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Review of brake friction materials for future development

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Abstract

Braking system in an automobile is always considered to be important for the designers. The main function of a braking system is to overcome vehicle's momentum and stop the vehicle by means of friction. Now days, with the increase of innovative technology and by varying design procedures, newly designed automobiles with high speed sprung on to the market, which are throwing prime challenges for the braking system designers to control the speed of the vehicle. After the gradual phasing out of asbestos as a braking material in many parts of the world, due to its widespread complaints as a carcinogenic material, automobile brake friction industry and people are looking for suitable alternatives to replace asbestos material. There is need to develop new friction materials to meet the stringent requirements of customers, such as effective braking performance and less squealing action .Therefore, the main challenge for the designer is to develop a brake friction material which intended to serve its effective braking performance and being eco friendly in nature. Therefore, with in this paper, an overall review of the research carried out in the area of friction materials is presented and the affect of fiber, filler and other ingredients on the braking performance is studied. Various experimental techniques used to study the behavior of squealing action in automobile braking is presented.

Key words: Brake friction materials, friction and wear, squealing, fade, recovery

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1. INTRODUCTION

Brake pads convert the kinetic energy of the vehicle to thermal energy by means of friction. Two brake pads are contained in the brake caliper with their friction surfaces facing the rotor. When, the brakes are hydraulically applied, the caliper clamps or squeezes the two pads together in to the spinning rotor to slow/stop the vehicle. During this process, the pads are subjected to wear. The wear rate mainly depends up on the type of friction material used, pressure applied on the pads, friction material temperature, friction material contact area, friction material finish, heat removal rate, ability to operate over various atmospheric conditions and fade resistance. In addition to all these factors, the other factors that affect the friction development are weight transfer, tire and road conditions, dimensions of brake drum, engine size and drive train gearing, and water on brake linings etc.

Fig 1 & 2 shows a typical disk brake and assembly found in passenger vehicles.

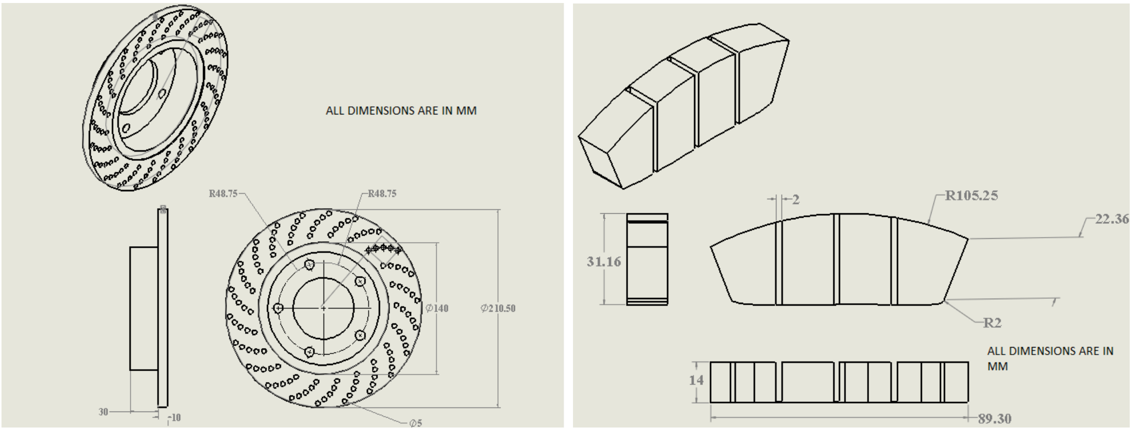

Fig1. *Automobile disc brake with friction material*

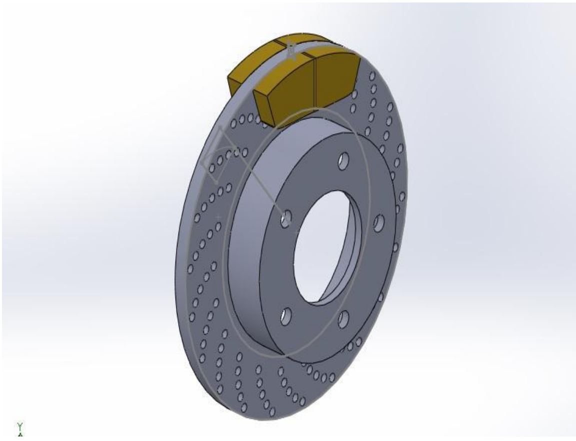

Fig 2. *Assembly of automobile disc with friction material*

The main characteristics of friction materials should possess are [1]

(a) Maintain a sufficiently high coefficient of friction with the brake disc.
(b) Not to decompose or break down in such a way that the friction coefficient with the brake disc is compromised, at high temperatures.
(c) Exhibit stable and consistent coefficient of friction with the brake disc.
(d) Wear resistant.
(e) Able to dissipate heat to the surroundings.
(f) Having sufficient fade resistance.
(g) Induce less squealing action and should be operated over different atmospheric conditions.

1.1 Classification of friction materials

In the past, asbestos reinforced fiber friction material is widely used because of its excellent comprehensive performance such as low density, high mechanical properties, high melting point, high friction coefficient, and less wear rate on disc. It has been proved recently, that asbestos is carcinogenic to human respiratory organs and cannot be used as a friction material [2, 3]. Based on the type of matrix material, brake friction materials can be divided in to metallic, Semi metallic, and non metallic.

1.1.1 Metallic matrix friction material

Depending up on the type of production technique, the metallic matrix friction materials can be divided in to two types i.e. metal casted and powder metallurgical. Steel, cast iron, bronze etc. can be categorized as main constituents for metal casted friction materials. Powder metallurgy friction materials mainly include iron based, copper based and combination of iron and copper based. Among them, iron based friction materials has high temperature strength, hardness, and thermal stability. While, the copper based friction materials has more stable friction coefficient, greater thermal conductivity and wear resistance. Iron and copper combination made friction materials having same content of copper and iron possess excellent mechanical properties and good wear resistance. Powder metallurgy friction materials are widely used in trucks and trains having a heavy braking load and extremely high speed.

1.1.2 Semi metallic matrix friction material

Semi metallic friction material consists of combination of fibers and metallic powders. Prominent fibers predominantly in use are ceramic, metallic, carbon and aramid. Whereas metallic powders are mainly of copper and iron. These materials possess excellent tribological properties and high heat resistance. The main disadvantages of semi metallic matrix friction material are low frequency noise, easy rusting, and serious damage to brake disc. Presently, semi metallic matrix friction material is widely used in automobiles, motor cycles and other light weight vehicles.

1.1.3 Nonmetallic matrix friction material

Non metallic matrix friction material consists of organic fibers such as Kevlar, Carbon etc. as reinforced fibers in combination with other ingredients such as modified resin by rubber powder, frictional additives, and filler materials. These materials are solidified by pressing against hot press. There are a number of nonmetallic matrix friction materials, out of which carbon –carbon friction material exhibits high strength and toughness and superior thermal stability. At present, C-C Composite friction material was mainly used in aero planes and race cars.

Among the above mentioned classified friction materials, Powder metallurgy and organic friction materials are widely been used in various applications. Organic friction material was most widely used due to its simple preparation method, excellent tribological properties and eco friendliness. Organic friction material consists of following components [1]

(a) Binder: The binder sticks all components together. The binder selected, should possess excellent heat resistance.
(b) Reinforcing fibers: The Reinforced fibers are used to improve friction performance and strength.
(c) Frictional additives: Frictional additives are responsible to improve friction properties of the brake pads and they are comprised of a mixture of abrasives and lubricants. The lubricant is generally used to reduce the wear of friction material and coefficient of friction and abrasive is used to improve the coefficient of friction.
(d) Fillers: Fillers are used to improve the manufacturability of brake pad and reduce the cost.

2. Friction and wear behaviors of various materials

Friction and wear behaviors of friction material depend mainly on the following important factors [4]

a) Selection of friction material for fabrication.
b) Manufacturing method involved for fabrication.
c) Material characteristics such as Physical, chemical and mechanical properties of friction materials.
d) Braking influential parameters such as braking pressure, initial braking speed, braking time, temperature rise in braking etc.

e) Other Conditions such as Surrounding temperature, humidity, air flow etc.
f) Structural parameters such as Shape, size, contact of brake pair etc.

Friction material characteristics play a vital role to improve the performance of materials. Among, the different types of materials available for manufacturing, organic type of composite materials are widely used in the industry. Now a days, composite materials plays a promising role in several fields of applications like aerospace, automobiles, sports items, bridge construction and pressure vessels etc.. The advantages of composite materials are ease of process ability, less weight, corrosion resistance, low cost and high specific strength to weight ratio. Among the different types of composite materials available, fiber reinforced composite materials plays a prominent role in several applications because of their excellent mechanical properties, corrosion resistance and good strength to weight ratio. The selection fiber, filler, braking conditions plays a key role in the design and manufacturing of friction materials. Therefore, the influence of these parameters on friction and wear behavior is studied in detail to select the appropriate friction materials for effective braking performance.

2.1 Influence of reinforced fiber on friction and wear

Selection of fiber reinforcement material plays an important role for the designer to improve friction and wear characteristics of friction material. Fiber is responsible for transmitting the given load and withstanding the given pressure. It gives mechanical strength to the entire composite. Selection of optimum wt% of the fiber is essential for the designer to achieve better wear and frictional properties.

K.L.Pickering, M.G.Aruan Efendy [5] Reviewed on recent developments in natural fiber composites and their mechanical Performance. It was observed that the mechanical properties of the fiber are improved due to inclusion of various filler materials. There is need to improve moisture resistance of the fiber in future. Emad omrani, Pradeep L Menezes [6] investigated about tribological behavior of polymer matrix composites reinforced with natural fibers and observed that chemically treated natural fiber gives good tribological behavior and better friction compared to untreated conventional fibers. The type of chemical treatment and fiber orientation are two important parameters to concentrate in order to achieve good strength. Umar Nirmal , Jamil Hasim [7] Reviewed on tribological Performance of natural fiber polymeric composites and identified the key parameters such as adhesive wear mechanism, operating and test parameters plays an important role in tribological properties. M.A.Maleque, A.Atiqah [8] Fabricated natural fiber reinforced aluminum composite for automotive brake pad. In this work brake pads are formulated by the following ingredients namely, Aluminum (45wt %), Silicon Carbide (20 wt %), Coconut fiber content is varied from four different formulations(0,5,10,15wt%), graphite(10wt%),Alumina oxide(13wt%), Zirconium oxide(2wt%), Phenolic Resin(10wt%). It was observed that, coconut fiber containing (5, 10 wt %) showed better physical and mechanical properties compared to other formulations. Xingming xiao, Yan Yin [4] Reviewed on the friction and wear behavior of brake materials. In this work friction material classification, friction interface and formation of various friction films has been studied. It was observed that the temperature, Velocity, and pressure plays an important role in the friction and wear behavior of friction materials and the wear rate induced in friction material is directly proportional to the operating parameters.

N.Aranganathan, Vishal Mahale. [9] Formulated an aramid fiber non asbestos organic friction composite. In this work, the friction composite is formulated by following ingredients, phenolic Resin (10 wt %), Fillers (Brass metal powder 10 wt%, cashew dust 10 wt%, vermiculite 10 wt %), Friction modified fibers (Grapite10 wt%, Alumina 2 wt%, Rock fibers 10 wt%, Glass fibers 5 wt%, PAN fibers 3 wt%), $BaSO_4$(30,28,26,24,22,20wt%), Aramid fiber (0,2,4,6,8 wt%) . The aramid fiber content is varied in proportions and physical, mechanical, chemical and tribological performance is evaluated. It was observed that 10 wt % Aramid pulp showed best performance in coefficient of friction (μ), μ fade, and μ recovery. Peng Cai, Zhenlian Li. [10] investigated about the effect of aspect ratios of aramid fiber on mechanical and tribological behaviors of friction materials. The friction material is fabricated with the composition of $K_2Ti_6O_{13}$ 29.2%, aramid fiber 18%, NBR 1.7%, Vermiculite 18%,Potash feldspar 2.6 %, flake Graphite 4.3 % , $BaSO_4$ 2.6% , Boron Phenolic resin 23.6%. It was observed that, by increasing the aspect ratio of fiber, flexural strength of the composite increased and compressive strength decreased while the coefficient of friction (μ) and wear rate of composite first increased and then decreased at selected load and speed. And With the addition of fibers, the coefficient of friction (μ) and wear of the composite is increased. It was observed that, Aramid pulp of 10 vol% is proved to be the best optimal volume fraction for improved friction and wear behavior of the composite. T.Singh, A.Patnaik[11] Developed hybrid phenolic composites based on lapinus and aramid fiber. The contents of aramid fiber and lapinus fiber are varied in proportions by keeping remaining compositions as constant. It is observed that physical properties increase with increase in lapinus fiber content and mechanical and thermo mechanical properties increase with increase in aramid fiber content. The composite having lapinus to aramid ≥ 25% to ≤ 5% and Phenolic Resin 15%, $BaSO_4$ 50%, Graphite 5% showed better braking and fade performance. Whereas, composite with lapinus content ≤ 22.5 % and aramid content ≥7.5 % proved best from recovery and wear performance.

Vivek Dhand, Garima Mittal [12] Reviewed on basalt fiber reinforced polymer composites and observed that the mechanical properties of basalt fiber were improved by hybridizing basalt fiber with silanes. Hence, basalt fiber can be successfully used in industries like transport, mining engineering, civil infrastructure and environmental applications. V.Fiore, T.Scalici [13] reviewed on basalt fiber and its composites .In this work basalt fiber is used as reinforcement in composites because of its good thermal, chemical and mechanical properties. Ashok Kumar Ilanko, Srinivasan Vijayraghavan [14] studied about, wear behavior of asbestos free eco friendly composites for automobile brake materials. In this work three different brake pad materials flax fiber reinforced phenolic composites (FFRC), Basalt fiber reinforced phenolic composites (BFRC) and flax/Basalt reinforced hybrid phenolic composites (HFRC) has been studied for various thermal, mechanical and physical properties. Brake pad is formulated with the following ingredients namely, Phenolic resin 25 wt%, fillers (barites 15 wt%, vermiculite 5 wt %), friction modifiers (Graphite 12 wt%, coke 18 wt %, MoS_2 1 wt %, MgO 5 wt %, potassium titanate 6 wt% , Al_2O_3 5 wt%, $ZrSiO_4$ 2 wt %), reinforcement (flax, basalt, flax/basalt 6 wt %).It was observed that, BFRC for pad exhibit good thermal and wear characteristics because of its good bonding strength with resin. B.K.Satapathy, J.Bijwe [15] studied the performance of friction materials based on variation in nature of organic fibers. In this work, the influence of organic fibers such as Aramid, PAN, Carbon fibers and cellulose fiber on the coefficient of friction (μ), fade and μ recovery characteristics of the composite is determined. It was observed that carbon fiber reinforced composite showed high resistance to coefficient of friction (μ) fade where as cellulose fiber composite showed least resistance to μ fade. The composite containing Aramid fiber and cellulose fiber exhibits highest and lowest wear resistance where as highest and lowest coefficient of friction is observed for cellulose and carbon fiber based composites. Bhabani K.Satapathy, Jayashree Bijwe [16] studied about influence of operating variable on friction composite. Organic fibers such as aramid, PAN, Carbon and Cellulose is studied with respect to the braking pressure and speed. It was observed that, carbon and PAN made the friction composite least sensitive to dynamic variations. The inclusion of cellulose fiber tends to increase the friction coefficient while aramid fiber improved wear resistance. A.P. Garshin, V.I.Kulik. [17] Reviewed on new generation of braking friction materials such as carbon and ceramic matrices. An attempt is made in this paper to formulate a carbon Ceramic matrices fiber reinforced composite friction material to reduce the mass of the braking system by 40-60%. It will have high wear resistance and ability to resist temperatures over 1273 K, and can be successfully used as friction materials in aerospace vehicles.

U.D.Idris, V.S.Aigbodion [18] developed eco friendly asbestos free brake pad using banana peels. In this work asbestos free brake pad using banana peels as reinforcement phenolic resin as the binder is formulated and tested for different morphology, physical, mechanical and wear properties. The resin content is varied from 5 to 30 wt%. It was observed that with the increase in wt% of resin compressive strength, specific gravity, hardness of the samples increases. The samples containing 25 wt% resins in uncarbonized banana peels and 30wt % carbonized banana peels have the best properties. K.K.Ikapambse, D.T.Gundu [19] Used palm kernel fibers for the production of asbestos free brake pad with epoxy resin as the binder .Resin is varied in proportions by keeping the remaining compositions as constant. It was observed that sample s6 with composition of 40% epoxy Resin, 10% palm wastes, 6%Al_2O_3, 29% Graphite and 15% $CaCO_3$ gave better properties than the other samples. Therefore, Palm kernel fibers can be used as a replacement for asbestos in brake pad applications.

Nagesh S.N, Siddaraju C[20] characterized brake pads by variation in composition of friction materials. Three brake pad S 2, S3, & S 4 are manufactured and compared with the existing brake pad sample S1. Brake pad sample S2 exhibits good properties and the constituents are, Steel wool (26.2wt%), Vermiculite(20 wt %), Natural Graphite(10 wt%) ,Carbon black (3. wt%), Ceramic fiber (17.7wt %), Phenolic Resin (21.5wt %) . Brake pad sample S3 is manufactured with Steel wool (29.2 wt %), Vermiculite (20 .8 wt %) , Natural Graphite(4.6 wt%) , Carbon black (2.3 wt%) , Ceramic fiber (20wt %), Phenolic Resin (22.3 wt %) .Brake pad sample S4 is manufactured with Iron oxide (27.7 wt %) , Barytes(18.5 wt%), Natural Graphite(8.5 wt%), Carbon black (3.8 wt%), Mineral fiber(18.5 wt%), Phenolic Resin (23.1 wt %). It was observed from the pin on disc apparatus, the brake pad sample S2, wear slightly high and the coefficient of friction was almost stable and slightly less compared to the existing specimen S1. The coefficient of friction for the sample S4 was slightly high around 0.45, due to the presence of higher percentage of abrasive which increases the friction coefficient and wear rate. The shear strength of the new prepared specimen showed better values compared with existing brake pads. Hence brake pad sample S2 and S4 can be used in place of existing brake pad and the cost of producing these brake pads are quiet low. R.Vijay, M.Jeesh Janesh [21] optimized the tribological properties of non asbestos brake pad materials using steel wool. Friction material is formulated with the following ingredients , steel wool(0wt%, 4 wt%,8wt%,12wt%),copper fiber (5wt%), Antimony trioxide(1.5 wt%) ,Alkyl Benzene Phenolic Resin(11wt%),NBR Rubber(3wt%),Syntheticgraphite(10wt%), Molybdenum disulphide(2wt%),Zirconium silicate(2wt%),Frictiondust(12wt%),Syntheticbarites(32wt%),Vermiculite(7wt%),Calcium carbonate(14.5 wt%). The steel wool content is varied in proportions by keeping the remaining ingredients as constant. It was observed that the non asbestos organic (NAO5) with high steel wool content showed better properties and exhibits good coefficient of friction and less wear rate than other compositions.

Sedigheh Bagheri Kazem Abadi, Alireza Khavandi [22] fabricated a brake friction material with phenolic resin, short carbon fiber, graphite, quartz, barite and steel fiber .The effect of mixing steel and carbon fibers on the friction and wear properties of a polymer matrix composite friction material is studied in detail. The ingredients of steel fiber (17.5 wt%,15 wt%,12.5 wt% ,10wt%) and carbon fiber (2 wt%,3 wt%,4 wt%,5 wt%) are varied in the given proportions, and it was observed that sample containing 4 wt% Carbon fiber exhibits better wear and friction properties.

Du-Qing CHENG, xue-tao WANG [23] studied the effect of friction and wear behavior of carbon fiber reinforced brake materials. A new composite brake material was fabricated with metallic powders (40 Wt %), barium sulphate ((17-23Wt %) and modified phenolic resin (25 Wt %) and carbon fiber (12-18 wt %).The friction, wear and fade characteristics of the glass, asbestos and carbon fiber reinforced friction materials (GFRFM, AFRFM and CFRFM) was studied in the temperature range of 100^0 C-300^0C.It is observed that CFRFM shows less wear rate compared to GFRFM &AFRFM. Zhishuang Dai, Baoyan Zhang [24] evaluated the effect of heat treatment on Carbon fiber surface properties and fiber/ Epoxy interfacial adhesion. In this work T 300 B fiber was heat treated and the effect of heat treatment was studied by means of x-Ray photo electron spectroscopy (XPS) and inverse gas chromatography (IGC) analysis. It was observed that the dispersive surface energy of T 300 B carbon fiber and contact angle between carbon fiber and epoxy E51 increases, while the interfacial shear strength of T 300 B / epoxy reduces with the heat treatment process. Kannan Balasubramanian and Marko Burghard [25] Reviewed on Chemically Functionalized Carbon nano tubes. Carbon nano tubes possess good structural, mechanical, and electronic properties. Chemically functionalized CNT can be used in several applications for improving all the mechanical properties of the composite. R.Andrews, M.C.Weisenberger [26] Reviewed Carbon nano tube polymer composites. In this review CNT/polymer matrix composite is studied in detail with main emphasis on toughness and bonding strength. Jia xian and Ling xiaomei [27] studied the friction and wear characteristics of polymer matrix friction materials reinforced by brass fibers. In this work, the influence of organic adhesion agent, cast iron debris, brass fiber, and graphite powder on the friction wear characteristics is studied in detail. The experimental results showed that the friction coefficient and wear loss of the friction material increased with the increase of cast-iron debris, but decreased with the increase of graphite powder content. When the content of organic adhesion agent is about 10-11%, the friction material has a higher friction coefficient and lower wear rate. D Chan and G W Stachowiak [1] reviewed on automotive brake friction materials .Various types of brake friction materials after the phasing out of asbestos is presented. The advantages and disadvantages of various brake pads are studied. It was observed from the review that there is need to develop automobiles with high efficiency and lower emissions considering all the environmental regulations.

Based on the work carried out by many researchers, it was observed that, fiber selection and the chemical treatments affect the strength of the composite. Further, it improves interfacial adhesion between fiber and matrix and improves the shear strength of the composite. Although the data presented here may be helps to select the of type of fiber for the required application to achieve good wear rate and stability of coefficient of friction, But, other parameters like filler ingredients , method of fabrication ,temperatures generated at the contact region, speed will affect the strength of the composite. Below tables 1&2 and figures 2.1 (a) &2.1 (b) will give an overall idea to select appropriate fiber volume % with respect to wear rate and coefficient of friction. The following notations are used for plotting graphs for different fibers with respect to volume%, wear rate and coefficient of friction. [NF-Natural fiber, AF-Aramid fiber, GF-Glass fiber, RF-Rock fiber, LF-Lapinus fiber, BF-Basalt fiber, CF-Carbon fiber, SF-Steel fiber, PKF-Palm Kernel fiber, Cellulose fiber, Copper fiber, Ceramicfiber].

Table1.*Selection of fiber based on volume% and wear rate*

Type of fiber	**Volume%**	**Wear rate /$10^{-6}mm^3$/Nm**
NF	8	8
NF+Treat ment	12	15
NF coconut+Al+SIC	10	28
AF+GF+RF+PAN	10	34
AF+K2Ti6013	10	30
AF+LF	30	38
BF	7	30
BF+FF	12	32
CF+AF+CelluloseF	14	44
BF carbunized	30	19
PKF	10	32
SF+Ceramic F	49	42
SF+Copper F	18	48
SF+CF	17	52
C,GF,SF	16	39

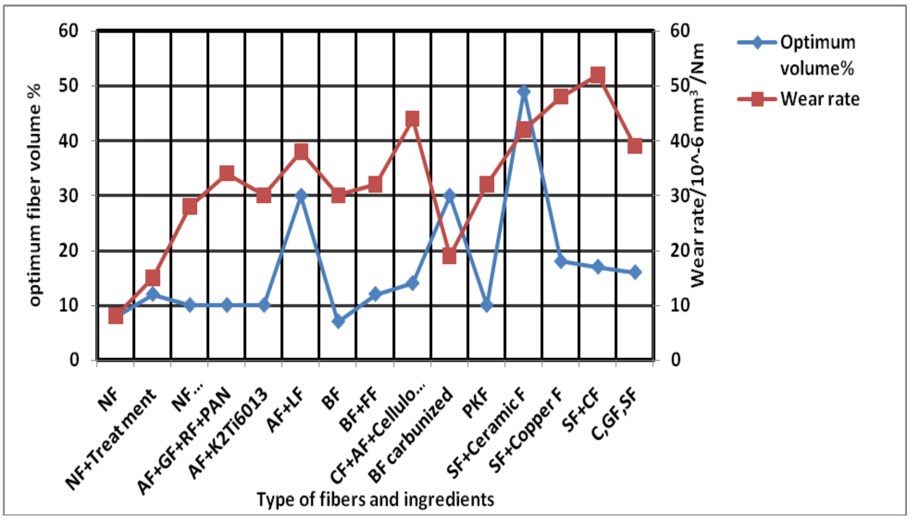

Fig 2.1(a) *Effect of wear rate on fiber volume %*

Table 2. *Selection of fiber based on volume % and coefficient of friction*

Type of fiber	Volume%	Coefficient of friction
NF	8	0.28
NF+Treat ment	12	0.3
NF coconut+Al+SIC	10	0.35
AF+GF+RF+PAN	10	0.4
AF+K2Ti6013	10	0.5
AF+LF	30	0.4
BF	7	0.38
BF+FF	12	0.4
CF+AF+CelluloseF	14	0.42
BF carbunized	30	0.3
PKF	10	0.35
SF+Ceramic F	49	0.45
SF+Copper F	18	0.52
SF+CF	17	0.54
C,GF,SF	16	0.4

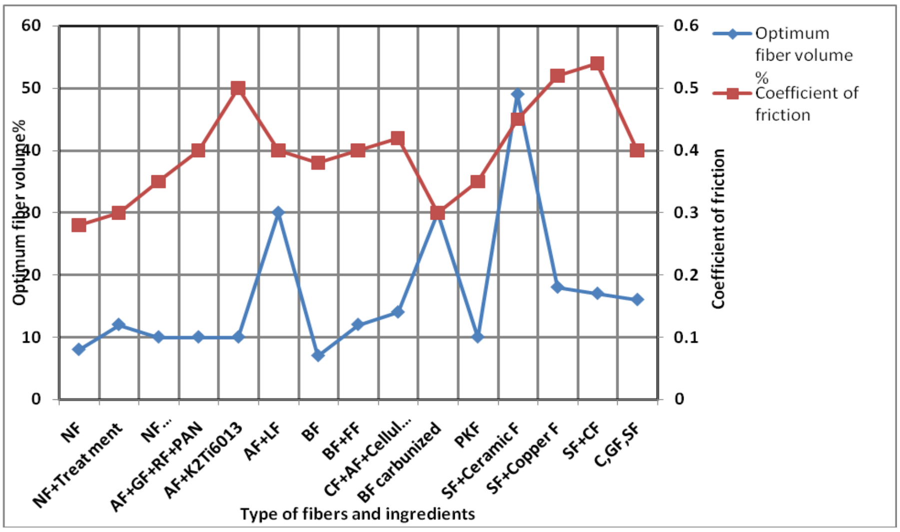

Fig 2.1(b) *Effect of coefficient of friction on fiber volume %*

It was observed from the above graphs, that the wear rate of friction material mainly depends up on the temperatures generated at the contact region between friction material and disc. Fiber material and other ingredients selected for the design should be able to with stand the temperatures generated at the contact plateaus to have sufficient fade resistance. Therefore optimum selection of fiber compromising with the given temperatures and pressure has to be selected to have stable coefficient of friction over wide range of temperatures.

2.2 Influence of metallic / organic fillers on the wear and coefficient of friction

Selection of metallic / organic fillers and other ingredients are selected based on the friction material usage for any application. Operating parameters such as speed, braking conditions will affect the selection of filler material. Because, the filler material has to with stand the given load at various speeds of the automobile. Various other parameters such as, manufacturing conditions, bonding strength between all ingredients, operating conditions, design conditions, atmospheric conditions affect the selection of filler materials. The ease of manufacturing of friction material also depends on the selection of filler material.

Generally metallic filler material is included in the friction material to with stand high temperatures. It is generally used for high speed vehicles like trains and sports cars. Now a day's metallic filler materials are replaced with organic filler materials to reduce vibrations generated during braking. Organic filler materials are used for low and medium speed vehicles. Few, researchers are also studied about semi metallic friction material, to compromise for both strength and vibration. The appropriate selection of filler material is given as a choice for the designer to consider better filler material with necessary ingredients for the design , which suits to given operating and human comfort conditions.

N.Aranganathan, Jayashree Bijwe [28] developed copper free eco friendly brake friction materials by using novel ingredients. In this work an alternative two new filler materials rock fiber and thermo graphite fiber is selected for manufacturing a brake pad. Five brake pad materials of Cu free rock fiber increasing Wt %(10, 15, and20 %) is fabricated along with 10% thermo Graphite. Physical and mechanical properties of the Cu based and Cu free based brake pad composite is evaluated. It was observed that Cu- based friction materials perform better than Cu –free friction materials in some properties but not significantly in main important properties. Glenn Kwabena Gyimah, Ping Huang [29] developed a novel type friction material with Cu and Several elements such as Al, SiO_2, Fe, Graphite, Sn, Mn, and MOS_2 by powder metallurgy technique. The effect of sintering temperature was studied on the mechanical and tribological characteristics of train brake pads. The materials prepared are sintered at three different temperatures (850^0C, 900^0C & 950 ^{0} C). It is observed that severe wear occurs at lower temperatures (850^0C, 900^0C) but wear reduced at the elevated sintering temperature of 950 ^{0} C. It is also observed that the porosity reduced at higher sintering temperature. The densification of the material was also improved. The volumetric and wear coefficients improve remarkably with increase in sintering temperature. Further increase of sintering temperature above 950 ^{0} C is expected to affect the microstructure and tribological characteristics of Cu based friction material. Ane Maite Martinez, Jon Echeberria [30] investigated about the reaction between metal powders and the solid lubricant Sb2S3 in a low metallic

brake pad at high temperature. Metal sulphides such as Cu, Fe, Sn, and Zn play an important role during braking. The effect of metal sulphides on solid lubricant Sb2S3 plays an important role. It was observed that, the reaction features and products depend on the temperature generated during braking, the specific combination of metal lubricant and the atmospheric conditions.
Guangyu bian, Houzheng wu [31] studied about friction surface structure of a carbon SiC Cf / C- SiC composite using a dynamometer. A thin friction layer was developed on the top of transferred materials and SiC regions with nano sized copper/iron oxide crystallites as the primary constituent. The main chemical elements in the friction layer on the brake disc surface are Fe,Cu,O,Si and FeO crystallites in a size around ten nanometers . It was observed that the bonding strength between carbon and SiC proved to be weak, and stable coefficient of friction cannot be achieved due to poor bonding strength between fiber and matrix. Guangyu Bian, Houzheng wu [32] Studied about Friction performance of carbon /Silicon Carbide Ceramic composite brakes in ambient air and water spray environment. In this work, carbon / Silicon carbide brake disc having composition 53.1% and, 17.7 % Sic composite is tested against an organic brake pad in air and water spray environment. It was observed that an average coefficient of friction of 0.52 and 0.4 was observed for a braking stop in air and coefficient of friction of 0.1 was observed for water spray environment. Repeated braking reduces the coefficient of friction and reduction of Sic content in the brake disc. S.G.Amaren, D.S.Yawas [33] made an attempt to include periwinkles shell particle size on asbestos free friction composite. In this work the periwinkle shell particle size of +125 μ m to + 170 μ m is varied in proportions. It was observed that, with increasing operating parameters, the wear resistance of the composite increases. The coefficient of friction obtained is within the recommended standard for automobiles. A.Almaslow, M.J.Ghazali [34] made an attempt to include natural rubber alumina nano particles in friction composite. In this paper, friction composites consisting of epoxidized natural rubber alumina nano particle (ENRAN), steel wool, graphite, and benzoxazine were prepared using a melt mixing method. The mixing work was carried out at 90 ^{0} C. It was observed that Samples with 29% of ENRAN exhibited the best friction coefficient of 0.437 with low specific wear rate of 0.27 x 10-7 cm^3 / Nm. Raffaele Gilardi, Luigi Alzati [35] Studied about Copper substitution and noise reduction in brake pads by graphite type selection. Graphite powder is mainly used in brake pads. The role of graphite is acting like a solid lubricant and coefficient of friction stabilization. In this work, brake pad consisting of phenolic resin (18 wt %), mineral fibers& Aramid pulp (5wt %), cashew dust (10wt %), BaSO4 (49wt %), graphite powder (8wt %) is mixed and hot pressed following curing operation. Noise, vibration and harness tests are conducted on the samples. It was observed that graphite increases the thermal conductivity of brake pads. Synthetic graphite T150-600 (Particle size less than 75micro meters) gives higher in plane thermal conductivity compared to KS150-600.It was also observed that, copper free resin bonded brake pads combining with synthetic graphite C-THERM011 gives the best results in terms of Noise vibration harness (NVH) performance and heat dissipation.

Mukesh Kumar, Jayashree Bijwe [36] studied about non asbestos organic (NAO) friction composites, role of copper, its shape and amount. In this work, two types of friction composites by varying the amount of copper powder and fibers (0, 10, 20 wt %) were developed and tested. It was observed that, inclusion of copper improves major performance properties. It is also observed that 10 wt % of filler size considered to be the best filler size in terms of wear and coefficient of friction. N Aranganathan, Jayashree Bijwe [37] carried out a comparative performance on NAO friction materials containing natural graphite(NGC) and thermo graphite(TGC). In this method two friction materials having natural graphite and thermo graphite is prepared with the following ingredients , phenolic Resin 8 wt%, Fillers(Vermiculite 10 wt%, Potassium titanate 10 wt% , Cashew dust 10 wt% , copper 15 wt%,) Barytes 14 wt% , Fibers (Glass fibers 5 wt%, PAN fibers 3 wt%, Rock wool 1 10 wt%) , Friction modifier abrasive Silicon dioxide 2 wt%, Solid lubricant (NG &NTG 10 wt %).Tribo performance of both the friction composites were evaluated by full scale inertia dynamometer. It was observed that TGC proved superior performance in terms of physical, mechanical, fade and wear properties .NGC on the other hand proved superior to NGC in recovery performance. Therefore, TGC can be successfully used in friction materials to improve thermal conductivity, fade performance, more lubricity and wear reducing tendency of the composite in copper less friction formulations. J.Wahstrom, D.Gventsadze [38] investigated on novel nonporous composite based and conventional brake pad materials focusing on airborne wear particles. Wear particles originating from disc brake contribute to particulate concentration in the urban atmosphere. In this work novel nonporous composite based and conventional brake materials were tested against cast iron discs in a pin on disc machine. In these pads, nano pores (200-500 nm) are introduced in to the friction material using diatomite particles. Copper, barites, and plasticizer are also act as ingredients of the friction material. A modified phenol-formaldehyde resin is used as a binder. The results show that two of the nano porous materials generated 3-7 times less airborne wear particles than the conventional brake materials.

Tej Singh, Amar patnaik, Bhabani K. Satapathy [39] studied the effect of nano clay reinforcement on the friction braking performance of hybrid phenolic friction composites. In this work, nano clay/lapinus fibers content (2.75wt%-2wt%)/(27.5wt%-20wt%) is decreased and graphite/aramid fibers content(2.25wt%-3wt%)/(2.5wt%-10wt%) is increased and master batch of phenolic/barite composition (15wt%)/(50wt%) is designed ,fabricated and characterized for their mechanical, thermo-mechanical and tribological properties. It was observed that addition of nano clay (≤2.25wt %) enhances the hardness, impact strength, storage, and loss modulus characteristics of the friction composites. The composite with minimum content of nanoclay (≤2.25wt %) exhibits highest friction stability as well as variability coefficient; where as composites with higher content of nano clay (≈ 2.75wt %) exhibits moderate level of stability coefficient and minimum variability coefficient. Fade performance improves with the addition of nano clay where as friction fluctuations also increase continuously as the nano clay content increases. The wear performance decreased with the increase in lapinus/nano clay; on the other hand it increases by increasing aramid/graphite composition in the friction composites.

A.R.Mat Lazim, M.Kchaou [40] Studied about Squealing characteristics of worn brake pads due to silica sand embedment in to their friction layers. In this work, three different sizes of silica Sand is introduced between brake pad and disc interface. Surface topography with and without Silica sand is examined and friction, squeal generated at the interface is measured. It was observed that, with the inclusion of silica sand particles, new flat area is observed and squeal occurrence depends on silica sand particle size. Higher size of Silica sand particles damages the pad surface and decreases the coefficient of friction. Optimum selection of SSP size is necessary to reduce the squeal generation between disc and pad interface. Mohammad Asif [41] evaluated the Tribological properties of aluminum based metal matrix composites used for automobile applications. In this paper Al based metal matrix composites are used to replace resin based brake pad. Two types of formulations FA101 & FA 102 is prepared by varying Sic & Graphite content and keeping the remaining compositions as equal. Brake pad formulation consists of Al (100 µm 78.35wt%), Sic (for FA101 , 200 µm 8.45 wt% for FA102 , 6.45wt%), Sb2S3 (40µm 2 wt%) ,BaSo4(40µm ,3 wt%), Zinc(50 µm ,3 wt%) , Graphite (for FA101 50µm 9.55wt% for FA102 7.54 wt%) .Wear behavior for brake pad was observed by krauss type of testing machine. It was observed that Al based composite possess less wear rate, same order of coefficient of friction as in resin based bonded brake pads. Fluctuations in coefficient of friction are slightly higher in comparison to resin.

A.Rehman, S.Das [42] carried out an analysis on stir die cast Al-SiC Composite brake drums based on coefficient of friction. In this work at attempt is made to replace cast iron brake drums with aluminum silicon carbide composite brake drum. Al-Sic MMC was reinforced with 10% wt and 15%wt SiC particles. The effect of heat treatment of the Al-SiC MMC brake drum was also studied. Performance was mainly evaluated on the basis of brake drum coefficient of friction. Friction material was developed with the following components such as, binder, reinforcing Elements, fibers, abrasive elements (SiO_2, Al_2O_3), filler elements ($BaSO_4$, CaCO3, Al_2O_3), lubricants (MoS3, Sb2S3, as well as sulphides of Cu, Sn, Sb, and brass), fire proofing substances, and aluminum hydroxides to protect the pad from fire .It was observed that the brake drum and brake shoe interface temperatures with all composite material brake drum are lower than cast iron brake drums. However, it was also observed that heat treated composite material brake drums had higher interface temperatures as compared to that obtained with other Al-SiC MMC brake drums. The Coefficient of friction with SiC particles in the aluminum alloy shows higher values. Telang A K, Rehman [43] studied about alternate materials in automobile brake disc applications with emphasis on Al-Composites a technical review .In this work grey cast iron rotor is replaced with AMCs and its friction coefficient and thermal conductivity is compared. It was observed that, the friction coefficient of AMC is 25-30% times that of cast iron rotor and exhibited better wear properties. The thermal conductivity of AMC can be two or three times higher than Cast iron. AMC is 60% lighter than gray cast iron and having high thermal diffusivity around four times greater than cast iron. Mukesh Kumar, Jayashree Bijwe [44] studied about Composite friction materials based on metallic fillers Sensitivity of coefficient of friction (µ) to operating variables. In this work, the sensitivity of µ towards braking pressure and sliding speed for various metallic fillers i.e. brass, copper and iron studied. It was observed that, copper powder is very effective in reducing µ sensitivity to dynamic variations in pressure and speed. Rongping Yun, Peter Filip[45] Evaluated the performance of eco friendly brake friction materials .In this work, eco- friendly brake friction materials were formulated without copper, lead , tin, antimony trisulphide and whisker materials, to minimize their potential negative environmental impacts on atmosphere. Friction material is formulated with the following constituents namely, binder (Phenolic resin 36.5 wt%, NBR (8.5 wt %)), fillers (Baryte 6.6 wt%, vermiculite (3.5 wt %)), friction modifiers (Synthetic graphite 4.8wt%, resilient graphite carbon 5.3 wt% , Coke14.2 wt%, molybdenum disulphide MOS2 0.4 wt% ,antimony trisulphide Sb2S3 0 wt% , MgO 3.3wt%,Potassium titanate 6wt%, Alumina Al2O3,4wt%,ZirconiumSilicate(ZrSiO4) 0.9wt %) and reinforcements as (aramid pulp 0 wt%, natural fiber 6 wt%, Metals 0 wt %). The contents of binder and fillers are maintained constant, and the remaining constituents are varied in proportions. Four samples are prepared on the basis of cost estimation. It was observed that the sample A with above compositions exhibits stable coefficient of friction, effectiveness, high fade resistance, good recovery capacity and low sensitivity to speed than other compositions.

Mukesh Kumar, Jayashree Bijwe [46] Studied about non asbestos organic (NAO) friction materials with various metal powders. In this work friction material was developed with parental composition 90 wt% and fillers with 10 wt%. Three different friction materials were formulated by varying filler materials such as brass powder, Cu powder and Iron Powder. The parental composition of the friction material consists of following ingredients: binder (Phenolic) 10 wt% , fibers (Aramid , Rock wool , Ceramic ,acrylic, Potassium titanate) 23 wt%, additives (graphite, alumina) 12 wt% and, fillers (NBR Powder, Cashew dust, Vermiculite ,barite) 45wt%. One composite friction material was fabricated without using any metallic filler material and compared with the three fabricated composites with metallic filler material as Iron powder, Brass and Cu powder. For tribo evaluation, inertia brake dynamometer testing was used. It was concluded that copper containing composite showed increase in fade resistance and decrease in wear resistance. It was also observed that friction material containing $BaSo_4$ as an inclusion shows the exactly opposite behavior.

Vlastimil Matejka, Yafei Lu [47] performed an experiment on the effect of Silicon carbide particle sizes on friction and wear properties of friction composites designed for car brake lining applications. In this study, a method is proposed for increasing the friction characteristics of friction material by inclusion of Sic particles of different sizes (3.4, 5.6, 9, 14.6 vol %).The friction material with five different compositions is formulated with the following ingredients namely Potassium titanate, wollastonite, Aramid pulp, Brass chips, BaSo4, NBR, PF, Sic. The highest value of coefficient of friction and lowest fade was observed with Sic 3 µm of size. The value of specific wear rate decreases with increasing Sic particle size. Nandan Dadkar, Bharat S.Tomar [48] studied the influence of fly ash filled and aramid fiber reinforced hybrid polymer matrix composites (PMC) for friction braking applications .The friction-fade and friction-recovery behavior has been evaluated as a function of temperature rise at the disk brake interphase. In this work, four samples of friction material was developed with the following ingredients namely, fly ash wt%(80,75,70,65) and novalc resin wt%(20,25,30,35),aramid fiber 5wt% is added to 95 wt% of fly ash for strength enhancement and four samples are prepared. It was observed that the fade behavior has been observed to be highly dependent on the weight fraction of resin. The frictional fluctuations are observed to be decrease with decrease in fly ash content. A higher recovery response is registered when the fly ash content is 80 wt%. The analysis of friction performance has revealed that the fade and static friction response are the major determinants of overall frictional response. Wear analysis has revealed that material integrity and temperature rise of the disc decides the wear behavior.

S.Anoop, S.Natarajan. [49] Analyzed the factors influencing dry sliding wear behavior of Al/ Sic brake pad tribo system. In this paper the composite material for brake disc investigation was developed by conventional liquid casting route from Al 6082 alloy by incorporating 15% Sic by weight. The design of experiments was done based on surface response method. The factors selected for investigation are temperature, load and sliding velocity keeping sliding distance as constant. It was observed that, with the increase of temperature the wear rate is found to be severe. At lower loads, the wear rate was found to be very less. At room temperature the effect of velocity is negligible but at higher temperature the wear rate increases with increasing in velocity. Keun Hyung Cho, Min Hyung Cho [50] investigated the tribological characteristics of brake friction material containing different shapes of potassium titanate. In this work, the friction material is formulated with the following ingredients, aramid pulp, rock wool(11wt%), Potassium titanate (20 wt%) ,Phenolicresin(16wt%),graphite,MoS_2,Sb_2S_3(8wt%),$ZrSiO_4$,MgO,Fe_3O_4(7wt%),Cashew, rubber, Cu Chips,$Ca(OH_2)$,(24wt%) vermiculite, $BaSO_4$ (14Wt%) .Potassium titanate is varied in the shapes of whiskers, platelets and splinters. It was observed that, the morphology of potassium titanate plays an important role in the formation of contact plateaus and transfer films on the rubbing surfaces. The friction material with splinter shape potassium titanate shows better friction stability and improved wear resistance compared to those containing platelet or whisker due to larger contact plateaus and stable friction films at the sliding interface.

Peter J.Blau, Brian C.Jolly [51] investigated on titanium based materials for brakes. In this work, an attempt is made to replace conventional cast iron rotor with titanium alloy rotor, which weighs approximately 37% less than a cast iron rotor with the same dimensions. The tests are conducted for a flat block of different pad shape presses against a brake rotor, consisting of repetitive on-and-off drags at sliding speeds from 2 to 15 m/s, using nominal contact pressure of 1.0 or 2.0MPa. Friction coefficients and temperature rise data were obtained for gray cast iron rotor and two commercial Ti alloys. Four experimental Ti based hard particle composites (10TiC, 5TiB, WTiC, 30TiB) and a thermally spray coated Ti alloy (ThSp), Two Ti structural alloys, Ti64 and Ti6242, are formulated and tested using brake dynamometer. It was observed that, friction coefficient decreases with increasing sliding speed and temperature for Ti alloy composites. At 2m/s, the friction coefficients are well within the normal range for brakes, but at 6 m/s and higher, they were at the lower end of the acceptable range. It was observed that under the current set of friction testing conditions, gray cast iron discs had better wear resistance than those made of Ti alloys and composites. However, adding hard particles to a Ti based composite can substantially improve its wear resistance. The highest value of friction coefficient was measured for the thermally sprayed coating on Ti and the lowest for cast iron. (0.35-0.55).Finally, it was observed that the thermally spray coated Ti alloy discs exhibits good frictional performance and very low wear and excellent resistance to fade. Jonathan N. Coleman, Umar Khan. [52] Reviewed on mechanical properties of carbon nano tube polymer composites. The mechanical properties of carbon nano tube make them the filler material of choice for current composite industry. Different processing methods have been formulated to improve strength and toughness. It was observed that, there has been much progress has been made over the last few years in composite industry to use carbon nano tubes as reinforcement. In future, CNT act as most important reinforcement in all the fields of application.

K.W.Hee, P.Filip [53] evaluated the performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings. The friction and wear characteristics of the composited using t without potassium titanate and with potassium titanate sample are tested using a dynamometer. Two friction composite materials were prepared containing several ceramic materials embedded in a phenolic Resin matrix. The first material sample (A) contains 25 wt% of fly ash and 14 wt% additional ingredients namely(phenolic resin, styrene butadiene rubber 25 wt%), barites 9 wt%, reinforcements(Twaron, steel fiber, pulverized mineral fiber, frax fiber, copper chips, Iron powder, fly ash) 47wt% , friction modifiers (asbury graphite, antimony tri sulphide, Coke, potassium titanate, magnesium oxide)19 wt%. The second sample (B) is formulated by adding potassium titanate, and having same above ingredients in the following percentages (20%, 9%, 47% & 24%). It was observed that sample B and C, containing less metal, exhibited lower and more stable friction coefficients. Fly ash by product can be effectively used in brake lining formulations when properly combined with other additives. The experimental results show that the potassium titanate inclusion improves friction stability, wear improvement and fade reduction for the entire composite. Mustafa Boz, Adem Kurt [54] has studied the effect of Al2O3 on the friction performance of automotive brake friction materials. This study consists of two stages. In the first stage, bronze based brake linings were produced and tested for friction and wear properties. In the second stage, 0.5%, 1%, 2%, and 4% alumina Al2O3 powders were added to the bronze based powders and Al2O3 reinforced bronze based samples are evaluated for friction and wear properties. It was observed that the optimum wear behavior was obtained in the samples pressed for 350MPa and sintered at 820^0C. The hardness of the bronze based specimen increased by 100 % due to work hardening occurs during wear test. However, hardness of the Al2O3 added specimens did not show any considerable change in hardness values. The highest friction coefficient was obtained in the samples containing Al2O3 in the range of 4% due to an increase in the temperature during friction. It was observed that the addition of 2% Al2O3 to the samples showed stable friction coefficient. The highest wear was obtained in the sample containing no Al2O3 and the wear resistance of the samples increase with increase in the amount of ZrSiO4. Yiqun Liu, Zhongqing Fan [55] Studied about application of nano powdered rubber in friction materials. In this work, an attempt is made to replace ordinary styrene butadiene rubber and nitrile butadiene rubber with nano rubber powder for manufacturing clutch facings and disc brake pads. Dynamometer test rig is used to evaluate the test results and compared with respect to the ordinary rubber powder friction materials. The results showed that nano powder rubber inclusion in the brake pads improves all the performance parameters and can be successfully used in the manufacturing of friction materials. K.Laden, J.D. Guerin [56] investigated about frictional characteristics of Al-SiC Composite brake discs. In this work, the use of light materials such as aluminum matrix composite reinforced with SiC in railway braking devices is studied. Continuous braking tests were run with organic brake pads in a dry environment. It was observed that 390 matrix disc exhibited high wear resistance compared with 514 matrix disc. It was also observed that, by increasing the reinforcement rate by 8 wt% and spherical Sic, instead of angular one improves the wear resistance, braking

power and high coefficient of friction for the brake disc system.
Ho Jang, Seong Jin Kim [57] studied the effect of antimony trisulphide (Sb2S3) and Zirconium silicate (ZrSiO4) in the automotive brake friction material on friction characteristics. In this work, Friction characteristics of nine automotive brake friction materials containing different amounts of antimony trisulphide (Sb2S3) and Zirconium silicate (ZrSiO4) were investigated using a brake dynamometer. Friction material is formulated with the following compositions , Phenolic Resin (20 wt%) , aramid pulp (6wt%) ,Ceramic fiber(3wt%) , Copper fiber (3wt%) , barium sulphate (20wt%) ,Calcium hydroxide (3 wt%) , molybdenum disulphide (3wt%) , graphite (5wt%) , Cashew particles (10wt%) , vermiculite (3 wt%) , rubber particles (3wt%) , mica(3w % , Sb2S3 (2-6 wt%), ZrSiO4(2-6 wt%),potassium titanate (balance). It was observed that inclusion of Sb2S3 improves the stability of friction coefficient. This appears to be due to the formation of antimony oxides at elevated temperatures and the oxides play a role as a lubricant at elevated temperatures. Torque variation during drag test is strongly affected by ZrSiO4 in the friction material, indicating that removable of friction film is undesirable in reducing torque variation. Friction stability is improved by adding more Sb2S3 in the friction material.

L.Y.Barros, P.D.Neis [58] studied about morphological analysis of pad disc system during braking operations .In this paper, the amount of friction layer generated between the contact regions of disc surface is studied in detail. Two types of brake pads NAO and Semi metallic were subjected to slide against a gray cast iron disc under normal forces of 600N and 1200 N. It was observed that both the friction materials form heterogeneous friction layer on the surface. But semi metallic friction material exhibits more uniform friction layer on the surface. It was also observed that, with the increase in normal force the friction layer of NAO friction composite increases on the disc surface where as for semi metallic friction materials tend to remove the friction layer on the surface. Ashish .D. Dhangar, Prof.R.J.Jani. [59] Reviewed on wear measurement of automotive disc brake friction material. Automobile brake system effectiveness is mainly measured by the performance, wear, noise and durability. .The materials used in the test are non asbestos organic and semi metallic brake pads sliding against a gray cast iron rotor. It was observed that the temperature generated at the contact region influences the efficiency of the brake disc. Therefore, ceramic discs have highest tendency to convert available frictional energy to dissipate to the surroundings and can be successfully used as a brake disc material for automobile applications.

Bulent Ozturk, Sultan Ozturk [60] studied the effect of resin type and fiber length on the mechanical and tribological properties of brake friction materials. Three types of resins i.e. straight phenolic resin (SR), cashew nut shell liquid modified resin (CR), and melamine resin (MR) is studied. Brake friction material was formulated with the following ingredients, lapinus fiber(23wt%) having length(150,300,650µm) , resin(16wt%) , barite(32wt%),Kevlar(7wt%),graphite(8wt %), Al2O3 , bronze, mica(14wt%). All mechanical, physical and tribological properties of all composites were investigated. The results showed that both resin type and fiber length played an important role on the mechanical and tribological properties of the friction materials. The highest and lowest friction coefficients for resin types were observed for SR and MR Composites. , while MR and CR composites showed the highest and lowest wear resistance. The wear resistance of the composite increases with increasing fiber length. The friction coefficient and specific wear rate of the composites generally decreases with increasing fiber length regardless of resin types. Yun Cheol Kim, Min Hyung Cho [61] studied the effect of phenolic resin, potassium titanate, and CNSL on the tribological properties of brake friction materials. In this study friction material was formulated with the ingredients namely fiber consisting (aramid pulp vol8% , rock wool vol 8% , potassium titanate vol 16 %) ,phenolic resin vol 16 % , lubricants (graphite vol 3% , MOS_2 Vol 3%), abrasives (zirconium silicate vol 3%), friction modifiers (cashew vol 16 %, others vol 27%).Tribological properties of non asbestos organic type formulation for seven different formulations are evaluated using pin on disc tribo meter. It was observed that phenolic resin increased the coefficient of friction and observed high noise during sliding. The noise occurrence was reduced by increasing CNSL in the friction material. Wear resistance of the friction material showed good results with the addition of phenolic resin where as CNSL and potassium titanate deteriorated the wear resistance. P.V.Gurunath, J.Bijwe [62] developed a resin for brake pad materials. In this work, a monomer capable of polymerizing through ring opening by thermal activation was synthesized in the laboratory and used as a binder for friction composite. Two types of non asbestos organic (NAO) friction composites with identical ingredients but differing in the type of resin (10wt %) were developed and tested for tribo performance properties. It was observed that composite with new resin proved better than composite with traditional phenolic resin in all performance properties including μ, fade μ, disc temperature rise, wear etc.

J.Wahlstrom, D.Gventsadze [63] studied about a pin on disc investigation of novel nano porous composite based and conventional brake pad materials focusing on air borne wear particles. Wear particles originating from the disc brakes develop particulates particularly in the urban atmosphere. In this work novel nano porous composite based materials and conventional brake materials are tested against cast iron disc in a modified pin on disc machine. It was observed that two of the nano porous materials generated 3-7 times less airborne wear particles than conventional materials. All tested materials exhibits wear particles of diameters approximately 350 and 550 nm. Rukiye Ertan, Nurettin yavuz [64] studied the effect of manufacturing parameters on the tribological properties of brake lining materials. In this study, a brake lining composition was investigated on experimental basis to observe the effect of the manufacturing parameters on tribological properties and obtain optimum manufacturing considerations. The friction tests were performed using a chase type friction tester to find out the relationship between manufacturing considerations and tribological properties. The results indicate that no systematic relationship exists between roughness measured after the friction test and the manufacturing parameters of brake lining. Under constant heat treatment parameters, molding pressure and temperature influence the tribological characteristics of composites. As the molding time increased, the tribological characteristics improved remarkably. But, if the moulding time continues to increase then, tribological characteristics changes slightly. The molding temperature should be held within optimum limits. It was observed that, stability of the COF decreased considerably, and the specific wear rate increased at high molding temperatures. The heat treatment temperature has a negative effect on the COF and wear rate at higher values.

Yu shu, Chen Jie [65] studied about the effect of braking speeds on the tribological properties of carbon/Carbon Composites. In this paper three types of micro structures samples rough lamina, (Sample A), Smooth lamina, (SampleB), Smooth lamina, (SampleC), is tested using a laboratory brake dynamometer. It was observed that, Sample A reached a peak value and exhibited good coefficient of friction with increasing speed, compared to sample B and C. The weight losses in all of the samples were observed to increase with increasing braking speed. The oxidation abrasion at 30 m/s is less than that of 28 m/s for all the samples due to the low bond energy between the graphite layers. M.A.Mlaeque, S.Dyuti [66] carried out a material selection method in design of automotive brake disc. In this paper an alternative material to replace gray cast iron rotor has been studied. Gray cast iron rotor material is widely used in automobiles and consumes more fuel due to its high specific gravity. A method is proposed to study alternative materials like aluminum alloy, titanium alloy, ceramic composites to replace gray cast iron rotor. It was observed from the results that Al matrix composite exhibits better mechanical properties including compressive strength, wear resistance, thermal conductivity, and specific gravity than other combinations. N.S.M. El-Tayeb, K.W.Liew. [67] Studied about the effect of water spray on friction and wear behavior of non commercial and commercial brake pad materials. In this paper the reduction in friction coefficient during rainy season and humidity environment is taken as a serious problem as it results no safety to vehicle. Four types of friction material (NF1, NF2, NF4, and NF 5) and two commercially available brake pads (CMA and CMB) were developed and tested by using a small scale tribo tester. It was observed that the friction coefficient for the sample NF1 & NF4 were less than 0.05 which was in the range of friction in mixed lubrication. It was also observed that spraying water eliminate the establishment of transfer layer at the friction inter phase. From the wet friction and wear results it was revealed that, highest friction coefficient was exhibited by NF2 at all pressures and speeds. Mean while NF1 showed best wear performance compared to all formulations. Frction material behavior is entirely depend up on atmospheric conditions. W. Osterle, H. Klob [68] Studied about a better understanding of brake friction materials. This work mainly focuses on surface changes induced by repeated brake applications and tries to provide explanations about how such material modifications might affect friction and wear properties. Surface films were investigated by TEM. Two low metal pads A-1 having mass (Rubber 1% , Resin 7% , Fibers 3% , Metals 38%, Fillers 23% , Lubricants 13% , Carbon 15%) and A-2 having mass (Rubber 2%, Resin 7%, Metals 39% , Fillers 20%, Lubricants18%, Carbon12%) is fabricated and tested on brake discs. Two important characteristics were observed both on the pad and disc surface, namely steel constituent, either ferritic pad or pearlitic disc. It was observed that coefficient of friction of 0.35 and 0.85 was observed for oxide on oxide and metal on metal contacts for automata of size 10 nm. R.K.Uyyuru, M.K.Surappa [69] studied the effect of reinforcement volume fraction and size distribution on the tribological behavior of Al composite .In this work, brake pad material was used as pins while the AMC is used as rotating disc. Load and sliding speeds were varied over a range to represent actual braking conditions in passenger cars. Effect of volume fraction and size distribution of reinforcement on wear and friction coefficient has been studied. It was observed that wear rate and friction coefficient vary with both the applied normal load and the sliding speed. The Wear rate increases with increase in normal load, Wear rate decreases with increase in sliding speed, friction coefficient decreases with increase in normal load and friction coefficient decreases with increase in the sliding speed. The harder tribo layer formation act as a lubricant layer and acting as a source of wear debris. M.Kermc, M.Kalin [70] developed an apparatus for tribological evaluation of ceramic based brake materials. In this paper the behavior of brake disc made of gray cast iron and carbon/ceramic SiC matrix are compared. The size of the samples was determined on the basis of vehicle's speed of (0-300 Km/h), contact pressure (0.1 to 10 MPa), and the temperature (20 ^{0} C to 900 ^{0} C). The temperatures generated at the contacts of ceramic carbon composite is high at 800^{0}C ,which is more than two times higher than conventional gray cast iron .The coefficient of friction at the contact region for ceramic carbon composite C/C Sic was observed to be above 0.5 and two times higher than gray cast iron. Therefore, depending up on the coefficient of friction and temperatures generated at the contact plateaus, a proper material is selected for the design.

K.M.Shorowordi, A.S.M.A.Hasseb [71] studied the velocity effects on the wear, friction and tribochemistry of aluminum metal matrix composites (MMC) sliding against phenolic brake pad. Two (MMC) reinforced with 13 Vol% SiC or B_4C particles were made by stir casting followed by hot extrusion. Effects of sliding velocity on the friction, wear, and tribochemistry of the worn surfaces of both composites sliding against a commercial phenolic brake pad have been investigated under dry condition. The wear tests were carried out using a pin on disc type apparatus at two linear sliding speeds, 1.62 and 4.17 m/s under a constant pressure of 0.75MPa for a sliding distance of 5832 m. It was observed that higher sliding velocity leads to low wear rate and lower friction coefficients of MMC's. V.M.Kryachek. [72] reviewed on sintered metals and alloys. In this work, production and testing of powder materials based on copper and iron powder are discussed and their applications are demonstrated and new methods for forming friction and coatings on them are analyzed.

S.Ramaousse, J.W.Hoj [73] studied about thermal characterization of brake Pads. In this paper the chemical and physical decomposition processes that occur in a brake pad heated to 1000^{0} C have been studied. Thermo gravimetric analysis, differential thermal analysis, used in combination with gas analysis and image analysis using SEM is performed. Brake pad consists of iron, carbon, and binder. It was observed that the decomposition of the binder system takes place between 250 and 475^{0}C. The oxidation of the coal occurs in two steps. The first oxidation starts at around 300 ^{0} C and ends at around 475 ^{0} C. The second oxidation of the coal takes place between 525 and 700 ^{0} C. The oxidation of the graphite takes place between 600 and 850 ^{0} C .The oxidation of the iron starts at around 500 and continues slowly up to 800 ^{0} C. Mikael Eriksson , Staffan Jacobson [74] Studied about tribological surfaces of organic brake pads. In this paper the tribological contact situation of organic brake pads against gray cast iron disc is studied on a microscopic level. when organic brake pads worn against rotor, the complex structure and inhomogeneous formation of the brake pads results in formation of large contact plateaus of few micrometer size above the surface. In this work, Organic brake pad is formulated with the following ingredients of fibers (Steel, Aramid, and glass fibers) 30 wt% , binder 8 wt%, others 11 wt% , friction modifiers (brass and bronze 15 wt% ,graphite 15 wt% , metal sulphides 8wt % , abrasives quartz 5 wt %, fillers Clay and iron oxide 8 wt % . It was observed that with increasing pressure, the plateaus will be slightly smaller than the equilibrium size at the contact pressure. This results in slightly lower coefficient of friction than during decreasing pressure. When comparing two pad materials, the one that showed the more pronounced plateau growth with increasing pressure also showed the good coefficient of friction.

From the work carried out by many researchers on filler materials, it was observed that, selection of filler materials plays a prominent role to improve the ease of manufacturing of the friction composite. The filler material inclusion is responsible for improvement of wear rate and stabilizing the coefficient of friction of the composite. It depends mainly on the speed of the vehicle and operating temperatures at the contact region of the brake disc. Based on these parameters, one has to select proper filler material for a required application.

2.3 Influence of temperature, pressure and speed on friction and wear

Braking phenomena involves transfer of kinetic energy to heat energy. The frictional heat generated at the contact region will affect the wear and friction coefficient of the friction material. By increase of braking pressure and initial braking speed, the friction temperature generated at the contact region will increase. First the matrix resin will be softened and charred to loose its bonding strength. The reinforced fibers are then pulled and escaped from the matrix, and friction films are formed on the friction surface. Second, the friction films will be deformed, cracked and peeled to form small debris which decreases the friction stability, increases the wear, and sometimes even causes severe vibration and noise. It was observed that, further increase of surface temperature leads to thermal decomposition of friction material and fading phenomenon will occur and friction coefficient will decrease. Besides having thermal decomposition, organic friction material will release gases to generate gas cushion films, which weakens the coefficient of friction to great extent. OZturk et al [89]. Studied the influence of temperature on friction and wear behavior of four different friction materials. Four different reinforced fibers are used in this study namely, ceramic fiber, rock wool fiber, glass fiber and steel wool fiber. It was observed that four different friction materials have similar influence on temperature. Fig2.3 (a) shows the behavior of ceramic fiber with increase of temperature. It can be seen that friction coefficient increases with temperature at first but starts to decline when the temperature reaches at 300^0 C. However the wear rate increase with increase of temperature and become serious at higher temperatures.

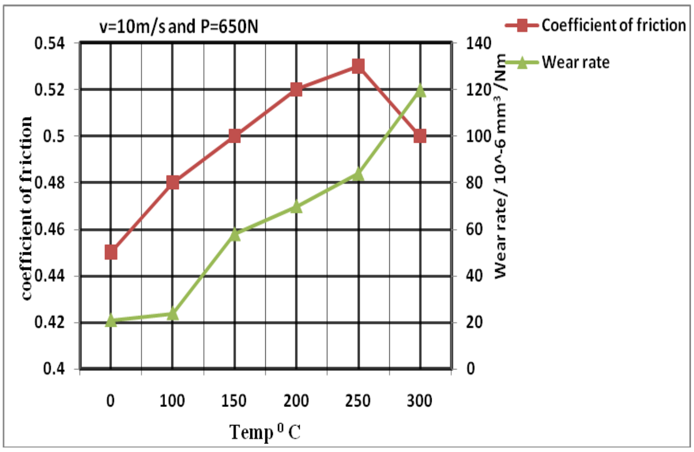

Fig 2.3(a) *Influence of temperature on friction and wear of organic friction material*

The braking pressure acting on the component affects the friction and wear behavior of friction materials.The approach of pressure on friction material is classified by four types . First, changing the actual contact area of frction pair. second ,affecting the generation of friction films .third influencing the component and oraganisation of friction material , and fourth,changing the wear type. Among the above mentioned , the first two types are generally considered as the most important factors. By increase of braking pressure , the asperities distributed on the contact interface are defrormed and broken to form some debris. when the braking pressure is further increased , more debris will form on the surface of friction material, which leads to formation of granular films.The friction film act as lubrication film on the interface , which reduces the meshing force to decrease the friction coefficient. Fom Fig2.3(b) , it is observed that the friction coefficient increases first and then decreases with increase of pressure.However, the wear rate keeps increasing with increase of pressure.

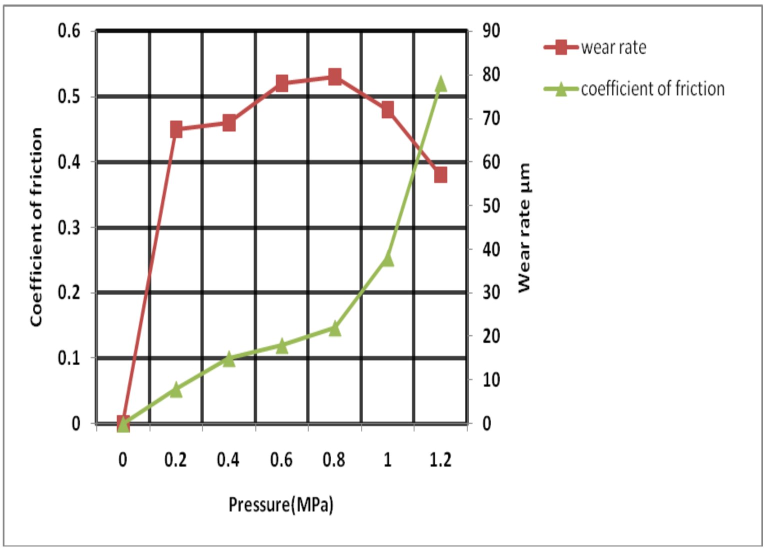

***Fig 2.3(b)** Influence of Pressure on friction and wear of organic friction material.*

As the actual contact area of friction pair is much lower than its nominal contact area, the direct influence of initial braking speed on the friction behavior can be ignored. From Fig 2.3(c), it was observed that, with increase in initial braking speed, the friction coefficient increases first. After the speed reaches a certain value, the friction coefficient decreases slowly and finally remains steady, while the wear rate increases continuously with the increasing initial braking speed. It has slower increasing rate of wear at medium braking speed.

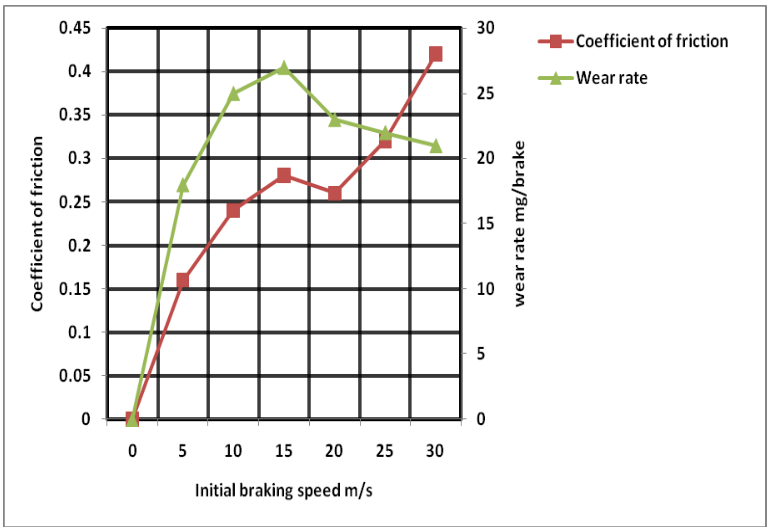

Fig 2.3(c) *Influence of initial braking speed on friction and wear of organic friction material*

2.4 Effect of modeling and simulation techniques on friction and wear

Many people have studied the behavior of friction materials performance by using experimental techniques like inertia brake dynamometer test rig. Now days, modeling and simulation techniques are widely used before design, because of ease of doing analysis, less time and cost effective. Simulation techniques help to predict the behavior and factor of safety to be assigned for the component before design phase, which makes easier for the designer to assess the performance of friction material before manufacturing.

X C Wang, J.L.Mo [75] Studied on Squeal noise of friction material with groove textured surface, using experimental and numerical analysis by varying the pad profile. It was concluded that cutting a135 deg groove can reduce unstable vibration and cutting a 45 deg or 90 deg groove on the pad surface shows a reduced squeal generation. It was also observed that, the maximum contact pressure is low for the 90 deg groove textured surface, followed by the 45 deg groove texture surface. A. Renault, F.Massa. Ali Belhocine, Wan Zaidi Wan omar [76] performed a numerical parametric study of mechanical behavior of dry contact slipping on the disc pads interface. In this work disc brake with pad is modeled and characterized for mechanical properties and simulation was carried out for baking time of t=45s and results are plotted for increment of initial time for 0.125s,0.25 s, and 0.5 sec respectively. Tensile, compressive and shear stresses induced in the disc for various types of mesh sizes and influence of modulus of elasticity of the pad material and rotational speed, friction coefficient is studied in detail. It was observed that gray cast iron disc produce better mechanical behavior and the presence of groove in the pad negatively affects the mechanical behavior of the brake pad. A. Renault, F.Massa. [77] Investigated on brake squeal analysis and observed that, pad topography and contact distribution plays an important role in the design of braking system. Vikrant J. Kotwade, H.P Khairnar [78] Reviewed on brake Squeal and observed that, holographic interferometry and numerical methods like finite element analysis using ANSYS plays an important role to eliminate brake squeal in design stage. Swapnil R. Abhang, D.P.Bhaskar [79] Studied about design and analysis of a disc brake to replace existing gray cast iron disc material. From the thermal and modal analysis results, carbon ceramic matrix composite disc achieved good braking performance. Amr M. Rabia, Nouby M. Ghazaly [80] Reviewed on experimental studies of automotive disc brake noise and vibration and proved that the experimental data gives good results compared numerical solutions. Saeed Abu Alyazeed Albatlan [81] investigated on the effect of pad shapes on temperature distribution for disc brake contact surface. Flat pad and hatched pad are tested using a brake dynamometer and concluded that, hatched pad perform better fade resistance than the flat pad. A.Belocine, M. Bouchetara [82] studied about thermo mechanical behavior of dry contacts in disc brake rotor with gray cast iron Composition. Three types of cast iron materials (AL FG 25, FG 20, and FG 15) are tested using ansys software. It was observed that the temperature field depends on the numerical and design parameters. Y.Yildiz and M.Duzgun [83] Conducted a stress analysis on ventilated type disc brakes using the finite element method for cross drilled disc, cross slotted disc, and cross slotted with side groove disc .It was concluded that C-SG disc showed best performance in terms of braking force output. M.Nouby, K.Srinivasan [84] investigated on disc brake squeal reduction through pad structural modifications using FEM using complex eigen values. The geometric characteristics and chamfer would affect the squeal propensity and eigen modes. Jinchun Huang, Charles M. Krousgrill [85] evaluated a critical value of coefficient of friction using brake squeal analysis. In order to reduce automobile brake squeal mode coupling analysis is performed. Eigen values and Eigen vectors are calculated for different types of mode couplings to estimate critical value of friction coefficient. A new method called reduced order characteristic equation is used to evaluate eigen values and their derivatives at μ=0.This method can be accurately applied to predict the stability boundaries of brake. Mohsen Masoomi, Ali asghar katbab [86] studied about reduction of noise from disc brake systems using composite friction materials containing Thermo plastic Elastomers (TPEs). Thermo plastic elastomers are visco elastic polymeric materials which are introduced in to the friction material in order to increase the damping behavior of the cured friction material. In this work, Styrene butadiene styrene (SBC), Styrene ethylene butylenes styrene (SEBS) and nitrile rubber/ Poly vinyl chloride (NBR/PVC) blend systems were used as TPE materials. Dynamic mechanical analyzer is used to evaluate viscoelastic parameters such as loss factor (tanγ) and storage modulus (E’) for the friction material. Natural frequencies and mode shapes of the friction material were determined by modal analysis. It was observed that, NBR/PVC and SEBS showed to be more effective in terms of damping behavior, preventing resonance and reducing noise squeal generation between pad and the rotating disc. O.O.Evtushenko, E.H.Ivanyk [87] Reviewed on analytic methods for thermal calculation of brakes. It was observed that, new applications of theory of heat conduction and thermo elasticity can be applied to solve dynamics of friction problems easily.

CONCLUSION

The future emphasis on automobiles will be lower emissions and fuel efficiency, as environmental regulations become more stringent. The brake friction material selected for the design and manufacturing should not release any toxic substances in to the atmosphere. The dynamic behavior of the friction material has to be studied in detail to understand the behavior of squealing action against the application of braking load. The bonding strength between fiber and matrix should be improved in order to achieve good wear resistance, fade resistance and mechanical properties of the friction composite.

There is also need to develop a friction material by selecting a proper chemical treatment method on fiber to use more effectively as reinforcement in polymer matrix composites. There is also need to concentrate on the interfacial adhesion, and bonding strength between fiber and matrix for a friction material to achieve better mechanical and tribological properties.

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