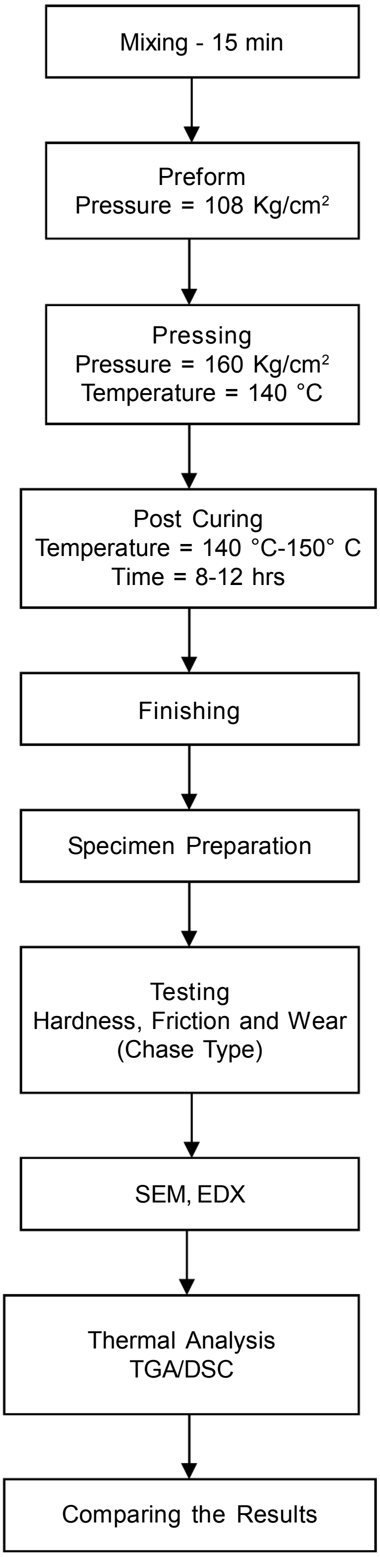


Table 2: Process Parameters

Parameter/Level	Level 1
Pressure (Kg/cm^2)	160
Temperature °C	140
Time (min)	4-6
Curing Temperature °C	155
Curing Time hrs	8-12

Asbestos Fiber Based Frictional Material

The brake is an important safety device in machines. The friction material is an essential part in brake and clutch devices. Different types of brake materials are used in different machines Traditionally, these friction materials contain chrysotile asbestos fiber as one of the major constituents to impart the desired characteristics. There is an important distinction to be made between serpentine and amphibole asbestos due to differences in their chemical composition and their degree of potency as a health hazard when inhaled. However asbestos and all commercial forms of asbestos (including chrysotile asbestos) are known to be human carcinogens based on sufficient evidence of carcinogenicity in human. The materials that are used for automotive brake lining applications, in particular, are based on asbestos, and are used in combination with a number of other ingredients. Asbestos is a cheap and easily available raw material. It is used extensively as lagging material, insulation material, raw material for making corrugated sheet and as lining material (Sampath, 2006). It is also used as reinforcement in the form of fiber, for making composite material. Due to its good thermal stability and high L/D ratio, it is the most prominent candidate for use as friction material where thermal stability is important criteria. Asbestos became increasingly popular among manufacturers and builders in the late 19th century because of its sound absorption, average tensile strength, and its resistance to heat, electrical and chemical damage. It was used in such applications as electrical insulation for hotplate wiring and in building insulation. Asbestos materials become dangerous when a product's integrity is compromised due to external agents like heat, water, weathering and aging and fibers are released in to the environment. The fibers continue to break in to smaller and smaller particles. The asbestos fibers are having 20 to 500 micron length and 0.5 to 50 micron diameter. The small size and lightweight of the fiber allow them to remain airborne for an extended period after initial release. The risk of asbestos-related disease increases with heavier exposure to asbestos and longer exposure time. Asbestos had a few engineering characteristics that made it very desirable for inclusion in brake linings. Asbestos is thermally stable up to 500 °C, it helps regenerate friction surface during use, it insulates thermally, it is 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

Flyash Based Frictional Material

The combustion of powdered coal in thermal power plants produces flyash.The high temperature of burning coal turns the clay minerals present in the coal powder into fused fine particles mainly comprising aluminium silicate. Flyash produced thus possesses both ceramic and pozzolanic properties. Flyash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify while suspended in the exhaust gases, flyash particles are generally spherical in shape and range in size from 0.5 μm to 100 μm.Flyash possesses low specific gravity in the range of 2-3, as compared to ingredients used in contemporary brake linings (Samrat and Chugh, 2007). Flyash particles are typically generated at very high temperatures, i.e., 1000 1C upwards. Hence, they should provide a thermally stable bulk for high-temperature environments that a friction composite experiences. The specific heat of flyash particles is also high (800 kJ/kg K). The successful incorporation of flyash or flyash derivatives into friction material formulations could greatly reduce the cost of the friction material, i.e., 50-60% assuming all the fillers are substituted (Nandan *et al.*, 2009). Also, majority of flyashes contain substantial amounts of silica, alumina, calcium sulfate and unburnt carbon in them, which are already being used in many of current commercial brake linings. Much of the flyash is presently treated as a waste product for uses such as land fill although a small quantity is utilized as fillers in concrete and other materials. Attempts to utilize flyash in manufacturing sectors where large volume usage of the same could be exploited will prove substantially beneficial in techno-commercial and environmental terms. Hence, incorporation of flyash would possibly cater to various functional roles which otherwise are expected from a set of fillers as ingredients. In this study an attempt has been made to incorporate flyash in the brake liner for the effective brake application for the light motor vehicle.

Measurement of Friction and Wear Characteristics

Friction and wear tests were conducted using a Chase-type friction tester with grey cast iron as the counterpart with a 280 mm diameter and a hardness of 210 HB, according SAE J661test procedure. Figure 3 shows the flyash based friction material used testing purpose.

Figure 3: Frictional Material Used for Testing Purpose

Measurement of Physical Properties

Hardness, Porosity, tensile strength, was carried out in accordance with the ASTM D638. Rockwell hardness tester with a ball indenter was used for measuring the hardness of the brake pads machined out of the friction composites. Tensile specimen has a constant rectangular 115 mm × 25 mm × 14 mm.

RESULTS AND DISCUSSION

Effect of Ingredients on Physical Properties

Physical properties hardness, porosity and tensile strength of the friction material specimens were measured from flyash based composites and barites based composites. The mechanical property studies were carried out to find out the suitability of the composites for brake lining applications. The presence of fibers in the phenolic matrix improves the hardness and tensile, this is expected, since the hard fibers reinforce the soft resin matrix.

The hardness, tensile strengths are the parameters that contribute significantly to the frictional behavior of the composites and these composites were found to exhibit good mechanical properties. Figures 4, 5, 6 and 7

Figure 4: Samples vs Hardness of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

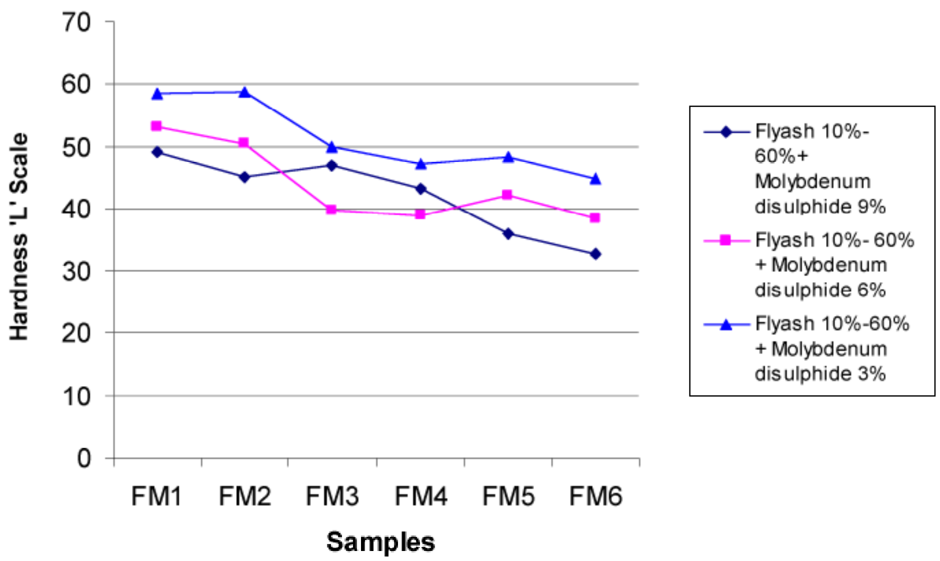


Figure 5: Samples vs Hardness of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm²

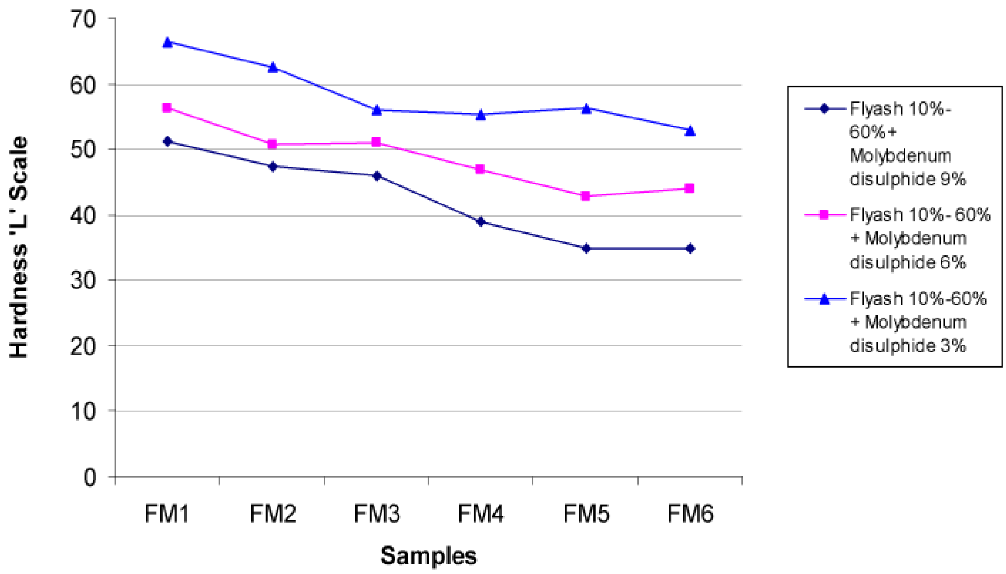


Figure 6: Samples vs Hardness of Barites (Without Flyash) with 9%, 6% and 3% Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm^2

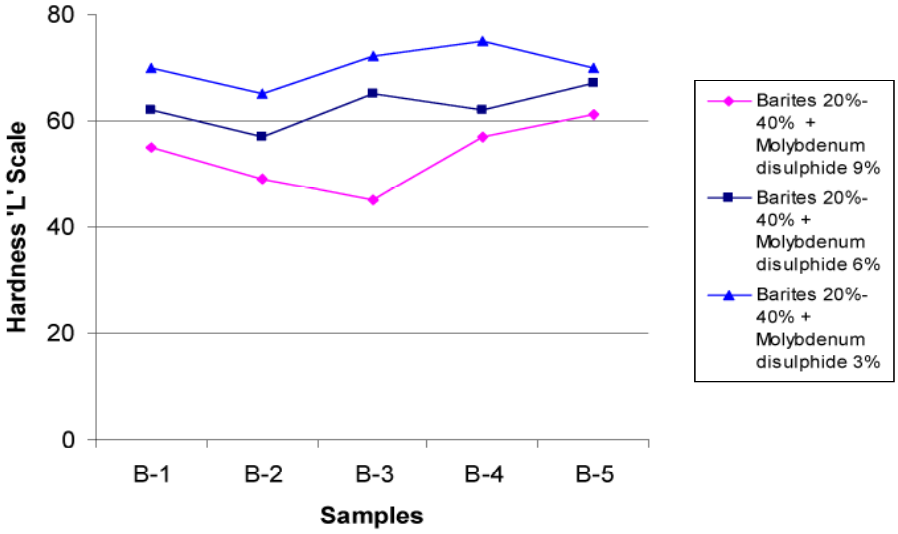
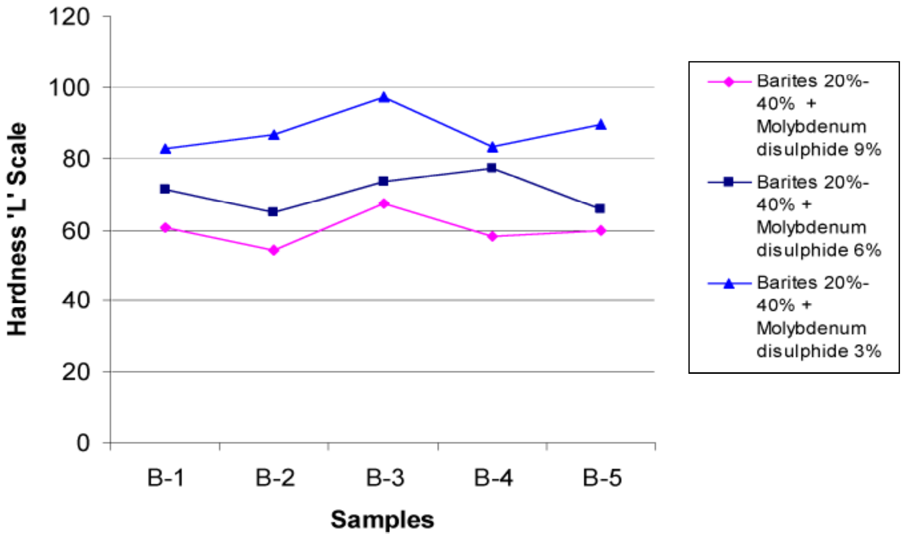


Figure 7: Samples vs Hardness of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm^2



exhibits correlation among the hardness of flyash and barites based friction material under constant temperature and constant pressure for the molding of time 4 min and 6 min. Figures 8 and 9 shows that the strength of flyash based friction materials exhibit low due to increase of percentage of filler materials and low percentage of fibers. The figure clearly indicates that the specimens with high hardness tend to exhibit low porosity. The low tensile strengths of the composites are attributed to the high filler content and the fibers being short in length. The Figures 10 and 11 shows the tensile strength of barites

Figure 8: Samples vs Tensile Strength of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

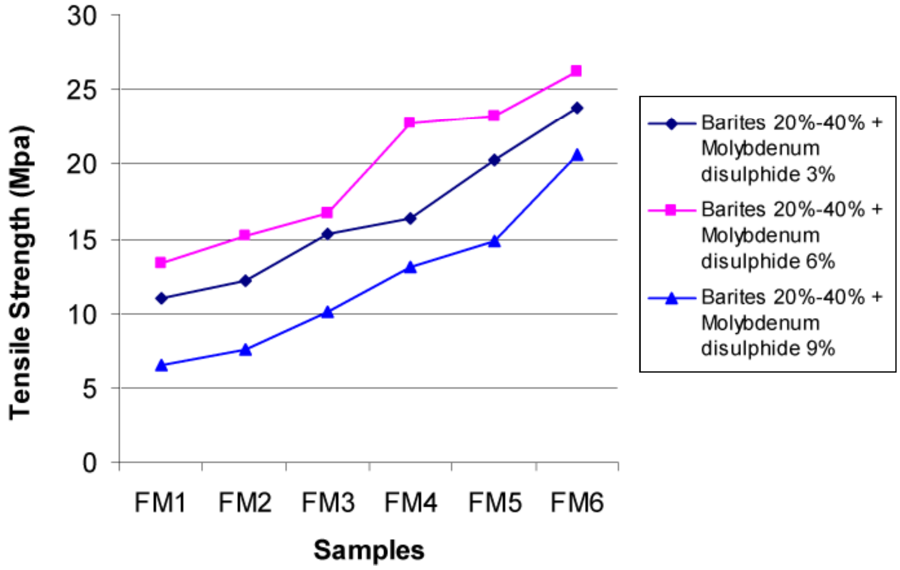
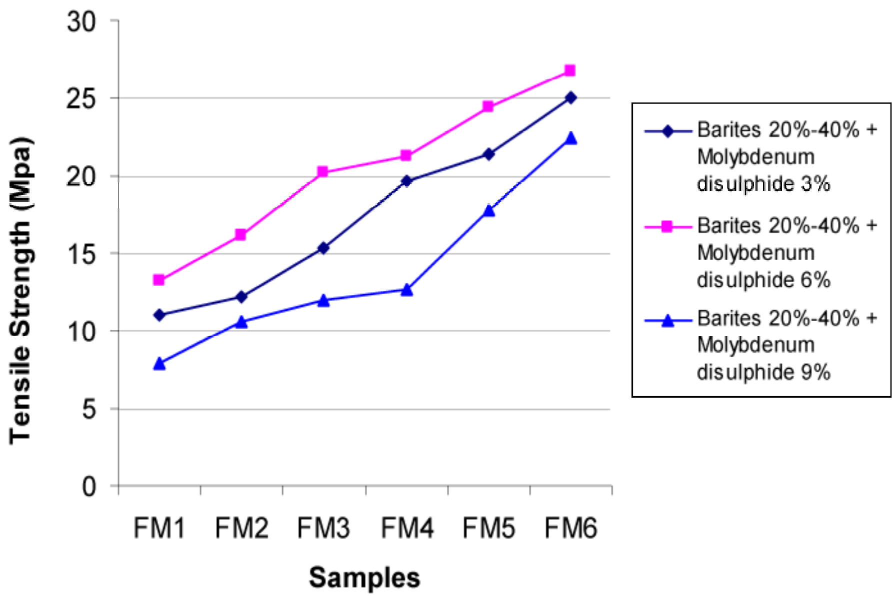


Figure 9: Samples vs Tensile Strength of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm²



based friction material were higher due to addition of twaron 1080 (aramid fiber), glass fiber which increases the strength of the composite.

The high hardness from the increase of phenolic resin is due to the fact that the binder resin is a thermosetting polymer showing high strength after curing. On the other hand,

Figure 10: Samples vs Tensile Strength of Barites (Without Flyash) Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

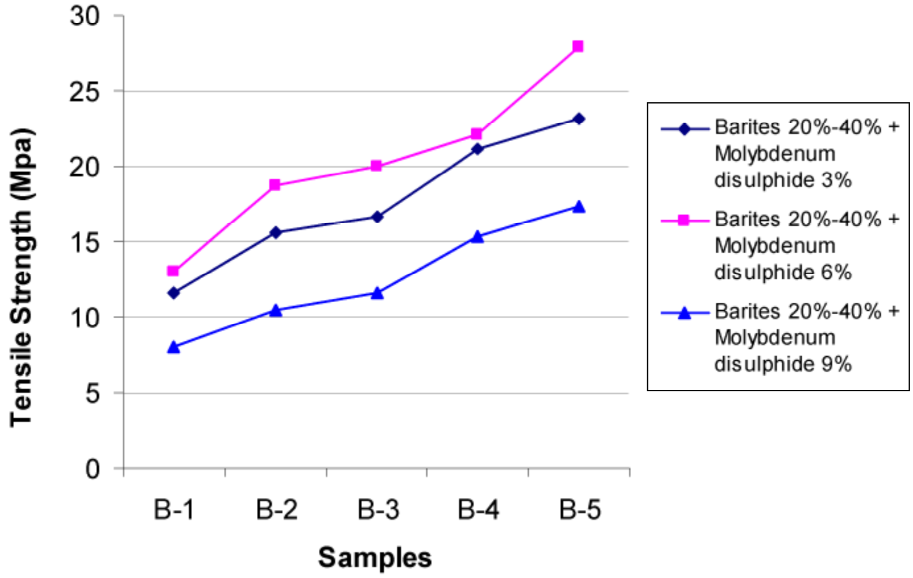
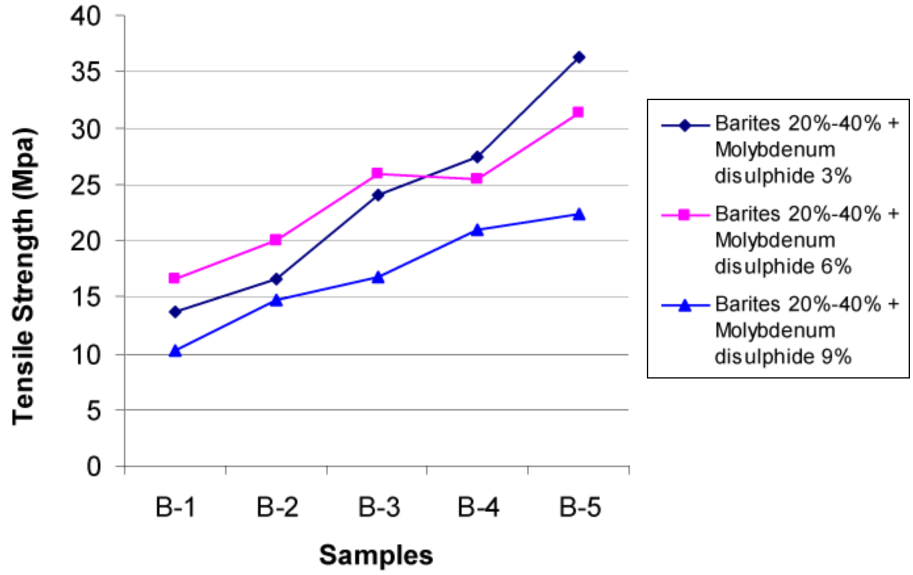


Figure 11: Samples vs Tensile Strength of Barites (Without Flyash) with Differenent of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 6min, Pressure 160 kg/cm²



potassium titanate and cashew have contrary effects on hardness. This is because the potassium titanate is in the shape of fine particulate. However, the potassium titanate plays a crucial role in the formation of friction films. Cashew particles also reduced the hardness since this polymeric material does not play a particular role for the enhancement of strength of a composite. The presence of potassium titanate particular powder, wollastonite, phenolic resin increases in hardness of composite decreases the porosity of the composite. Porosity was increased with E-glass fiber, ceramic wool, rock wool and cashew dust powder, suggesting that these ingredients did not flow during hot molding as shown in the Figures 12 and 13. Phenolic resin reduced porosity since the resin ran and filled the pores during hot molding. The Figure 12 shows that friction material was molded with

Figure 12: Samples vs Porosity of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

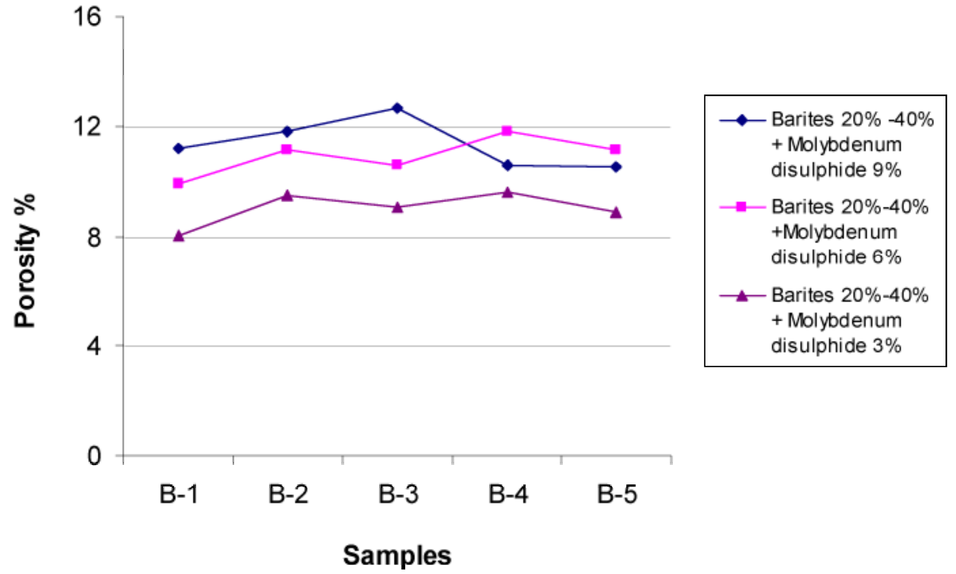
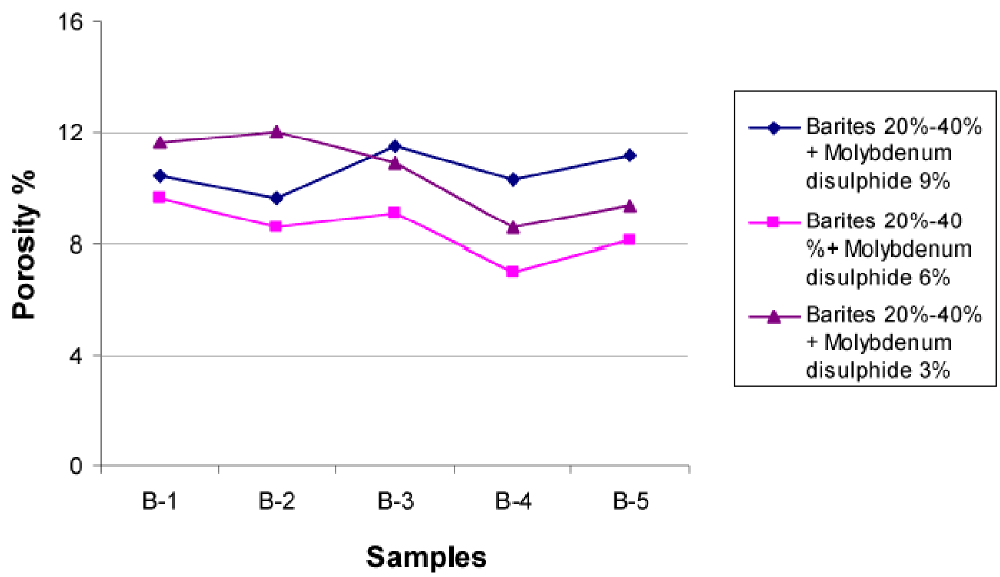


Figure 13: Samples vs Porosity of Barites (Without Flyash) Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm²



molding time 4 min, since molding time was insufficient for the resin to flow uniformly through out the friction material thereby increase in porosity of the friction material. Figure 13 shows that increase in molding from 4 min to 6 min had significant decrease in porosity and increase in tensile strength since fills the porous holes in the friction material.

Effect of Ingredients on Friction and Wear Characteristics

A study of the literature pertaining to wear/failure mechanisms of friction materials reveals that there are at least four or more different failure modes operating during braking: adhesive wear, abrasive wear, chemical wear, fatigue wear, thermoinstability, and microcracks (Ho, 1977; Liblisch and Rhee, 1977; Talib *et al.*, 1977; Azhari and Talib, 1998; and Vaziri *et al.*, 1988). The rate of wear and the coefficient of friction of friction materials are very important parameters for selection, since they decide the suitability of the materials for brake lining applications. It is the fibers that add to the wear resistance and the coefficient of friction. When the fibers are removed from the matrix by pull-out or abrasion. Even though many researchers have worked on the wear mechanisms in friction materials, still not much is known as to what happens exactly in the material process zone of the brake system. It is proposed that third body layers develop (Kato, 2000; and Filip *et al.*, 2002). These layers have compositions different from those of the mating parts. Many researchers pointed out that the formation of a friction film by wear debris compaction plays an important role in stabilizing the coefficient of friction (Rhee and Ludema, 1978). The barites based and flyash based friction material were tested in the chase type friction test rig and the average of coefficient of friction of normal

Figure 14: Samples vs Average COF of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

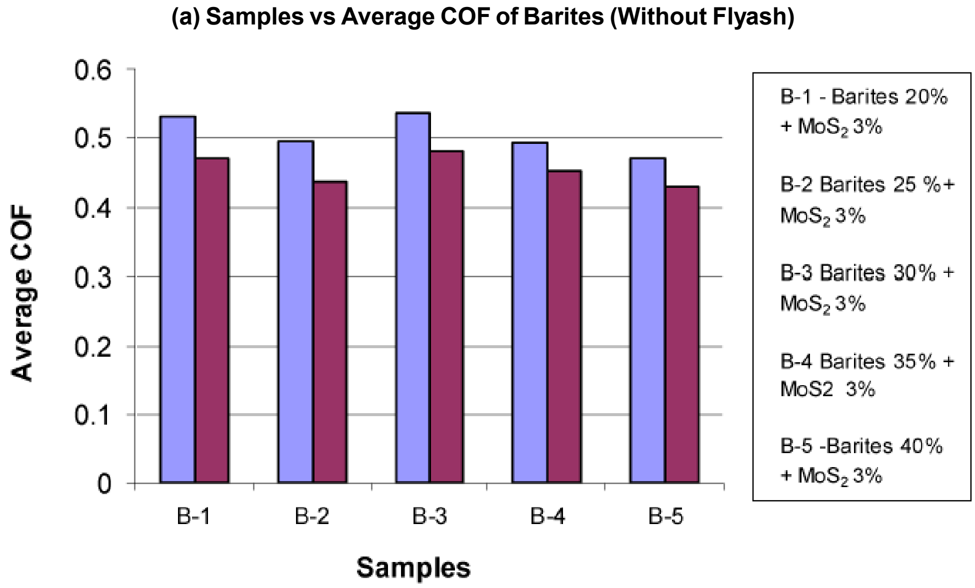
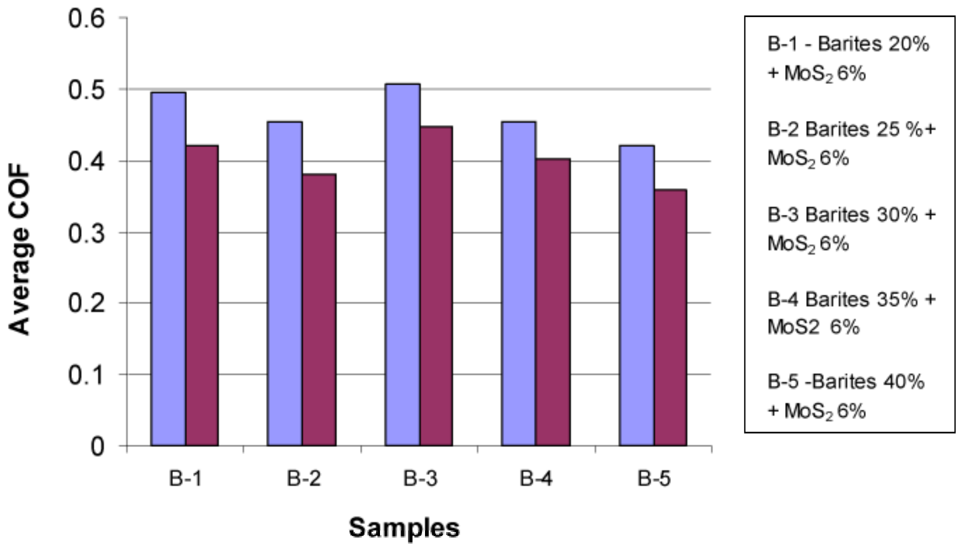
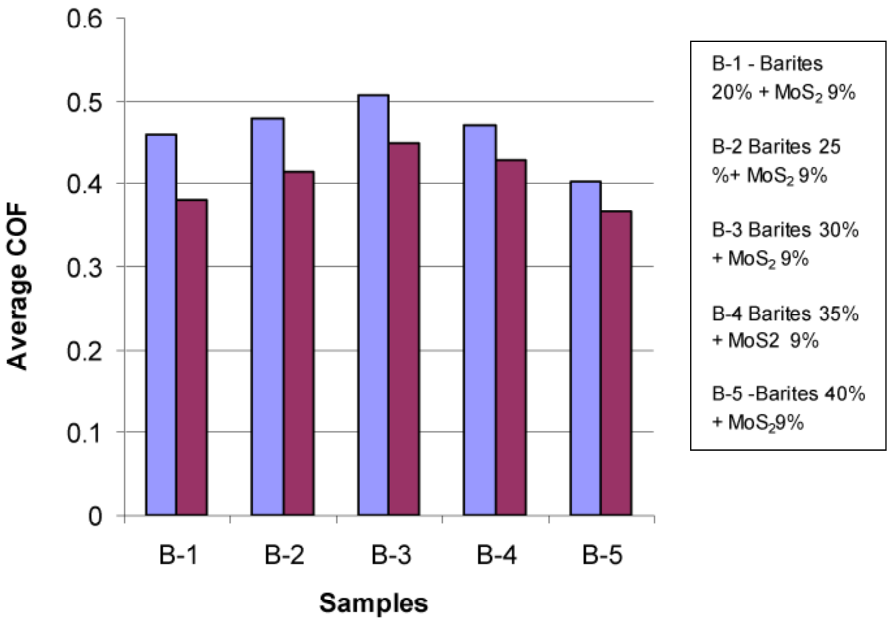


Figure 14 (Cont.)

(b) Samples vs Average COF of Barites (Without Flyash)

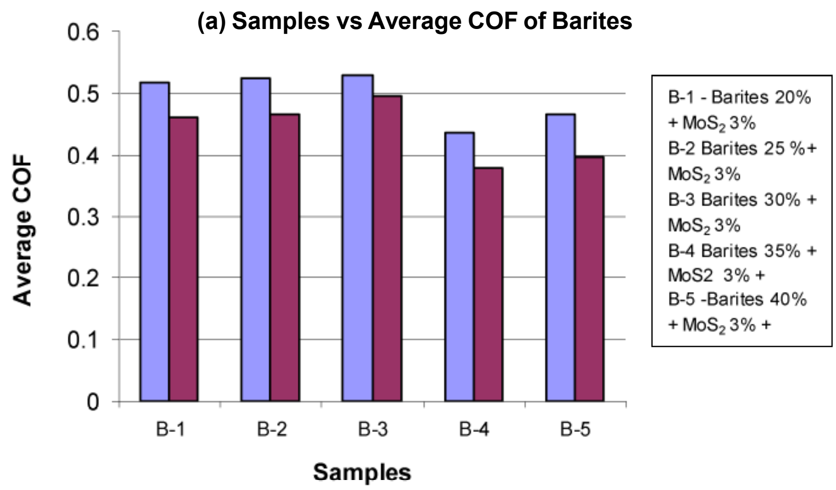


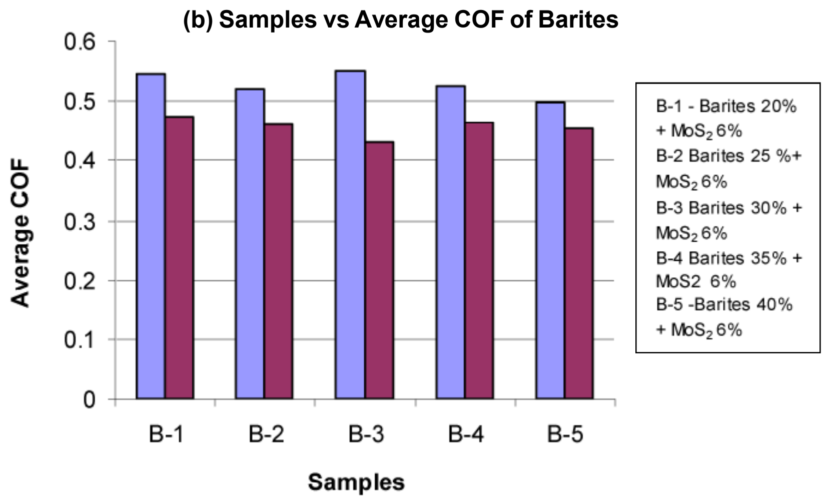
(c) Samples vs Average COF of Barites (Without Flyash)



mu, Hot mu and wear of these composites were measured. The phenolic resin, wollastonoite and cashew increase the coefficient of friction and potassium titanate zircon, and rubber decrease the friction coefficient. The Figures 14 and 15 shows the coefficient of friction of barites (without flyash) molded at different time of 4 min and 6 min under uniform molding temperature and pressure. The Figures 16 and 17 shows that the coefficient of friction of flyash based friction materials were lower when compare to non flyash based friction material due to higher amount of fillers and solid lubricants.

Figure 15: Samples vs Average COF of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm²





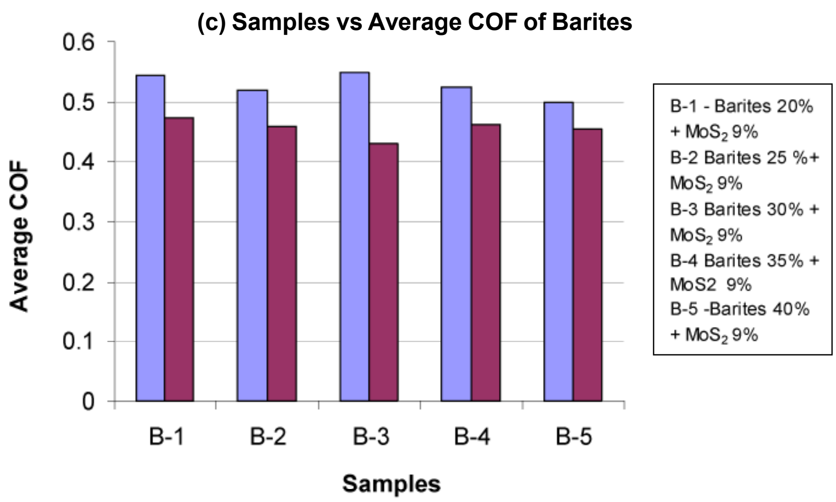
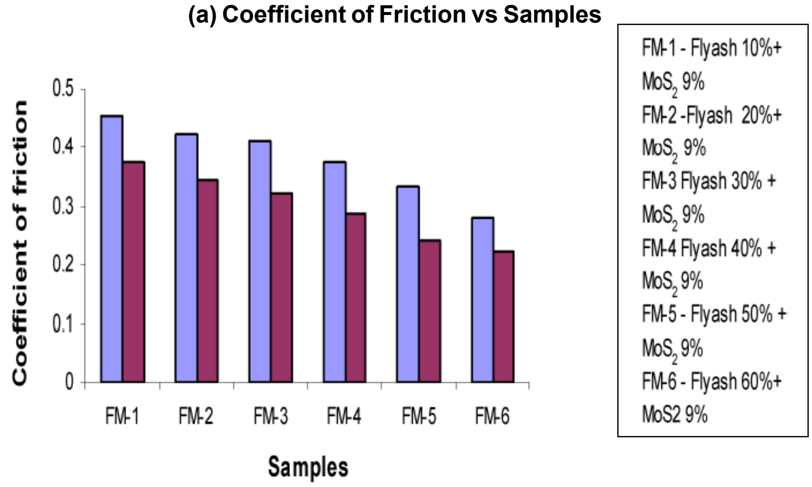
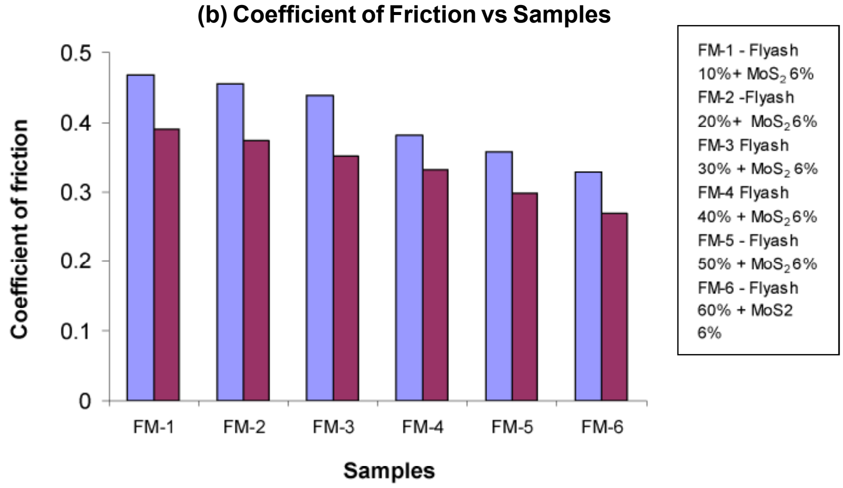


Figure 16: Coefficient of Friction vs Samples of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Molded at Temperature 140 °C, Time 4 min, Pressure 160 Kg/cm²

(a) Coefficient of Friction vs Samples



(b) Coefficient of Friction vs Samples



(c) Coefficient of Friction vs Samples

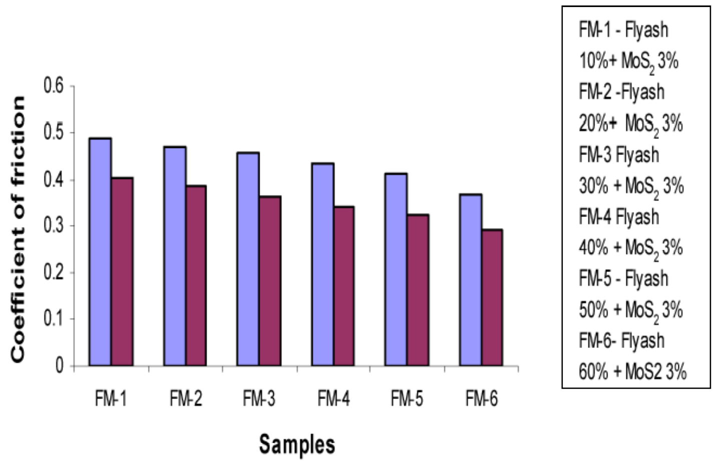
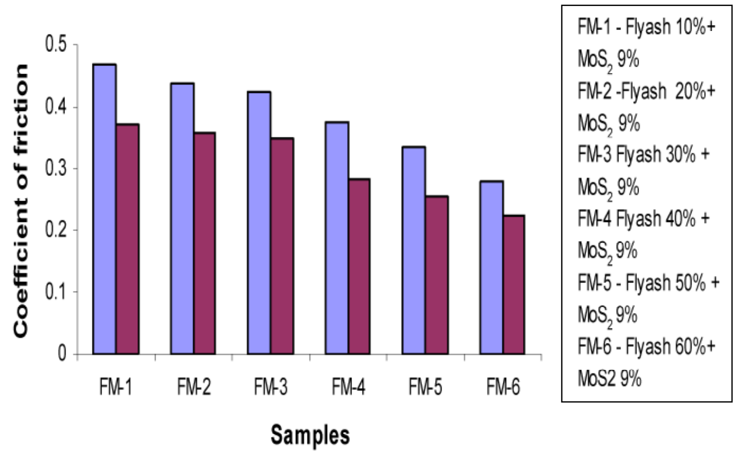
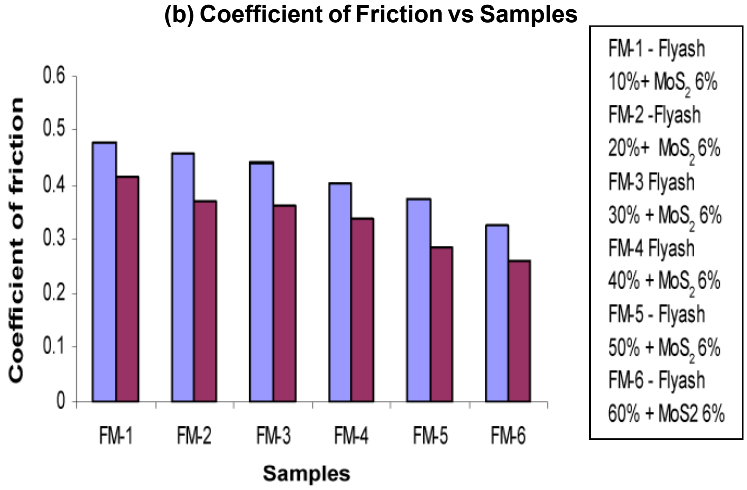


Figure 17: Coefficient of Friction vs Samples of Flyash with 9%, 6% and 3% Molybdenum Disulphide Based Friction Molded at Temperature 140 °C, Time 6 min, Pressure 160 Kg/cm²

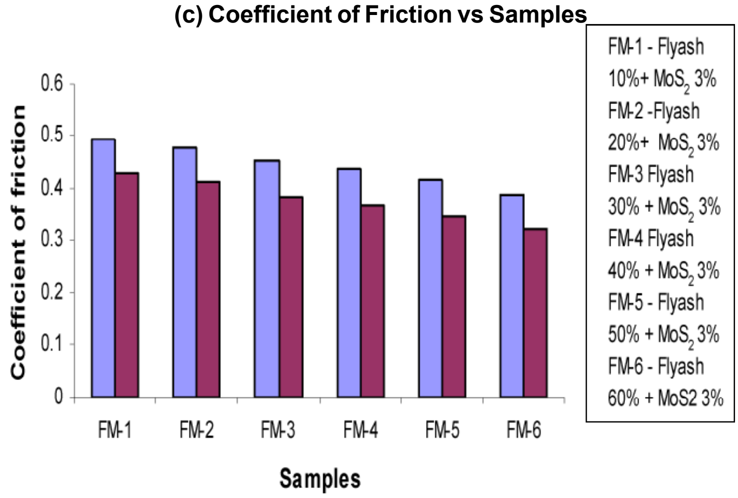
(a) Coefficient of Friction vs Samples



(b) Coefficient of Friction vs Samples



(c) Coefficient of Friction vs Samples



The change of the coefficient of friction is closely related to the hardness and morphological feature of each ingredient. Therefore, the ingredients with high hardness such as phenolic resin, and cashew increase the coefficient of friction due to abrasive action against the cast iron brake drum. The COF increases relative to the amount of cashew dust, wollastonite, barites added to the samples. From the Figure 15 indicates that increase in molding time from 4 min to 6 min had significantly improved in friction coefficient. Wear of barites (without flyash) based friction material lower due to addition of potassium titanate, wollasnoite, to the samples.

Alternately, the increase in addition of other filler ingredients vermiculite, mica can result in low COF. Figures 18 and 19 shows the wear of flyash based friction material molded at different time of 4 min and 6 min. The wear was higher n due to insufficient molding time and increase in percentage of fillers such as flyash, vermiculite, mica, hydrated lime powder in friction material FM-1, FM-2, FM-3, FM-4, FM-5 and FM 6 when compared to wear of the Barites based frictional material B-1, B-2, B-3, B-4 and B-5 usage of potassium titanate (terraces), Twaron 1080 (Aramid Fiber) in the composite, increases the coefficient of friction and generally not in usage due to high cost.

It may viable to be used in the heavy vehicle brake lineras shown in Figures 20 and 21. From the figure it can seen that lower amount of molybdenum disulphide shows better results when the higher amount of molybdenum disulphide. The increase in percentages of molybdenum disulphide from 3% to 9% reduces the hardness of friction material and increases wear of the friction material. The lowering of the friction level due to zircon is also attributed to the morphological effect. In general, zircon particles are used to either control the friction level or clean the pyrolized

Figure18: Samples vs Wear of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²

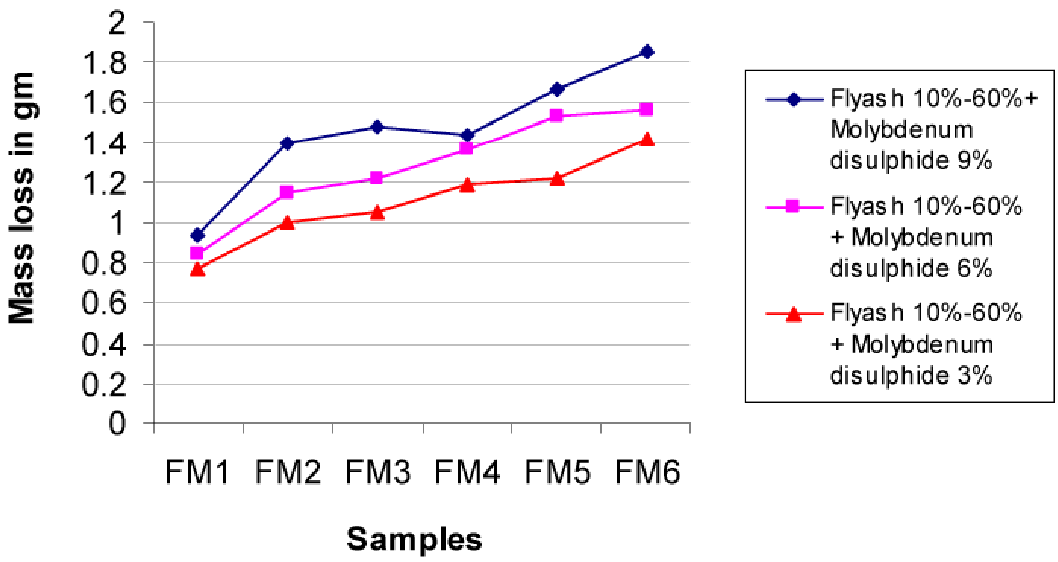


Figure 19: Samples vs Wear of Flyash with Different Percentage of Molybdenum Disulphide Based Friction Material Moulded at Temperature 140 °C, Time 6 min, Pressure 160 kg/cm2

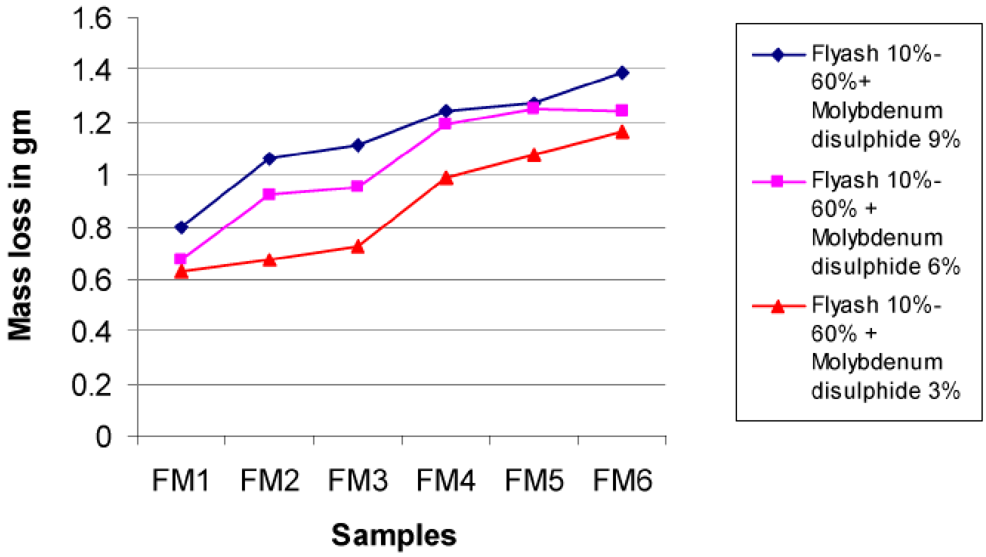
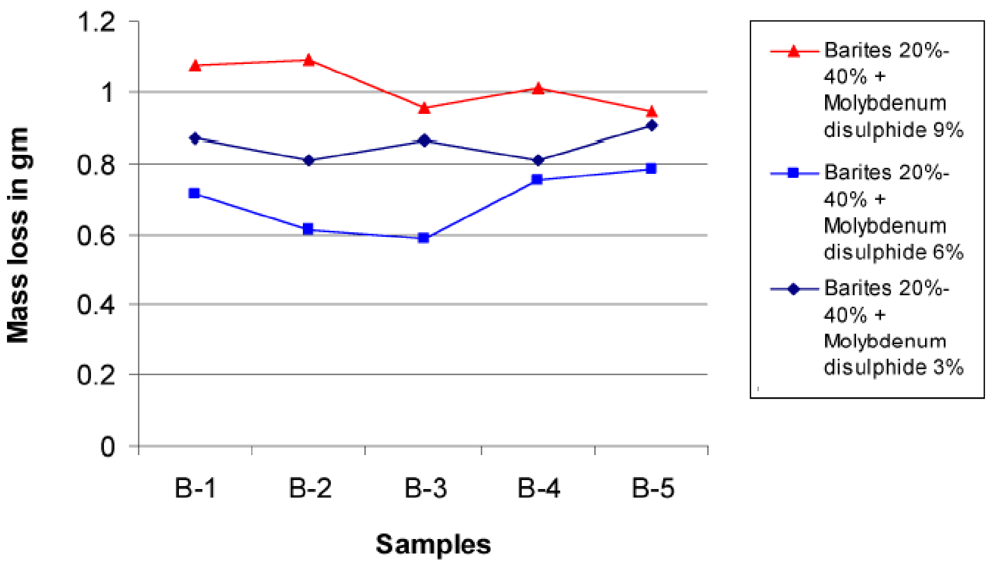


Figure 20: Samples vs Wear of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C, Time 4 min, Pressure 160 kg/cm²



friction film. Coarse zircon (Yuning and Graz¡yna, 2008) particles are normally used to control the friction level and fine zircon flour is used to remove the friction film. However, zircon can improve negative wear rate caused by either gas release or thermal expansion of the nonmetallic friction materials. The wear rate of barites(without flyash) friction materials with zircon is larger than that of without zircon as shown in the Figures 20 and 21.

Figure 21: Samples vs Wear of Barites (Without Flyash) with Different Percentage of Molybdenum Disulphide Based Friction Material Molded at Temperature 140 °C,

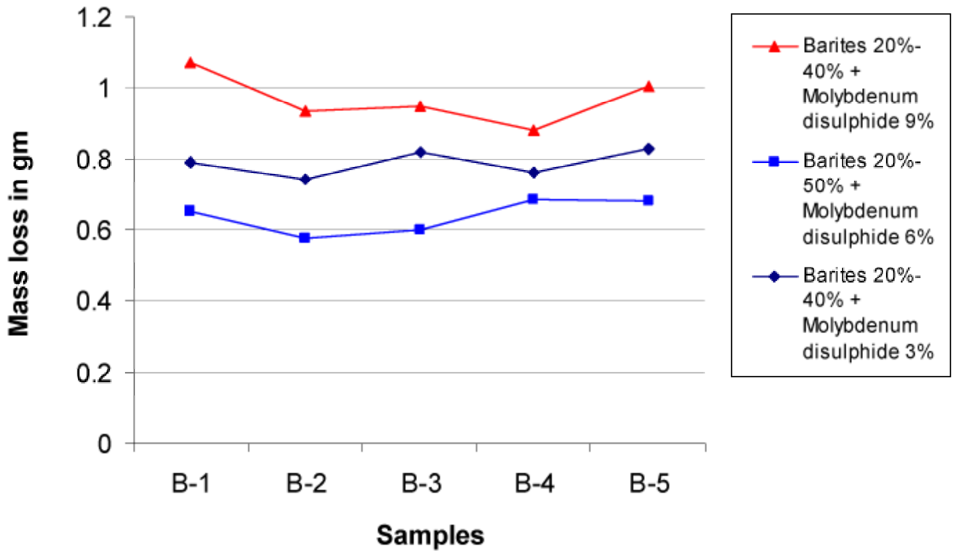
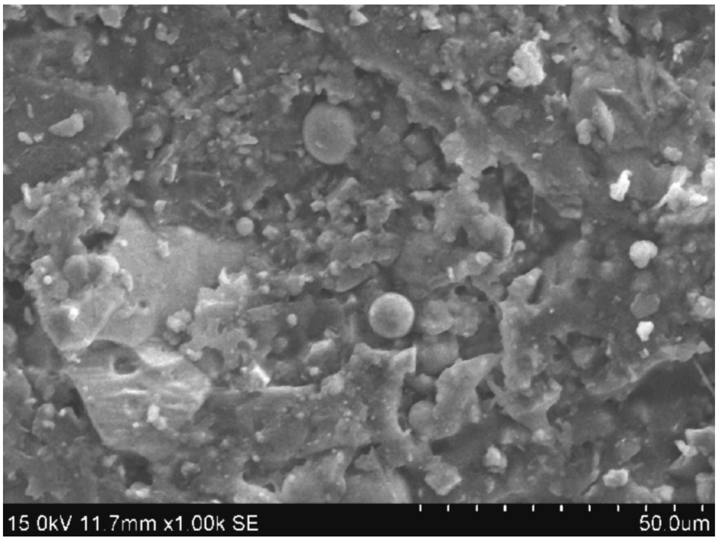


Figure 22 shows the composite containing flyash 60% with abrasive, fillers, fibers and friction modifiers such as cashew dust powders, potassium titanate (terraces) and wollastonite.

Figure 22: SEM Image of FM-6



The Figure 23 shows the composite containing abrasive, fillers, fibers and friction modifiers such as cashew dust powders, potassium titanate (terraces) and wollastonite.

Figure 24 shows the EDX of FM-1 sample with different material composition used for making friction material. The presence of silicon, ferrous and oxides in the flyash

Figure 23: SEM Image of B-1

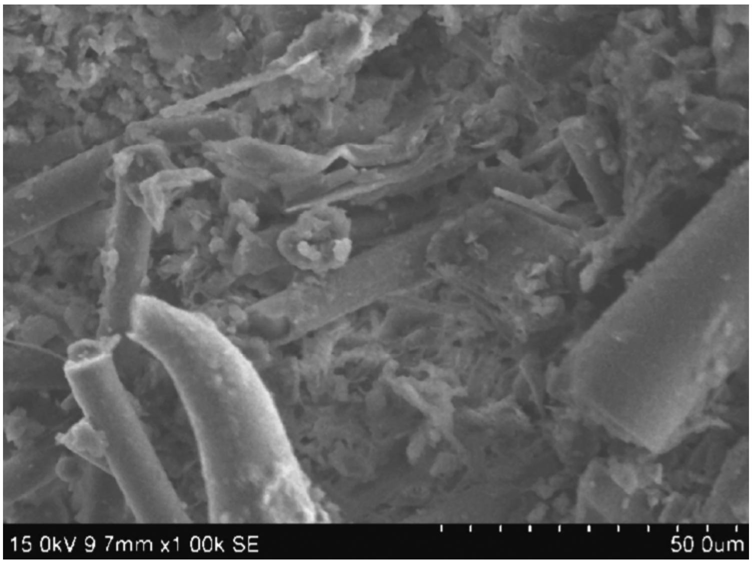
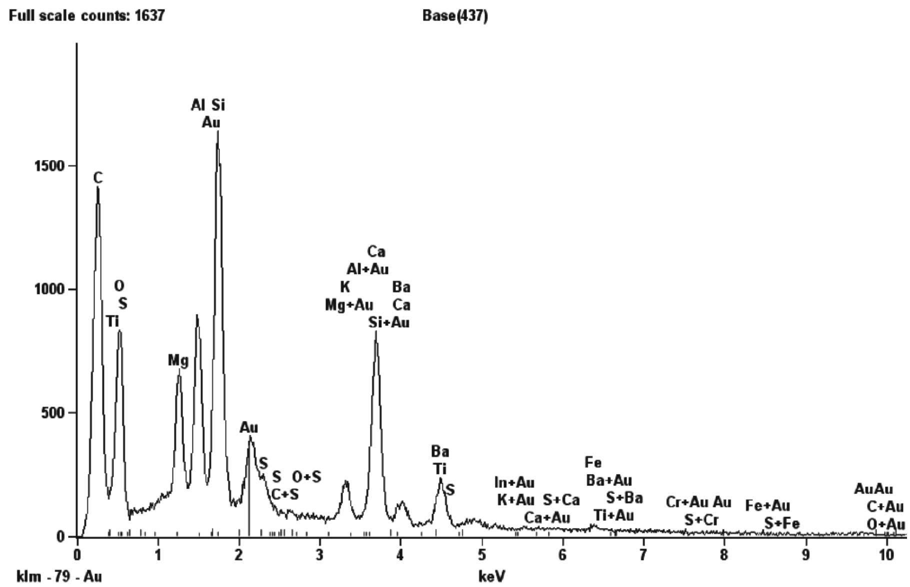


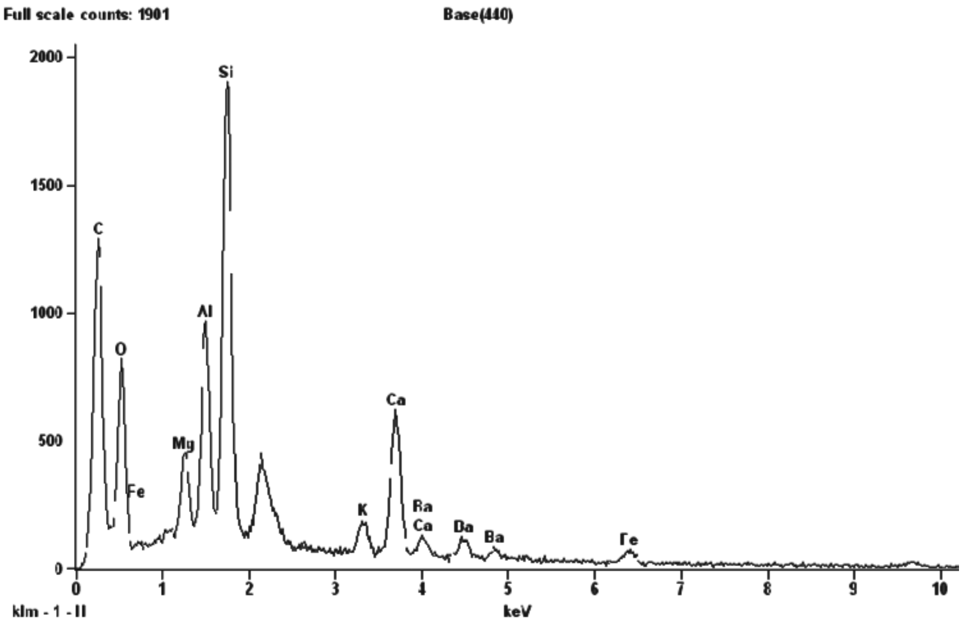
Figure 24: EDX of FM-1



potassium titanate, wollastonite and Barium sulphate in the material composition that has been highly influenced to increase the coefficient of friction and wear to decrease.

Figure 25 shows the EDX of B-1 (without flyash) sample with different material composition used for making friction material. Since the percentage of fillers has increased to a higher amount and to maintain the coefficient of friction to an optimum level. The others materials such as , E- glass fiber, twaron 1080 (Aramid fiber) barium sulfate and potassium titanate, zircon that are added to the friction material.

Figure 25: EDX of B-1



Figures 26 and 27 the coefficient of friction keeps on changing when the number of brake applications was increased, this is due to when drum temperature was increased beyond 250 °C the morphological changes occurs in each ingredients and it was closely related to the hardness, therefore, the ingredients with low melting point degraded and lose its bits bonding strength as a result the coefficient of friction decreases.

Figure 28 the coefficient of friction changes when the number of brake applications was increased, this is due to morphological feature of each ingredients and closely related to the hardness. Therefore, the ingredients with high hardness such as

Figure 26: Number of Brake Application vs Coefficient of Friction of FM-1

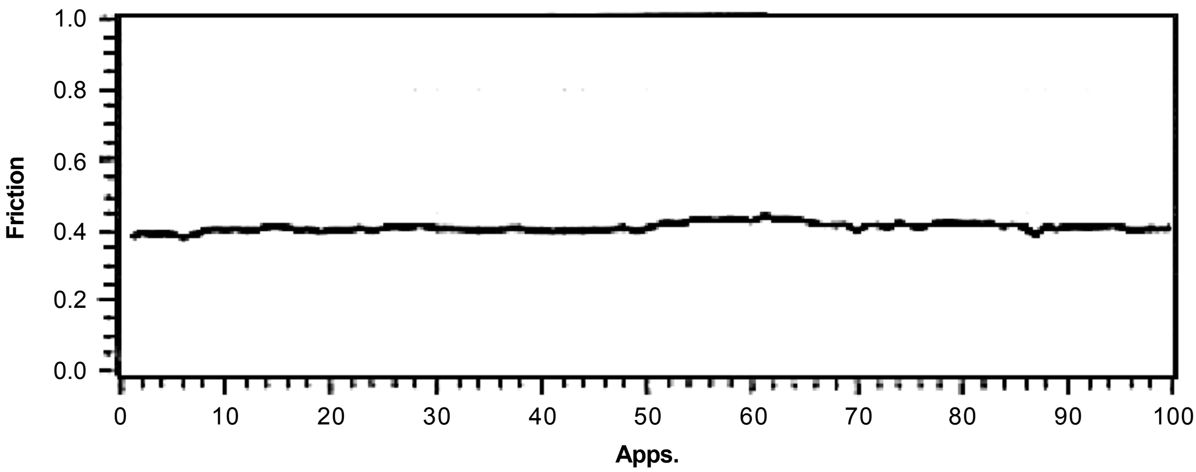


Figure 27: Number of Brake Application vs Coefficient of Friction of FM-6

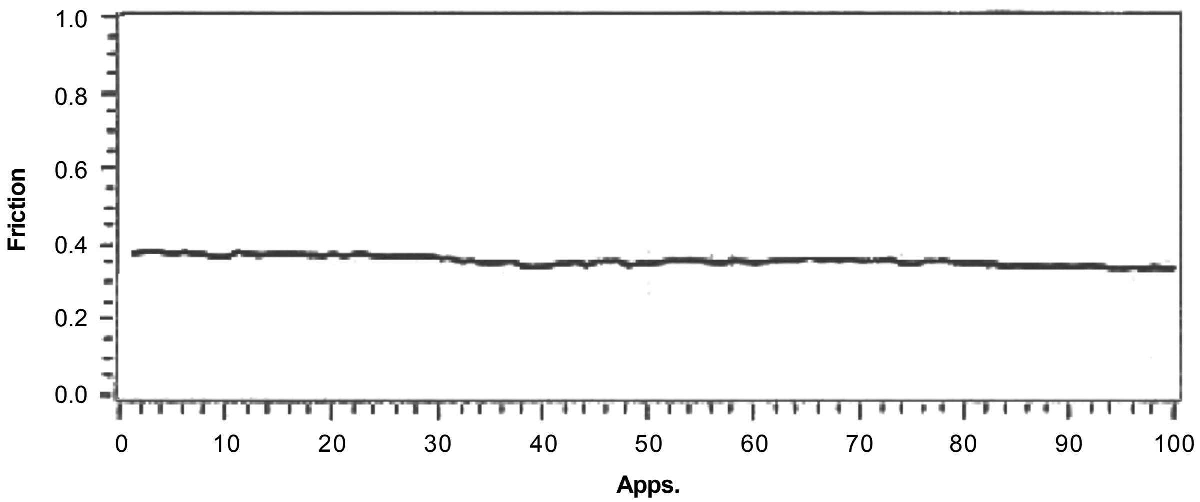
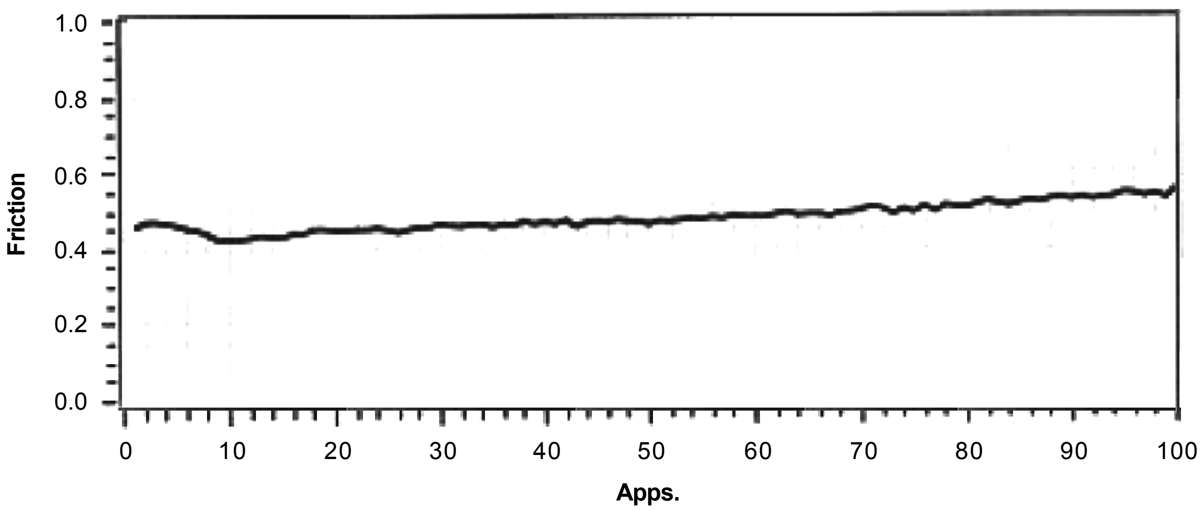


Figure 28: Number of Brake Application vs Coefficient of Friction of B-1



modified phenolic resin, and cashew increase the coefficient of friction due to abrasive action against the cast iron brake drum.

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CONCLUSION

- The increase in percentage of flyash reduces coefficient of friction and also and the weight of brake liner and it is suitable for light motor vehicle.
- In the flyash based frictional material, the COF were moderate and wear losses were high. However in the case of non flyash frictional material, it was observed that the

COF were too high and the wear losses were minimum. The wear resistance and coefficient of friction was significantly improved by addition of Twaron 1080 Fiber, Wollastonite and ceramic wool.

- The presence of potassium titanate particular powder, wollastonite, phenolic resin, and zircon increases in hardness of composite and decreases the porosity of the composite. The hardness has strong influence on porosity which reduces the wear of the friction material.
- Increases in percentage of rubber powder, vermiculite and cashew friction dust powder reduce the hardness of the sample and increases the porosity of the samples. Increase in molding time 4 min to 6 min has improved in performance of friction material.
- It was observed that the tensile strength of flyash friction material was lower than the barites friction material. The low tensile strengths of the composites are attributed to the high filler content and low fiber content in the friction material also due to short in length of fiber.
- Addition of abrasive powder to the sample F2, F4 and F6 increase hardness of the friction material. The usage of potassium titanate (terraces), Twaron 1080 (Aramid Fiber) in the composite, increases the coefficient of friction and generally not in usage due to high cost. It may viable to be used in the heavy vehicle brake liner.

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