DEVELOPMENT OF FRICTION MATERIALS THROUGH POWDER METALLURGY

A THESIS

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis, entitled **DEVELOPMENT OF FRICTION MATERIALS THROUGH POWDER METALLULRGY** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Metallurgical and Materials Engineering of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from January, 2004 to Dec, 2007 under the supervision of Dr. P.S Mishra, Professor and Dr. Kamlesh Chandra, Associate Professor, Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee.

The matter embodied in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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Abstract

Friction materials are mainly employed in brakes, clutches and gear assemblies of automobiles, locomotive trains, commercial/fighter aircrafts, earth moving equipments, agricultural equipments, cranes, heavy presses, and excavators etc. When the brakes are applied, the kinetic energy of the moving system converts into heat due to friction between friction material on brake pads/discs/linings and rotor, which dissipates through brake assembly to the surrounding.

Three categories of friction materials are normally available. First, resin bonded friction materials, second, sintered friction materials, and third, carbon-carbon friction materials. Out of these categories, sintered friction materials segment has selected to improve upon its quality to meet higher expectations of automobile and aircraft industries. It is aimed to produce them with better characteristics employing newly developed technology, namely, Hot Powder Forging with appreciably reduced cost.

Metal based friction materials contain different constituents such as lubricants, abrasives along with other alloying elements. The metallic constituents provide strength, high temperature stability, oxidation resistance, and high thermal conductivity, whereas abrasives improve co-efficient of friction, fade resistance and wear resistance. Lubricants in these are usually solid type which are meant for smoother application of brakes and anti-seizure. Their simultaneous presence gives rise to parallel enhancement of certain properties of brake material.

Sintered metallic friction materials can be operated under two conditions either dry or wet. Usually, copper based friction materials are used in wet conditions i.e. immersed in oil whereas iron based friction materials are operated in dry conditions only. The sintered copper based friction materials are suitable for temperatures up to 600°C whereas iron based sintered friction materials are suitable up to 1100°C.

In the present investigation, the new iron-based friction material pads with improved performance and with built-in steel backing plate are produced by a novel P/M technique i.e. 'Hot Powder Forging' (described in Indian patent filed on Nov. 7, 2006). It employs high rate of forming where the material undergoes severe plastic deformation under application of impact load; purpose of compacting and sintering both are thus

fulfilled simultaneously in a single step. The powder mixture is encapsulated in steel capsule and is heated to temperature range of 1000-1100°C and then hot forged in a forging press followed by homogenization treatment. The steel capsule cover later on serves as backing plate since it joins securely with the forged slab. The process as described above largely overcomes the limitations of presently practiced conventional P/M route based on compacting and siintering.

Detailed characterization of friction pads produced this way exhibits improved physical, mechanical, frictional and metallurgical properties. Subscale dynamometer tests have been performed and compared with results of existing sintered materials for military aircraft applications such as AN-32, MIG 21 and MIG 27 aircrafts.

The technology developed has capability to control density and hardness parameters in very precise manner and therefore it is possible to develop friction layers for different ranges of application (light to very heavy duty) by merely controlling these two parameters. In Pin-on-disc wear test, wear is gradually increasing from very low value to higher values thereafter it shows a significant drop in the amount of wear. This is possible because there is simultaneous role of wear resistant constituents and lubricants. The noise level during the test is not significantly altered in all the cases. This is because of the fact that the noise level is related to met metal content of the brake elements which in our case varies from 82% to 90%.

In sub scale dynamometer tests, the most significant aspect of the samples relate to stable performance with large number of braking cycles. In this context, brake fading tendency in our pads is completely absent. It is also noteworthy to mention that for application like AN 32 aircraft, a high dose of abrasives in the chemistry formulation is not necessary. Mere addition of 0.8% Phosphorous takes care of abrasive resistance of the pads, and, accordingly, a very simple chemistry like FM08N has qualified for such an application. This aspect has emerged out from the present investigation only and has not been reported sofar. Further, it is noteworthy to mention, that MIG 27 stator application is very specialized high energy condition for which chemistry of sintered pads is very complex and costly. In comparison to this, chemistry developed in the present investigation is much simpler and offer wide variety of choices to suit this challenging application.

Based on the results described in these tests, it can be mentioned that higher density, greater than 5.4 gm/cc of brake pad friction element, is desirable for low energy application such as AN 32. But contents of the lubrication (such as Ba SO_4, Sb_2S_3, Sn, and graphite) should not exceed 13%. It may be therefore inferred that density for such a range of application is significant parameter and higher density is desirable for improved wear performance. For MIG 27 aircraft, stator application is very specialized high energy condition for which chemistry of sintered pads is very complex and costly. In comparison to this, chemistry developed in the present investigation is much simpler and offer wide variety of choices to suit this challenging application. Quality of lubricants such as Sb_2S_3 would be more suited in comparison $BaSO_4$ and BN. It is established form the present investigation that apart from chemistry, annealing treatment and density adjustments are equally important for different energy ranges of application

All the microstructures of forged samples at the interface indicate strong bonding between backing plate and friction element because of enhanced diffusion of carbon from friction element side to backing plate side and absence of any layered structure at the interface. It is clear from SEM with EDAX pictures that the constituents present in the sample are uniformly distributed. There appears to be no segregation of constituents in the structure. Accordingly, the performance of these samples in actual service conditions is expected to be more consistent in comparison to sintered samples.

Bend test is performed to confirm the joint quality of friction material and backing plate. The bending behavior of forged brake pad samples is significantly superior to sintered sample for equivalent applications. It may also be mentioned that the separation of backing plate with friction element is not observed after bending in case of our forged samples where as for sintered sample there is clear cut separation along the interface. This establishes that joining between backing plate and friction element is superior owing to hot forging technique in comparison to pressure sintering technique employed in MIG 21 sintered pads. Ultrasonic testing and metallographic examination further confirm that the forged brake pads developed in the present investigation possess sound, defect free interface between backing plate and friction layer unlike sintered pads.

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(LENIN SINGARAVELU D)

Preface

The entire work carried out for this investigation has been presented into six chapters.

Chapter one begins with brief introduction of sintered materials their development and scope etc.

Chapter two is a literature review for different materials and technologies relevant to current work. It also deals with application aspects of these materials their selection criteria, patented literature and market survey reports etc.

Chapter three consists of the formulation of the problem, it begins with the scope of the thesis, limitations of existing technology, methods proposed in present investigation leading to improvement in existing technology. Aims, detailed objectives and methodology have been suitably described.

Chapter four deals with the experimental work which includes and explains the steps followed in carrying the present investigation based on 'Hot Powder Forging' technique and the characterization methods of friction materials so produced.

Chapter five consists of results and discussions; where the physical, wear, frictional and metallurgical characteristics of the friction materials are described. The bend test and ultrasonic testing is performed to establish joint quality between backing plate and friction element.

Chapter six deals with conclusion and suggestions for future work.

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Chapter 1
INTRODUCTION

Friction materials are mainly employed in brakes, clutches and gear assemblies of automobiles, locomotive trains, commercial/fighter aircrafts, earth moving equipments, agricultural equipments, cranes, heavy presses, and excavators etc. For application of brakes, kinetic energy of the moving vehicle converts into heat due to friction between friction material on brake pads/discs/linings and rotor. The kinetic energy, which is now converted into heat energy during braking, has to dissipate through brake assembly to the surrounding. This arrangement leads to deceleration of vehicle on one hand and ensures stability of brake assembly on the other hand for its repeated application.

Safety (quick response of brakes with out fading), comfort (smooth engagement of brakes without noise and vibrations) and economy (low production cost and longer life) are the prime motto for the development of different friction materials and their selection to suit brake application. For this friction material should simultaneously possess consistently stable coefficient of friction without degradation on rise in pressure, temperature or humidity; good heat dissipation; low wear loss; and should not have an offensive odor, noise, vibration and harshness etc. during braking; should not be made of too costly ingredients and the processing should also be not too costly. Further, the brake lining should not lead to seizure, score or excessive wear with the mating part.

Requirements as mentioned above are widely varying in character. In order to meet them simultaneously it is essential that multiple constituents of composite nature are there. Based on nature of brake applications, following category of friction materials are normally available..

a. **Resin bonded friction materials..-** These may be containing asbestos or non asbestos. The former one is now being discontinued owing to health hazards. Such type of brake materials are not suitable for severe operating conditions where resins might decompose at higher temperature.
b. **Sintered friction materials..-** These materials are metal based with iron, copper or aluminium as their main ingredient. These are produced by powder metallurgy

route consisting of compacting and sintering powder systems.. Sintered materials are suited for heavy duty brake applications like trucks, racing cars, military and commercial aircrafts and high speed trains etc.

c. **Carbon-Carbon friction materials..-** These materials are also produced by compacting and sintering route but containing predominantly graphite based powder. The friction and mating part both are graphite based and are essentially lubricating type of materials with very low coefficient of friction. However, due to high temperature stability of ceramic graphite, these are excellent friction materials for heavy duty applications.

The metal based sintered materials processed by conventional Powder Metallurgical (P/M) route and as described in **b.** above, are cold compacted and pressure sintered with steel based backing plate. These are much less costlier than Carbon-Carbon (C/C) friction materials as described in **c.** above. The demand for this metal based friction material is constantly growing with the growth of automobile and aircraft industries.

The present thesis is an attempt to improve upon the quality of this segment of friction material to meet higher expectations in automobile and aircraft industries. It is aimed to produce them with better characteristics employing newly developed technology, namely, Hot Powder Forging with appreciably reduced cost.

Business Communications Company Inc. (BCC) has critically surveyed the major market, economy, and production technologies. Its report (AVM028C) on the friction product and materials market indicates, a compound annual growth rate (CAGR) of 4.5% during 2007 -2012 alone in aircraft/aerospace industries.

Metal based friction materials contain different constituents such as lubricants, abrasives. The metallic constituents provide strength, high temperature stability, oxidation resistance, and high thermal conductivity, whereas abrasives improve co-efficient of friction, fade resistance, wear resistance. Lubricants in these are usually solid type which is meant for smoother application of brakes & anti-seizure. Their simultaneous presence gives rise to parallel enhancement of certain properties of brake material for example; abrasives and lubricants together improved wear resistance of friction element. These sintered metallic friction materials can be operated under two conditions either dry or wet. Usually, copper based friction materials are used in wet conditions i.e. immersed in oil whereas iron based friction materials are operated in dry conditions only. The sintered copper based friction materials are suitable for temperatures up to 600°C whereas iron based sintered friction materials are suitable up to 1100°C.

Metal based sintered brake pads are made of three parts namely back plate to provide tough support to brittle brake element, interface layer to facilitate joining of back plate with brake element, and friction element to stand frictional conditions of brake assembly. The last two are processed by powder route whereas back plate is a steel plate which may be heat treated to improve toughness. Economy and performance of such pads are strongly related to the chemistry and processing of brake elements. Steel back plates are also electro plated with nickel or copper to facilitate joining during pressure sintering. In spite of best efforts to join friction element, the quality of joint still remains uncertain and failures leading to separation and loss of friction element during braking application has been observed. **This is a major limitation of existing technology namely compacting and sintering.** This technology is being followed world over and up till now there is no substitute available. Modifications such as double sintering, hot pressing are still going on but there is neither substantial improvement in the quality nor reduction in the cost of the product owing to limited density level, higher quality of raw material requirements, and heavy investment in processing.

In the present investigation, the new iron-based friction material pads with improved performance and with built-in steel backing plate are produced by a novel P/M technique i.e. 'Hot Powder Forging' (described in Indian patent filed on Nov. 7, 2006). It employs high rate of forming where the material undergoes severe plastic deformation under application of impact load; purpose of compacting and sintering both are thus fulfilled simultaneously in a single step. The powder mixture is encapsulated in steel capsule and is heated to temperature range of 1000-1100°C and then hot forged in a forging press followed by homogenization treatment. The steel capsule cover later on serves as backing plate since it joins securely with the forged slab. The process as described above largely overcomes the limitations of presently practiced conventional P/M route.

Total of sixteen formulations were developed based on iron as a main constituent for heavy duty friction materials. Iron varied from 68.50 to 82.25%, copper varied from 5 to 11% and graphite varied from 5 to 8%. Other constituents were Phosphorous, Aluminium, Asbestos, Boron carbide, Silica, Calcium sulphate, Tin, Zinc, Silicon carbide, Ceramic wool, Antimony sulphide, Tungsten carbide, Barium sulphate and Boron nitride in varying percentages.

The samples are either normalized or annealed in the temperature of 680°C to 1050°C. Based on above chemistry and their processing parameters, Table 4.1 provides complete details of nomenclature of friction material developed in the present investigation. This table also gives an idea of density of the final product ranging from 4.96 to 6.69 gm/cc and hardness from 60 to 342 BHN. Based on the chemistry and processing parameters symbols are also assigned to each type of friction materials developed in the present investigation.

The density levels were altered by exercising number of repressing. Our technique of manufacturing permits us to control density parameter and therefore, it has been possible to produce friction materials which are not available in the literature elsewhere.

Detailed characterization of friction pads produced this way exhibit improved physical, mechanical, frictional and metallurgical properties. Subscale dynamometer tests have been performed and compared with results of existing sintered materials for military aircraft applications such as AN-32, MIG 27 aircrafts. Investigations were carried out in detail in selective cases only where there is a scope for further exploitations towards application of friction elements developed in the present investigation for heavy duty military aircrafts for which entire work of the thesis is concentrated.

Chapter 2
LITERATURE REVIEW

2.1 FRICTION MATERIALS

Friction materials are used in clutches and brakes of an automobile/equipment to accelerate or decelerate it. The brake system differs from clutch system that the vehicle stops under particular distance in shorter duration with higher frictional heat generation. Whereas clutch system opposite to that of brake system. The friction force between the surface of the friction material and counterpart of the vehicle converts the kinetic energy into heat [4].

The rotating counterparts in the friction assembly are usually made of cast iron because of its excellent friction and wear properties. Recently, new brake discs or counterparts based on non-ferrous alloy system of Aluminium Metal Matrix Composites (Al-MMCs) or carbon based brake discs are also employed. But cast iron is still practiced as counterpart in variety of modern automobiles. The design of brake rotors are made into many groups like solid, vented, fin holes and many others types for faster heat dissipation, faster cooling rate, excellent friction and wear properties etc [13,61].

These friction materials are mainly employed in various brakes, clutches and gear assemblies of different kinds of automobiles, high speed trains and railways, commercial/fighter aircrafts, earth moving equipments, agricultural equipments, cranes and hoists, high way trucks, presses, excavators, machine tools, forging and pressing equipments, heavy lifting devices etc [4,33,39,46,111].

The choice of friction materials will depend upon vehicle load, speed, pressure, energy to be dissipated, counter face material etc. Wear resistance is one of the major factors influencing the choice of materials for friction pads [35, 37]. The reduction of material losses due to wear and friction require a new class of materials and processes, and also a new generation of thoroughly trained, knowledgeable tribologists in the coming decades [91,120].

2.2 CLASSIFICATION OF FRICTION MATERIALS

The friction materials that are used for brake applications are broadly classified into following three sub-groups [4]. In all three sub-groups the energy quantum, stopping distance/time, environmental issues like NVH (Noise Vibration Harshness) play a major role. For an automobile, like motor cycles, passenger cars, trucks and buses there should be less NVH where as for the aircrafts/railways this is a secondary parameter [123,125].

1. Organic Friction Materials:
    - Asbestos or organic friction materials
    - Non-Asbestos Organic (NAO) friction materials
        - Low metallic
        - Non metallic
    - Semi-metallic friction materials
2. Metallic Friction Materials:
    - Iron based
    - Copper based
    - Aluminium based
3. Carbon-Carbon (C/C) Friction Materials:

2.2.1. Organic Friction Materials:

They were used in earlier days, in brakes and clutch systems. These consist of wood and leather [132]. Asbestos fibers were used as reinforcing materials in brake pads as early as 1908's and employed till 1985's [13]. Asbestos based organic materials were widely used due to their better frictional stability up to 500°C. Above this temperature it produces silicates which is harder stabilizes friction, more abrasive, excellent durability, better thermal resilience. Asbestos fibers can lodge in lungs and induce adverse respiratory conditions found later by medical research and was therefore banned in 1986 by the Environmental Protection Agency (EPA). This led to conversion of non-asbestos brakes by the friction material suppliers and vehicle manufacturers. However, asbestos based brake products are still used in the aftermarket despite the fact many people think asbestos was replaced by non-asbestos years ago; since asbestos is an economical fiber for low temperature brake applications [RR1]. Now, Non Asbestos Organic (NAO) type friction materials are establishing in view of restrictions by EPA. NAO based materials consist of resin binders with low metallic and non-metallic constituents, different variety of fibers, various fillers and friction additives. These constituents as composite in nature are shown in Table 2.1, 2.2, 2.3 and 2.4. Semi-metallics are another kind of organic based material where 50% metallic constituents with a variety of fibrous materials present in the system are later development. This type of friction material is mainly involved in racing cars and bikes due to their higher coefficient of friction requirements. NAO type friction materials comprise composites of binders, reinforcements, friction additives, fillers etc[129, 142].

NAO material consists different fibers like chopped glass fiber, mineral wool, para-aramid (Kevlar), cellulosic and other organic forms etc. The binder resins shown in Table 2.4 used for organic friction material are usually thermosetting polymers, mainly based on phenolic type. The liquid and powder forms of resins are normally used [4,13,96].

Bijwe et al [11] describes low metallic NAO based friction materials of varying with SiC, SiO_2, ZrO_2, Al_2O_3 as abrasives and studied the influence of operating parameters by using decision making approach. The author reported that abrasives cause significant effect on their wear performance.

NAO type friction material with different ingredients including solid lubricants (graphite and Sb_2S_3) was evaluated for their frictional characteristics [92]. Higher content of solid lubricants had shown positive effect on the fade characteristics. This is due to graphite oxidation of and Sb_2S_3 decomposes into oxides at elevated temperatures and loosing its effectiveness as solid lubricant. Thermal decomposition of the solid lubricants strongly affects the friction characteristics at elevated temperature [16,17]. Therefore, role of solid lubricants should be carefully analyzed. The three different solid lubricants namely, Cu_2S, PbS and Sb_2S_3 of Non-Asbestos Organic friction materials are analsysed to evaluate their effects. Sb_2S_3 based formulations had the highest coeffienct of friction and low wear as compared with other two lubricants [92,130]. The effect of Sb_2S_3 as lubricant and $ZrSiO_4$ as abrasive on frictional characteristics was investigated by using a brake dynamometer under two different modes. Higher contents of Sb_2S_3 in the friction material improved the stability of friction coefficient at elevated temperatures. In general, solid lubricants are added to the friction material to build up a stable friction film (3rd

body layer) on the rotating counterpart and abrasives such as $ZrSiO_4$ are added to remove thermally decomposed layer of the friction film [53,54]. Therefore, it is established that Sb_2S_3 mainly improves friction stability and better fading resistance in combination with abrasives [112].

NAO low metallic type friction material with four different abrasive additions was examined to evaluate wear data using a regression model based on orthogonal test design. The contribution of these abrasives towards wear rate had shown better influence on the various factors such as load, sliding speed and braking pressure [9]. The influence of different metal fibers on its frictional characteristics of NAO friction materials was also evaluated [54]. Modified resins were also used for making friction materials [RR1]. They improve frictional stability even at high temperature. Sometimes, resin modification may result in high wear rate and decrease in porosity [13]. Five different modified resins with constant proportions of other ingredients are examined for mechanical and frictional performance. Considerable efforts were made [11] to correlate frictional characteristics of resin based brakes including combinations of different resins. However, it is concluded that no resin combination is available where frictional properties can be scientifically optimized.

Semimet linings are separate from the other NAO linings because they have a restricted composition range, with unique friction and wear properties. Semimet linings comprise 50-60 wt % total metallic content, steel wool, graphite with a heat-resistant phenolic-type binder. The coefficient of friction of these materials is around 0.40 to 0.55. These materials are typically semi-metallics. When these pads are cold, they may be near impossible to deal with on the street because they do not reach the optimal operating temperature during normal driving. But, when they are warm, the braking performance of the vehicle is greatly increased. Also, these high COF friction materials have superior resistance to fade. According to Ho et al [55], the effects of carbonization in the temperature range 400-800°C were studied to improve the high-temperature performance of a copper/phenolic resin based semi-metallic friction materials on its mechanical and tribologial behavior. Low carbonization rate results in higher mechanical properties and fewer cracks. Increased carbonization temperature results in improved tribological properties. In general, carbonized samples exhibits better mechanical and tribological properties, better high-temperature heat/oxidation resistance etc. than non-carbonized samples. This is possibly due to formation of lubricant in the form of graphite during carbonization [55].

Abrasives:

Abrasives improve the friction performance to a desired level, and they are added in various sizes and concentrations to friction composites to create and as well as to increase better friction/surface film which is formed when the brakes are applied. This will also induce low wear and frictional stability and thus improving braking efficiency over variety of applications. Further, abrasives help in maintaining the cleanliness of mating surfaces. However, some of the inclusions present in the abrasives may affect the friction stability, damage the counterface (by roughening or polishing) and result in wear of both the disc and pad surfaces.

Table 2.1Abrasives [RR1]

S. No.	Material	Description / Comment
1.	Aluminium oxide	Very hard and most in abrasive form either in hydrated form or anhydrous form is used.
2.	Iron oxides	Hematite (Fe_2O_3) and magnetite (Fe_3O_4) act as a mild abrasives
3.	Quartz	Crushed mineral particles (SiO_2)
4.	Silica	May be natural or synthetically-produced (SiO_2)
5.	Zirconium silicate/oxide	($ZrSiO_4$) or (ZrO_2)
6.	SiC	Very hard abrasive for severe conditions are used.

Friction Producers / Modifiers

These are responsible for control of coefficient of friction or the type of wear. They may form interfacial films and may also act as lubricant. Solid lubricants are used to stabilize the coefficient of friction, primarily at elevated temperatures.

Table. 2.2 Friction Producers/Modifiers [RR1, 13,53,54,106]

S. No.	Material	Description / Comment
1.	Antimony trisulfide	Solid lubricant added to enhance frictional stability; lubricates>450oC, Sb2S3 is potentially toxic
2.	Brass	Typically 62%Cu – 38% Zn; sometimes used as chips or machine shop cutting swarf, said to improve wet friction and recovery, common additive.
3.	Carbon (graphite)	Cheap and widely-used solid lubrucant; many forms are available; synthetic or natural crystalline type used; burns in air at >700°C, friction level is affected by moisture and structure.
4.	Ceramic 'microspheres'	Special product consisting of alumina-silica with minor iron or titanium oxides, low-density filler; reduce rotor wear and control friction
5.	Coke	Cheap solid lubricant, improves friction performance
6.	Copper	Uses as a powder to control heat transport; improves thermal conductivity; can causes excessive cast iron wear
7.	Friction dust	Processed cashew resin, may have a rubber base; to reduce spontaneous combustion or help particle dispersion.
8.	Friction powder	Sponge Fe, e.g for semi-metallic brake pads a number of different particle grades (sizes) are available depending on requirements for surface area, light-medium-heavy duty vehicle applications.
9.	Lead oxide	PbO as friction modifiers; toxic in nature
10.	Metals – fluxing compounds	Pb, Sb, Bi, Mo as fluxing compounds serve as oxygen getters to stabilize friction induced films and promoting thick films.
11.	Metals oxides – various	Magnetite (Fe_3O_4) improves cold friction; ZnO lubricates but can cause drum polishing; Cr_2O_3 raises friction
12.	Metals sulfides – various	Cu_2S, Sb_2S_3, PbS are modifies and stabilize the friction coefficient; Sb_2S_3 has highest COF; PbS - soft solid lubricant additive which reduce noise, pad & rotor wear; MoS_2 – a typical layer-lattice-type lubricant and adheres more readily to metal surfaces than graphite; ZnS is a low cost solid lubricant for high loads and temperatures
13.	Mineral fillers	Mullite, kyanite, sillimanite are friable and controlling frictional behavior; higher amounts tends to wear the counter-face.
14.	Petroleum coke	Low cost, can lower friction, low ash

Reinforcements/Fillers

Reinforcements provide mechanical strength. Fibers of metal, carbon, glass and rarely mineral and ceramic fibers are used. Fillers are principally used to make the material less expensive and/or improve processing. Some fillers may also affect friction characteristics of the material [164].

Table 2.3. Reinforcements, Fillers and others ingredients [[RR1,13,53,54,62,97,101].

S. No.	Material	Description / Comment
1.	Anti-oxidants	Graphite – common anti-oxidant in metallo-ceramic composite brake; maintains proper oxide film thickness on aircraft brakes; higher oxide leads to unstable friction and can wear off.
2.	Aramid	Good stiffness to weight ratio; excellent thermal resilience; good wear resistance
3.	Asbestos	Most common filler in early brake materials
4.	Barium sulfate ('barytes')	(BaSO4) basically inert; increases density and wear resistance, stable at high temperature.
5.	Calcium carbonate	$CaCO_3$ is a lower cost alternative to braytes, but not quite as stable at high temperatures
6.	Calcium hydroxide	$Ca(OH)_2$ a cheap filler
7.	Cashew nut shell oil	Improves resilience in the binder system and reduces brake noise
8.	Cotton	Reinforcing fiber for the matrix
9.	Fibers – mixed oxide	Reinforcement fibers; produced from a base slag mineral wool; contains mixture of silica (40-50wt%), alumina (5-15wt%), calcia (34-42wt%), magnesia (3-10wt%), and other inorganics (0-7wt%); controls fade and increase braking effectives.
10.	Glass	Sufficient thermal resilience; brittle
11.	Iron	Cheap filler, better high temperature characteristics, In semi-metallic type higher contents are used.
12.	Lime	Ca(OH)2 is used to avoid corrosion in Fe-additives, helps in processing, raises fade temperatures
13.	Magnesium oxide	MgO promotes curing of binder,
14.	Metal fibers	Cu fiber, Steel fiber, Al Fiber
15.	Polyacrylonitrile	PAN fiber is used as reinforcement

16.	Potassium titanate	Inert filler material; very hard and good wear resistance; thermally resilient
17.	Rock wool	Fibrous material
18.	Rubber – diene, nitrile	As stabilizers to promote cross-linking and increase wear resistance; rubber modifies the compressibility (modulus/stiffness)
19.	Rubber scrap	Ground up tires ('tire peels'), decreases cost, must not contain road dirt
20.	Sea coal	General low-cost particulate filler, may contain harmful ash; not good for high temperatures
21.	Steel wool	Used as reinforcement
22.	Styrene-butadiene rubber	(SBR) used as toughening agent for the binder
23.	Vermiculite	Expanded type used

Binders

Binders are matrix for organic type friction material that holds the other components together and forms thermally stable matrix and preserves the brakes pads including its structural integrity under mechanical and thermal stresses which are developed during braking. Table 2.4 below shows common binders for friction material application [26,59,162].

Table 2.4 Binder Materials [RR1, 13,100]

S. No.	Material	Description / Comment
1.	Phenolic resin	Common binder; too little quantity leads to material weakness; if too much is used, there is a friction drop-off at higher temperatures; cheap and easy to produce; brittle, highly toxic.
2.	COPNA resin	High bonding strength with graphite; better wear resistance; decomposes at relatively low temperatures (450-500°C)
3.	Cyanate ester resin	High heat resistance; chemically inert; vibration dampener, brittle
4.	Thermoplastic polyimide resin	Abrasion resistant; does not exhibit thermal fade; lower thermal conductivity
5.	Modified resins	A variety of modifications includes phenolic, cresol, epoxy, cashew nut shell liquid (CNSL), PVB, rubber, alkylbenzene, linseed oil and boron are used to alter bonding characteristics and temperature resistance.

Optimization of friction material formulation were carried based on Taguchi design, multiple regression analysis coupled with genetic algorithms, chemometrics, and golden section principle in combination with relational grade analysis to develop friction material of better triboligical performance aimed with higher wear resistance and moderate or high COF [9,22,67,128, 153,155, 156]

Automotive brake squeal can be described as an irritating sound with a main frequency between 1 to 20 kHz, generated by the components. This noise generation needs to be suppressed for the better or efficient brake design and manufacture. The articles [27,71,98,99] clearly states the important factors for noise level generation were vibration and waves, brake rotors designs, contact pressure and temperature. Also, experimental studies on brake squeal of different brake friction materials, eliminations of brake squeal problem, friction laws, contact geometry asperities, modeling of brake squeal are carried. Squealing in brake is mostly due to the contact between brake pad and disc (counterpart). The sizes of contact plateaus at the different brake pressures and higher temperatures evolved during friction affects the generation of brake squeals [6,44,58,88,107].

Binding agents present in the conventional organic friction materials exhibit poor frictional stability under varying temperature conditions. Higher temperatures generation during braking cause binders to disintegrate. Thermal degradation of binders results in inferior frictional characteristics, giving rise to fade and often resulting in increased wear. Furthermore, organic materials, particularly resins, tend to have a short shelf life, and are not always easy to reproduce [145, 146]. To overcome these deleterious effects of poor thermal resistance in a organic friction material, sintered metallo-ceramic friction materials which withstand considerably higher thermal stresses have been developed and are described below. These brake materials are known for better frictional and wear performance under heavy duty applications. High mechanical strength, better thermal conductivity and thermal capacity, high heat resistance are some of the main attributes of metallo-cermic brakes and are therefore much superior in performance than organic brake materials.

2.2.2 Metallic Friction Materials

These types of brake materials were introduced in the late of 1930's and comprise of on either copper or iron as matrix. Since these involve ceramics constituents also they are often called metallo-ceramic or cermet friction materials. The manufacturing technology for this type of friction material is conventional powder metallurgy based on compacting and sintering technology [20]. Sintered friction materials contain of metallic and nonmetallic constituents, in varying the proportions of the friction producing nonmetallic ingredients. Variety of shapes can be produced, for various kinds of brake applications.

The components in these materials are divided in to three sub groups: one metallic base (matrix) with alloying elements to provide load carrying capacity and thermal shock resistance, second, friction additives to raise coefficient of friction, and, third, antiscuffing additions or solid lubricants which prevent seizure and sticking with rubbing parts, ensure even friction and increases wear resistance [78, 89, 141]. Metal matrix with different metallic constituents like Tin, Copper, Ferro alloys, etc. (in the range about 50-80 wt.%), ceramics and non-metallics like Al_2O_3, SiO_2, ZrO_2, SiC, B_4C, WC, Bentonite, Asbestos, Spoudumence, feldspar, Kayaniteand etc. (in the range about 20-28 wt.%) and solid lubricants like graphite, MoS_2, Sb_2S_3, $CaSO_4$, $BaSO_4$, BN etc. (in the range about 5-25 wt.%)are blended/mixed either wet or dry mixed and then the powder mixture is cold compacted followed by pressure sintering with steel backing plates. There are two principal types of applications or operating conditions for metallic friction materials: "wet" and "dry". Under wet conditions, the friction components, such as clutches in power shift, automatic transmissions and brakes are immersed in oil. Dry operating conditions involve direct contact of friction components with rotor such as in aircraft brakes [4,21,35,77].

Sintered metallic friction materials have been used as brake disks, especially for heavy-duty applications, because of their good braking performance and low wear rate under high temperatures [34,36]. These have been developed for very high power input densities..For example, solid-state-sintered bronze and mullite linings are used in race car and high-speed railroad brakes. Sintered iron with graphite is used in some heavy-duty brakes in civilian/military aircrafts; both stator and rotor disk brakes, and as well as on a few production passenger cars drum brakes [7,20,154]. Multiple-disk brakes have alternating rotors and stators forced against adjacent members by hydraulic pressure. Metallic friction materials are also used in other heavy-duty applications, such as clutch facings on tractors, trucks, earth-moving equipment, and heavy presses [20,23].

The most widely used metal matrices for heavy-duty friction materials are copper and bronze where service temperatures are less than 600°C. Iron matrices are used where service temperatures are likely to exceed 1100°C [4,52]. Cu based materials are better at low to medium brake load conditions whereas Fe base are suitable for severe conditions. Fe-based alloys are known for decreased and better frictional stability, while the Cu-based alloys display a "fade" phenomenon under higher load and speed conditions [126, 127,159]. Normally, the density of Fe base friction materials is in the range of 5-6.1gm/cc, its hardness 80-105 HRF, and a friction coefficient in combinaton with cast iron is 0.34–0.40, whereas Cu based friction materials has density of 7.0–7.5 gm/cc, its hardness 30–40 HB, and a friction coefficient of 0.28–0.30 in combination with chromium-plated steel [25,75, 77,109].

Iron, as the friction material matrix is chosen due of its stability under higher temperatures (1100°C) and can be applied under heavy dry operating conditions because of its high melting point and other improved properties which include strength, hardness, ductility, heat resistance and stability etc.[105], Further, during braking, surface/oxides films on its surface are responsible for better frictional properties. Due to of these reasons, iron base materials have been chosen in the present investigation and have been reviewed in detail.

2.2.2.1 Role of composition and new production technologies

Iron powder grade selection for the application of friction material should be carefully chosen. Sponge iron produced by reduction of iron oxides is known for its frictional stability and widely used as matrix as compared to atomized power. Good friction properties are obtained while using certain quantity of larger particles. Powder of size <120 μ has coefficient of friction in the range 0.30-0.60 [24].

Investigations on sintered iron base friction materials on two different iron powder grades namely, sponge iron powder obtained by magnetic reduction and fiber like structure iron powder are studied. Although these two different iron powders have different morphology, chemical and physical properties, the test results exhibit no significant effect on their suitability and are applied equally within the acceptable range of required values for metal matrix [102].

The degree of oxidation of iron powder may influence the physiomechanical properties of iron base friction materials. The sintering of oxidized compacts i.e. the combination of sintering operation with reduction improves mechanical properties. Increase in degree of oxidation leads to a slight decrease in compacted density. Sintered density will increase with increased oxidation level due to greater sintering shrinkage. Higher degree of oxidation of iron powder leads to higher hardness, lesser wear but independent of COF. The higher the degree of oxidation of the iron powders, the more the carbon is burnt up. Reduction of oxide films with the formation of active iron atoms improves the contact surface between grains and increases shrinkage during sintering, and this causes increase in density. These higher porosity levels and reduction in carbon content will change the mechanical and frictional properties. It may also be possible to avoid the operation of pre reduction of iron powders during the making of sintered friction mixtures. However, the use of reduced powders simplifies the technological process, reduces the amount of dust in the shop atmosphere, decreases the labor consumption by 10-15%, and ensures the production of high-grade parts from sintered friction mixture [52].

Sintered iron-phosphorous base friction material was developed for moderately loaded friction units operating without lubrication. The intermediate working layers consists of mixture of copper and iron oxides, heterophase structure is responsible for better frictional characteristics, better oxide films, and prevention of frictional thermal fatigue [133,134,135].

Optimum phosphorus content in the range 0.8-1wt.% is added in the form of ferrophosphorous for an iron base materials provides highest friction properties due to the presence of uniformly distributed phosphide eutectic network with a vein thickness of 0.95-1.33μ at the grain boundaries of the alloyed ferrite [35,134, 135].

The structure of sintered iron-graphite can be affected by the addition of alloying components. Copper was the first element tested and recommended for the improvement of sintered iron-graphite materials. Copper additions to the sintered iron base friction materials are widely used since they activate the sintering process by forming a liquid phase and thus increases the strength. But attention must be paid towards the growth effects by the higher addition of copper. Higher content of copper results in increased thermal conductivity, higher thermal wear and COF gradually decreased. Compressive strength increased initially reaching a maximum value and thereafter gets reduced with further addition of copper [119,160].

Friction additives are the components raising the coefficient of friction are expected to possess the following characteristics: a high melting point and a high heat of dissociation; absence of polymorphic transformations in the range from ambient to the sintering temperature; absence of reaction with the metallic matrix; adequate mechanical strength and hardness; wetting of, or strong adhesion to, the matrix. Among friction additions employed are oxides of metals (silicon, aluminum, molybdenum), certain carbides, complex oxides, and minerals [79].

Addition of silica to the iron based friction material enhanced higher COF and less temperature rise, and upto 4% provides thermal stability and further increment may result in decrease of thermal wear resistance, mechanical properties such as compressive strength and hardness. The reduction of silica may be attributed to carbon monoxide according the following equation,

$$SiO_2 + 2CO = Si \text{ (dissolved in Fe)} + 2CO_2$$

Silicon dissolves in iron and carbon dioxide reacts immediately with free carbon, thus regenerating the monoxide:

$$CO_2 + C = 2CO$$

This mechanism explains the possibility of silica reduction at a relatively low temperature, about 1000°C. The rate of reduction is slow. Even direct reduction by carbon is possible, but the system requires 1590°C. However, the presence of iron diminishes the activity of silicon and supports the reduction. Therefore, following reaction may occur at a lower temperature.

$$Fe + SiO_2 + 2C = FeSi + 2CO$$

Alumina has similar effect as silica that thermal stability increases rapidly with small additions and no negative influence with larger amounts. Temperature rises moderately. Compressive strength decreased with higher contents of alumina, but hardness variations are insignificant. In comparison to silica, alumina remains stable during sintering. Direct reduction by carbon is possible only beyond 2000°C and hence the rate of indirect reduction by carbon monoxide is far slower than that of silica [116].

Solid lubricants (graphite, MoS_2, BN, phosphides of certain metals) should posses high lubricating power, be inert with respect the metallic matrix and resist decomposition at the sintering temperatures [77]. Addition of graphite gives a high frictional stability. Usually, 6 -26% of graphite quantity is used in iron base materials. Selection of optimal grade and proper particle size was another challenging criterion. Carbon diffusion into the iron component, chemical effect which leads carbon drops by about 2% and antifriction effect during service are observed by the addition of graphite. Sometimes, higher content of graphite results in higher COF [24,]. Decrease in wear may also obtained when graphite addition exceeds certain amount and increased when the addition is still increased from the required amount (about 26%) due to excessive loss of strength.

Further, the presence of graphite to the iron base friction materials provides better seizure resistance [118]. However, higher graphite content (about 15-20%) are suitable for low temperature performance conditions and for higher energy conditions it may results in poor heat transfer, hence its content is limited to 6-8%. This will lead to poor frictional characteristics and can be further compensated by the addition of barium sulphate. $BaSO_4$ which undergoes following chemical reaction of complete reduction by carbon during sintering [118].

$$BaSO_4 + 4C = BaS + 4\,CO$$

Higher amount of barium sulphate addition improves resistance to high temperature wear. However, being an non-metallic content, it is limited to 12% as higher content will deteriorate mechanical properties such as compressive and shear strength of the friction material rapidly [70,118].

Lead as a soft constituent, better antiscuffing behavior is also frequently employed in friction materials. Small addition of lead modifies the structure of the matrix and further, it tends to spheroidize the grains of the main alloy component. Lead is replaced by bismuth due to its insolubility in copper and excellent lubricating properties, low specific gravity, low melting point than lead and it non-toxic in nature [52,65,68].

Calcium pyrophosphate and as well as calcium sulphate are lubricants under 'white solid lubricants' group proves better lubricating property in iron base composite materials under tribological conditions. It provides better sinterability of iron composites as well as better compactibility which leads to higher density. The particles of calcium pyrophosphate filled the pores of sintered compacts and evenly spreaded on the metallic matrix. Presence of this lubricant changed the friction conditions and the mechanism of wear and ensured a significant decrease of the motion resistance and wear during friction; 10% volume fraction has better tribological properties [62,92,137].

Another metallic friction material is cast iron. Although this venerable material is use on some old railroad tread brakes, no new automotive applications are known to use cast iron as the brake lining. However, it is the predomimotive drum and disk brakes. Therefore, it remains a friction element, although not a brake lining.

Few materials based on other metals than copper and iron are known such as other matrices based on Ni or W or Mo may also have to be used for certain applications [127].

Aluminum-base material with a composition of (wt.%) 0-20 copper, 0.2-20 hard components (oxides, carbides, and/or nitrides of silicon, aluminum, and/or zirconium and also of solid solutions) and strengthening components (Mg, Si, Sn, Mn, Zn, Ni, Cr, Mo) have been proposed. The aluminum matrix significantly reduces the weight of the alloy. However, aluminum-base materials have not obtained wide use since the method of their production is very complex, sinterability of aluminium base materials was poorer and they are expensive. These materials are used primarily in rubbing pairs for aerospace technology [19,31,32].

Investigations on Aluminium bronze type friction material consists of mainly copper-tin matrix with higher contents of aluminium (10-15%). The wear resistance of these materials is maximum when their matrix has a single-phase structure (with the maximum aluminum concentration in α solid solution) or a two-phase structure ($\alpha + \gamma_2$) of minimum eutectoid content. The optimum combination of frictional characteristics and wear resistance under unlubricated friction conditions is exhibited by materials containing 11-14 wt.% A1. The structure of the matrix of these materials consist of a heterogeneous mixture of a ductile (α solid solution of aluminum in copper) and a brittle (the intermetallic compound Cu_2Al) component, the concentration of the latter being sufficiently low to produce no marked decrease in strength [80,81,85].

Ceramic-base (silicon carbide and nitride) [51] friction powder materials which possess a unique combination of properties including low specific gravity and high strength, wear resistance, and chemical inertness. Their main disadvantages, brittleness and poor machinability, are among the basic reasons preventing broad use of ceramic base materials as friction materials [19,20,43].

In order to achieve high performance materials with low cost many researchers put more their own efforts to improve upon the existing technology and creating new materials and as well as production methods.

For improving the quality of preparation of powder mixtures and for better compacting of a powder charge it is proposed to have ultrasonic vibrations act on it at 150°C for 1-3 sec before pressing. Surface treatments nitriding, boriding and borochromizidng for the purpose of increasing its mechanical properties, wear resistance, and frictional stability may also carried [14,139]. This surface treatment not only improves wear resistance of friction layer, also increases wear resistance of mating surface by number of times [18,20]. Methods for the production of friction elements through electric current, plasma spraying, arc deposition, rolling of powders, special method on degassing of friction products, special protective coating of ceramics by chemical vapor deposition, special heat treatment processes, zinc coated iron powder production are directed towards the improvement of existing and creating of new technology [19,20]. Friction material produced by forging involves, a powder mixture of friction composition is pressed onto a steel framework and then subjected to hot deformation by forging at a rate of 0.1-2.0m/sec [19]. This technique is similar to powder forging of connecting rods where the compacted/sintered preform is forged under hot conditions.

Different types of friction materials are reviewed. On the basis of principle of dispersion hardening, dispersed phase should be particles of Cu combined with Sn, Zn, Pb, Al, and Al-Fe, Ni-Sn, Al-Ni, Al-Si are suggested. Additions of glass lubricant with Fe or Cu matrix are also mentioned for better frictional characteristics [19,36]. A wide class of friction materials based on iron containing metallic elements (Mn, Si, Cr, Mo, Ni, Mg, Cu, Sn, Pb, Zn etc.), non-metallic elements (iron borides, Ca, Li, Na, K, P, B, S, etc.) friction additions (Al_2O_3, SiC, SiO_2, B_4C, $ZrSiO_4$ etc.) and solid lubricants (graphite and graphite granules, $BaSO_4$, MoS_2, WS_2, BN, Pb etc.) in appropriate amounts for variety of brake/friction applications such as aircrafts, rail wagons, freight cars, tractors, heavily loaded machines, wet applications, shock friction conditions, shock absorbers etc. are briefly reviewed by mentioning different processing steps such as sintering technique, carbothermal synthesis, continuous rolling, material from grinding, cheaper raw materials from industrial waste etc. for producing them [86,87].

Intermetallics based power metallurgical metal matrix composites with reinforced aluminides (Ni_3Al, Fe_3Al) produced by Mechanical Alloying (MA) system are also used for triboligical applications [60,150]. Fe_3Al-based friction materials exhibit good oxidation resistance especially at high temperatures, higher bending and compressive strength. Wear resistance of Fe_3Al-based friction material are greatly higher than sintered Fe-based friction material. But COF decreases little bit; this is due to they are hard and brittle materials, whose capacity of adhering and sticking to the counterpart is poor during the friction process. However, stability of friction coefficient is better and maintained [62,93]. Dry sliding wear studies on Fe_3Al intermetallic have improved wear resistance, under abrasive and erosion conditions. These intermetallic compounds alloys having higher wear resistance than sintered iron matrix. However, particularly for braking applications the study was not yet carried [150].

An investigation of sintered copper-tin based brake material rubbing against carbon/carbon-silicon carbide composite disc on its frictional characteristics is differential approach. COF is increased with increase in graphite. The wear of linings is high with addition of graphite and SiC. The addition of SiC decreases COF due to some physical and chemical changes on the friction surface [165]. However, frictional characteristics are not compared with commercial one for braking applications where sintered metallic friction material normally rubbed against grey cast iron or steel disc.

Different production technologies such as, for better mechanical, microstrutural properties of required size of friction disks upto 550-600 mm with powder layer thickness of 0.5-0.7mm are produced by 'free pouring' method on copper base material, hot compaction of iron base material at 1060±15°C with a pressure of 2.3MPa for 2.5 hour, deposition on a steel body and powder lining sintered under pressure by passing an electric current, use of rolling method describing short-term sintering, possibility of coating which gives high wear resistance, good adhesion properties and a prolonged operating life etc., method of gas thermal deposition, friction coatings applied by electric-arc deposition of powder wires, composite electrolytic coatings by means of a laser treatment, different variety of self-propagating high-temperature synthesis are some of the new production technologies other than sintering process are developed with the aim to reduce the production cost of sintered materials [87, 143].

The growth rate of iron base powder friction materials is gradual with mean annual increment of 6%. In 1998, the world production was 320 thousand tons with an estimated growth for 2005 year as 428.7 thousand tons [86].

The present thesis is an attempt to improve upon the quality of this segment of friction material to meet increased demand in automobile and aircraft industries. It is aimed to produce them with better characteristics employing newly developed technology, namely, Hot Powder Forging with appreciably reduced cost.

Therefore, the present investigation broadly pertains to iron base metallo-ceramic class of friction materials. The newly developed technology differs considerably from sintered tecyhnology. However, chemistry/formulations of materials are similar to it. The following table summarises chemistry commonly employed in sintering technology [19,20,77,85,94].

Table 2.5 Iron base Powder friction brake designations and typical compositions

S. No.	Composition / Designation	Description / Comment
1.	2-5 Cu; 1-3 Sn; 1-5 Pb; 0.5-1.2 crystalline graphite; 0.5-0.8 pencil graphite; 3-8 high speed powder steel; 0.5-1.6 "Mazhef" compound	Recommended for friction plates of tractor starters, mopeds and motorcycles. Superior strength.
2.	4-6 Sn; 8-9 C; 1.5-3 MoS_2; 2-4 SiO_2	Used with steel in friction shock
3.	0.5-3 Cu; 3-5 graphite; 10-20 ferrophosphorus; 0.08-0.15 Sn; 0.05-0.1 Mn; 0.15-0.3 Ni; 2.5-5 Cr	Characterized by superior were resistance, friction coefficient equal to 0.4
4.	4Cu;5Pb;2Sn;5Co	Magnetic material
5.	1-4 C; 9-20 Cr; 0.05-3.5 Mn; 0.1-10 one or several elements from the group Mo, V, Nb, Ta; 0.1-10 Co, Ni, or their mixture	Powdered copper or copper-tin alloy is applied to porous framework formed after sintering. The powder melts upon heating to 1130°C and impregnates the sintered framework.
6.	1-4 C; 4-7 Cr; 0.5-2 P; 2-5 Mo or 0.5-3 B	Carbides of Cr, Nb, Ta, Ti, W, V, Zr, and Hf, with a hardness 1000-1130 I-IV are dispersed in the matrix of alloy and do not decompose during sintering. The material has high wear resistance.
7.	3 Cu; 1 C; 2 MoS_2; 3 PbO; 1 Al_2O_3	Used to make automobile brake shoes
8.	0.04-0.1 C; 0.1-0.6 Si; Mn; 0.04 P; <0.02 S; <0.6 Ni; 1.5-13.5Cr; <0.5 Cu; 0.005-0.05 N	Recommended for motorcycle brake disks
9.	1-5 Cu; 3-6 $NiSO_4$; 4-8 graphite; 1-3 devitrified glass; 3-10 $CaSiO_2$;0.2-1 SiC; 0.4-2 Si; 0.5-5 asbestos; rem.Fe Composition the same but 1-5% Cr instead of devitrified glass	Possesses increased friction, wear, and strength properties
10.	2.5-3 SiC; 2-2.5 graphite; 2.5-	May be used for operation under conditions of

	3.5 pozzolan; rem~ Fe	dry friction and friction with lubrication
11.	1.5-3 Cu; 1-2 Sn; 4-8 Ba_2SO_4; 1-8 graphite; 1-5 devitrified glass; 10-20 Pb; 0.5-4 BN; rem. Fe	Addition of BN leads to an approximately four fold reduction in wear in an oil medium
12.	Cu + 8.5-16 flaky substance or mixture of flaky substance with graphite	Used for brake shoes
13.	4-15 Cr; 1-3 C; 0.1-5 Mo; 0.3-1.5 Si; 0.2-1 P; 2-20 dispersed phase	Composition of the dispersed phase, in %: 10-20 Cr; 1.5-3 C; 0.5-5 Mo; 0.3-1.5 Si; 1-10 of one or more elements of the group Mb,Ta,Ti,V
14.	1-25 Cr; 1.3-6 C; 0.5-5 Si; 0.05-2 Pb or B; 0.2-20 of one or more elements of the group Mo, W, Nb, Ti, V, Zr	Possesses high wear and corrosion resistance; damps acoustic and mechanical vibrations well
15.	8-25 Si_3N; 0-3-1.5 P; 0.2-1.5 C; 0.1-3 C; 0.i Sn or Zn; 1-10 Cu; 0.3-1 P	A phase of ternarly alloy Fe-P-C with hardness 300-850HV uniformly dispersed in the matrix, f = 0.34
16.	0-23 Cu; 0-4 Sn;1-5 graphite; 2-5 MoS_2; 1-8 Bi; 0-9 Pb; 0-.4.5 Al_2O_3; 0-14 $ZrSiO_4$; 3-14 graphite; 2-12 coke; 3 Sn or Zn; Bi, Pb, 3-10 frictional components	Has constant wear rate at temp. above 300°C
17.	10-70 C; 0-2.5 S; <10 Al_2O_3; component of group including Cu, Mn, ferrochrome, chromium carbide	Designed for production of railroad car brake shoes. Presence of Cu, Mn, ferrochrome prevents seizing
18.	0.8-1.5 C; 0.5-2.5 Cr; 2-5 Mo; 1.5-5 Ni; 0.1-2 W; 0.2-5 Cu	Complex carbides formed in Fe-Cr-W-C system dispersed in the matrix
19.	15 Cu; 9 graphite; 6 $BaSO_4$; 3 SiO_2; 3 asbestos.	Trade mark as FMK-11; COF is 0.21-0.22 in dry friction; applied in braking units of tractors and load lifting mechanisms.
20.	7-9 Al; 1-3 SiO_2; 1-3 asbestos; 0.7-1.0 P; Mn, Si, Ni, Cr and others upto 2, rem.- Fe.	Trade mark as JAF-1; COF is 0.28 in dry friction; brake blocks working without lubrication under medium load conditions..
21.	64- Fe; Cu-10; 3 Asbestos; 8 C; 5 Iron sulfate; 5 SiC; 5 B_4C	Termed as MKV-50A friction material developed in USSR.
22.	9-11 Cu; 7-8 graphite; 2-4 BN; 4-6.5 $BaSO_4$; 5-7 SiC; Bal. Fe. (mass %)	Termed as FMK- series' for antonov aircrafts
23	3 Cu; 1.2 Sn; 3.6 C; 15.0 SiO_2; Bal. Fe (mass%)	Two different iron grade powders of sponge iron powder and fiber-like structure is used.
24.	63 Fe; 4 chilled iron grit; 3 iron silicide; 2.5 PbO; 4.5 Sb; 6 SiC	Aircraft brakes

2.2.3 Carbon-based Friction Materials

This was firstly developed during the year 1960's and early 1970's and they were mainly developed for advanced military and commercial aircraft of multiple rotor and stator brake disks because of their greater mass reduction, lower wear, high temperature stability and a higher reliability under extreme braking conditions. Some are now used on racing cars and other automobiles where weight is significant, performance is challenging, and cost is secondary [4]. These are extensively used in braking devices of railways, tanks and other mechanical engineering products. Friction between rotating and stationary disks causes these composites to heat upto 1500°C (surface temperature can be as high as 3000°C), so good thermal shock resistance is required. In addition to requirements of friction materials mentioned in section 2.3, any braking material must be a good structural material, an efficient heat sink, and have excellent abrasion resistance. Carbon-carbon friction materials are made from carbon fiber (also called graphite fiber) that is bonded with amorphous carbon [RR1, 4, 104]. The friction and wear of C/C materials is exerted by the value of elastic modulus of reinforcing fibers. Therefore, properties of reinforcing fibers and its type on the friction coefficient and wear are carefully noted [115]. However, both COF and wear are practically independent of the material porosity over a relatively broad range of its values (upto 20-25%), while at a porosity over 27%, wear increases. There are basically three methods that are being used for forming the carbon matrix. They are either thermal degradation of a thermosetting resin or a thermoplastic pitch, and the chemical vapor infiltration (CVI) by depositing carbon into a fibrous preform and third is repeated cycles of CVI to densify [63]. Once desired density level is reached, the process of carbonization and graphitization are followed for the composites. Usually the density for aircraft C/C brakes is in the range of 1.7-1.9gm/cm^3 [4,12] C/C composites can offer much higher strength at the same density. The advantages of using C/C for disk brakes are excellent thermal conductivity, adequate and consistent friction coefficients independent of surface temperature(when dry), high thermal capacities, good strength, impact resistance, fatigue resistant, about 60% weight savings compared with metallic brake systems [RR1]. Further, C/C composites are mainly employed in aircraft brakes for three basic reasons. First, the heat capacity of carbon is 2.5 times greater than steel, the kinetic energy from aircraft can be converted into heat and stored in the C/C brake heat sink, and this heat is dissipated slowly to prevent melting of nearby metal structures. Secondly, C/C can provide sufficient friction to bring the aircraft to a smooth, controlled stop under different K.E. conditions including normal and rejected takeoff (RTO). Third C/C composites have high mechanical strength, it is comparable to steel, at high temperatures, and carbon is nearly twice as strong[41,42,66].

Consider the demands made of a braking material in a Boeing 767 aircraft of about 170,000kg. Take-off velocity of about 320km/hr and the resultant kinetic energy at this take-off is 670MJ. Under these extreme braking conditions, this energy must be dissipated in about 30 seconds, by the eight brakes on the aircraft. An aborted take-off is, indeed, the worst case scenario, but then the braking material must be able to meet such requirements. Let us also consider the weight savings while replacing the conventional brakes by the of C/C brakes. In a large aircraft, a multiple stator and rotor arrangement (a sintered high-friction material sliding against a high-temperature steel) weighs about 1100kg whereas C/C brakes (both the stator and rotor are made of carbon/carbon composite) weigh about 700kg, resulting in a weight savings of 400kg .

The major disadvantages are oxidation behavior under higher temperatures, weight loss from oxidation is significant for non protected C/C. oxidation time may start at 450°C. However, in the modern aircrafts it may start beyond 800°C say from 850°C-1200°C. Hence C/C friction materials are protected under those temperatures. Further, it involves costlier raw materials and as well as costly and complex materials processing. However, C/C friction materials are beyond the scope of our investigation [69]

However, organic and carbon-carbon friction materials discussed/included here are just for literature survey/review purposes and therefore they are beyond the scope of the present investigation. The present thesis is purely confined to iron base metallo-ceramic friction materials only and literatures pertaining to iron base are therefore only appropriate.

2.3 REQUIREMENTS AND CHARACTERISTICS OF FRICTION MATERIALS

The basic requirements of friction materials which are used in brakes of different vehicles are similar i.e. they should posses high coefficient of friction (COF), stable COF under wide ranges of speed, pressure and temperature, low wear rate, good thermal conductivity to dissipate heat, good strength to withstand high pressure and temperature rise during braking, negligible wear of the opposing member, fabricabilty and low cost [7,20,47,77]. Therefore, these essential requirements of friction materials are briefly discussed below.

1. Coefficient of friction is essential for efficient braking and hence the vehicle is stopped in time. Higher value is desirable.
2. The coefficient of friction may vary with rise in temperature, speed and applied pressure of the moving surface and kept constant under different climatic conditions encountered in service. Stability of the coefficient of friction over the temperature range is known as fade resistance and hence brake fade should as minimum as possible.
3. Good thermal conductivity results in higher resistance to heat flow and hence it solves problems due to higher temperature generation at the braking surface; conduction of the heat towards the interior tends to minimize warpage of pressure plates, or other parts of the assembly. This may results in faster heat dissipation.
4. Good strength levels; where the friction materials are subjected to complex state of stresses in which compressive, shear, tensile, fatigue, centrifugal forces or any other stresses encountered during service. Hence, the friction materials should have good mechanical strength to withstand these stresses.
5. Good wear resistance: This decides the life of the component. Particularly in this property that powder metallurgy products have excelled over other materials. Variation in composition has a considerable effect on the property.
6. Further, friction materials should also possess other properties like resistance to score, gall & ablation, proper energy capacity, proper engagement characteristics, good thermal properties, high heat capacity, adequate durability, fabricability or formability, negligible wear of the opposing member and safe to use.
7. Free from environmental issues and
8. Minimum cost.

2.4 SELECTION AND APPLICATIONS OF FRICTION MATERIALS

Selecting the perfect brake lining for a heavy-duty brake application is very important to ensure that the vehicle and the load type can be stopped. The perfect brake lining will need to have an appropriate coefficient of friction that will remain constant for the life of the vehicle under all operating conditions of speed, braking pressure, vehicle load, temperature, and humidity. The perfect lining would not score or wear the drum, would not be subject to vibration and noise, would wear slowly, and would not have an offensive odor while applying. The selection of lining is a balance of all these factors and will depend on the service that the brake will be subjected to during its useful life [SAE, brake bible, 40].

Lining fade is the inability of friction material to maintain its normal effectiveness when it is forced to work at elevated temperatures. This is called "heat fade" and is the result of reduced coefficient of friction as the brake temperatures increase. Fade resistance is another feature of high performance pads. Brake fade can be caused by the out-gassing of the pad that creates a boundary layer of gases between the pad and rotor. Recovery is the rate at which the lining returns to its original friction level after having been exposed to a fade condition.

Recovery is typed as Normal recovery, slow recovery, or over recovery. Most desired is normal recovery in that it will return to its pre-fade friction level with very little temperature reduction. Other, less-expensive friction may require almost returning to ambient temperatures before braking again.

Speed Sensitivity is the measure of a lining's ability to maintain its coefficient of friction at different rubbing speeds. The friction level of most friction materials is reduced with increasing speed.

Brake Noise is a vibration in the brake system whose frequency is in the normal hearing range. Low noise levels leads to better engagement characteristics.

Brake Wear is a cost of operation consideration. The best lining will have minimum wear at low to normal operating temperatures and only a modest increase in wear rate at elevated operating temperatures. All of these mentioned terms are to be considered for selection and type of application in an automobiles or aircrafts [SAE]

2.5 FACTORS AFFECTING PROPERTIES OF FRICTION MATERIALS

The following factors which affect the friction and wear of brake friction materials directly or indirectly. [SAE]

1. Brake design; disk, drum stator and rotor brake disks are designed in such a way that the fins, or vent holes provided in disk of the rotating part which may help in faster cooling, faster heat dissipation or unless it may not be, and further if they make more or less contact area with the rotating counterpart. Hence a careful design is required
2. Disk/ Drum and Lining materials composition: Lining materials constituents should not contain very hard or very high wear resistance material and it may lead to wear out or score the drum/disk material since it may not be frequently changed rather than brake pad/lining material.
3. Higher operating temperatures may directly affect friction of brake friction materials and may lead to fade (decrease in coefficient of friction with rise in temperature) so the friction material lose its stability.
4. Rubbing speed, if low or high it naturally affects wear of brake materials.
5. Higher contact pressure leads to lesser stopping time, friction materials wears fast at lower contact pressure makes lesser friction and results in lesser stopping distance. Hence application of pressure on the brake elements inversely affects its properties.
6. Exposure to environmental contaminants such as road dust, local rust debris, moisture, etc. may also affect the friction and wear of friction materials. Now a days, asbestos is banned since it penetrates into human lungs and causes cancer.
7. Prior usage history and resulting surface conditions may indirectly affect friction and wear properties [SAE].

2.6 Steel backing/carrier plate

Friction materials are usually of a high metal to non-metal ratio; it is not possible to produce friction facings of sufficient strength, to be entirely self supporting. They are too weak when used as load carrying members; therefore require the support of a steel backing plates. Backing plates can play a distinct role in creating a positive pedal feel and stopping ability. The backing plate creates a foundation for the friction material that must be stiff and stable. If a backing plate is flexing, the friction material is not in full contact with the rotor. This can cause longer stops, a softer brake pedal, and it increases the potential for unwanted noise. High-performance backing plates might use thicker and better quality steel. The composition and physical properties of the steel are of considerable importance. In compacting and sintering manufacturing process, steel backing plates of the same shape and contour as that of the friction material element are nickel plated by sulphamate process and are diffusion bonded under pressure and temperature, during sintering operation itself. The selection of suitable steel for use as a back plate material depends on the stresses, brake torque limit and maximum temperature rise encountered during high energy braking. Usually, Plain, Low Carbon Steels are used for low-medium energy brake applications. Stabilized high strength low alloy steels of high hardenability with good thermal fatigue properties are used for high energy brake applications. However, HSLA or Ultra HSLA steels are widely used as backing plates for these metallic friction materials due of their higher strength, higher hardenability, and thermal shock resistance etc. Further, addition of 1% Si for increased hardenability by means of special processes and special heat treatment process may also employed [20, 24].

2.6.1 Shapes and Sizes

The friction materials are manufacturing in the form of discs, sectorial, radial, linings, and steel frame on either single or double sided layer of sintered friction materials.

Choosing a right composition or new formulations is the most important factor in designing of modern friction materials. Determined by the endeavor to meet the two principal requirements namely, rise in the coefficient of friction and increases in the wear resistance of the material.

The friction elements fitted with friction product are manufactures in the form of discs, sectoral linings and blocks of different shapes, as a rule, there design consist of a load-bearing steel frame lined with a single or double sided layer of a sintered friction materials. The sintered material consists of the base metal, the components improving the mechanical and thermo physical properties of the base, and the components improving the resistance of the material to seizing and the coefficient of friction of the pair[110].

Disc shaped elements are mainly used in the friction assemblies working with lubrication. In order to ensure the required lubricant circulation between the friction surfaces, grooves of different shapes are made on the disc. They ensure supply of cooling oil, fast removal of the excess oil from the rubbing surfaces at the instance of starting, and trapping and removing the wear products. In the friction assemblies working under dry friction conditions (brakes, clutches, etc.) besides the dis-shaped working elements, one makes use of the components in the form of cones, strips, blocks, etc[114].

Most frequently, the friction products are manufactured in circular form or as segments (mainly reinforce with steel frames) and are bonded to the load bearing steel structures. The Fe based friction elements are usually produced in the form of linings with cup shaped reinforcing iron strips. Such linings are bonded in pairs to a disc shaped steel support usually having slots for avoiding warping due to thermal stresses originating during operation. Such a design of brake pads is recommended for heavy duty application for example in aircraft's. The brittleness of the friction product makes it necessary to bond it to a reinforcing steel frame by sintering. Sintered friction elements work in a friction assembly in pair with an abradant. Generally these abradants are made of steel [7,20].

2.7 Counterpart (drum/disc) material:

Grey Cast Iron (GCI) is the dominant material for use in brake drums/discs for the past history and is still used as counterpart material in most of the automobiles [8, 9, 13, RR1]. The excellent wear resistance of GCI under dry sliding conditions is due to the presence of graphite flakes in the microstructure (fig), a pearlitic matrix and type A randomly distributed flake graphite of medium size 4-5 gives the optimum performance [146, ASTM A247]. Fine graphite flakes result in low wear of the rotor and friction material/lining [4]. The effect of frictional characteristics with regards to gray iron microstructures and the correlation between the relative amounts of phases on the gray iron were made by changing the carbon equivalent and cooling speed of melts. It was found that the amount of free ferrite (and pearlite) on the gray iron disk did not affect the COF, with higher graphite area percentage, COF got increased on the gray iron disk and it was common for steel-containing linings such as semi-metallic type friction material. Fade resistance was improved with higher graphite content on the gray iron disks [15]

Under braking conditions, graphite in the microstructure smears out on to the sliding surface and forms a surface layer which reduces metal to metal contact and thus improves coefficient of friction (COF), also provides frictional stability to the brake pad material. It has good thermal conductivity due to the graphite phase, which is an excellent thermal conductor and graphite flakes are interconnected and disposed in the form of plates which results in faster heat dissipation [16].

Further, addition of alloying elements like molybedenum, silicon, neobium, titanium etc. and high carbon enhances mechanical, thermal properties and as well as frictional properties. Such kinds of combinations are introduced for passenger car and heavy truck brake rotors [16,113]. Addition of phosphorous improves wear resistance, seizure resistance and scuffing resistance under mild to severe conditions. Grey cast iron with 1.2% phosphorous content was standardized for railway brake blocks in France and U.K.. Influences of different graphite morphologies in cast irons with phosphorous addition of 0.7% are studied and suggested phosphorous compacted graphite cast iron is most suitable material due to combinational effect of highest friction coefficient and lowest wear loss as compared with other morphological phases.[5]

There is a limitiation of using grey cast iron brake disks i.e. some times, grey cast iron disks will corrode and/or surface oxidation takes place after service period of under prolonged time. This surface oxidation may result in high wear for grey cast iron [91,144]. However, it was seldom found and not only corrosion resistance of cast iron also its tribological characteristics can also be improved by means of different coating. Three different coating on Ni-base, Co-base and Fe-base were deposited using high-velocity oxy-fuel thermal spray (HVOF) technique [90]. These coating had better corrosion resistance and low wear rates. Slight decrease in COF but frictional stability was found for these coating. However, coating business would not give satisfactory response under severe sliding conditions though the friction was high [163].

In the last several decades, a great deal of effort has been devoted to improve the friction performance of brake rotors (or drums). The effort includes the development of non-ferrous materials such as copper alloys, aluminum metal matrix composites (Al-MMCs), and carbon composites as new candidates. However, gray cast iron is mainly used for automotive brake rotors due to its excellent damping capacity, high thermal conductivity, easy fabrication, and, in particular, low cost [16].

Aluminium Metal Matrix Composites (Al—MMCs) are latest brake disk materials and competitor to grey cast iron. Advantages of Al-MMCs with regards to brakes are low weight, high theraml conductivity, ~~low~~ high thermal expansion, high specific strength, hardness, wear resistance, and improved mechanical properties etc. Many automobile manufacturers' put their efforts on the replacement of cast iron by Al-MMCs for brake applications throughout the world [48,148,149]. Research on this material are growing for the application of brakes are interested due to of its better frictional properties, weight savings, enhanced load-bearing capacity due to addition of ceramics etc [136].

The sliding wear of Al-MMC against an organic and three semi-metallic brake pad materials shows its suitability at higher speeds and loads, Al-MMCs have improved frictional characteristics as compared to cast iron discs; it proves the exact fit of rotor disc with the pad material. Organic brake materials are the exact fit or best suited for Al-MMCs than the semi-metallic brake pad materials. Wear rate in organic friction material was found lower due to the formation of graphite-rich transfer layer whereas in semi-metallic friction material higher wear rate was obtained because of the abrasive action of the metallic chips or fibres present in the friction material [56,140].

Altering type of reinforcement (SiC, B_4C etc), its amount, its type and so on variety of Al-MMCs are developed and its tribological properties are evaluated against different types of organic friction material [10,131]..The NAO type friction materials with different metal fibers addition sliding under two different counterdisks namely grey cast iron and Al-MMCs were investigated. Al-MMCs had higher COF and lead to better frictional performance. However, the wear trend is same for both types of disks [53].

The physical properties and microstructures of grey cast iron and Al-MMCs are mentioned below (shown in Table 2.6) where graphite flakes in former and composite phase in latter are visible [53].

Table 2.6. Physical properties of gray cast iron and Al-MMC

Physical properties	Grey Cast Iron	A 356 Al alloy + 30% SiC
Density ($\times 10^3$ kg/m^3)	7.2	2.85
Specific heat (J/g K)	0.498	1.027
Thermal conductivity (W/m K)	47.3	148.1
Coefficient of thermal expansion at 50–100°C (10^{-6} K^{-1})	12.6	17.4
Hardness (kg/mm^2)	80 ± 10	98.4 ± 2.4

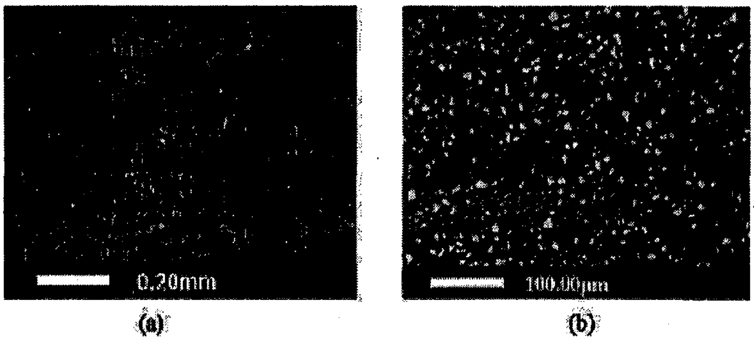


Fig.2.1. Microstructures of two counterdisks (a) gray cast iron; (b) Al-MMC.

2.8 MANUFACTURING TECHNOLOGIES FOR FRICTION MATERIALS

Conventional manufacturing technology of making composite friction materials are briefly described here. However, methods pertaining to its modifications, alterations, improvements etc. from the existing technique and the new solutions or production techniques for making such materials are not included/covered here.

2.8.1 Manufacturing technique for Organic type Friction Material

Steps involved are as follows

1. Dry mixing
2. Hot pressing
3. Post curing
4. Finishing

Dry Mixing: Mixing was carried in plough shear-type mixer to ensure the macroscopic homogeneity for the desired mixing using a chopper speed of 3000rpm. The mixing sequence involves feeding of all the powdered ingredients, then the metallic additives, inorganic and organic fibers. Glass fibers were added last to minimize fiber damage and to open up the strands to provide mechanical isotropy to the mixture. The mixing duration will vary according to powder characteristics, type, size etc. but here it was 5min. the resin-based organic friction material was prepared by firstly, dry mixing of appropriate amount of different powders such as phenolic resin powder, copper powder, steel wool, and so on.

Hot pressing: The mixture was then placed into a four-cavity mould supported by the adhesive-coated back plats. Each cavity was filled with constant quantitye of the mixture and then heat cured in a compression-moulding machine at different temperatures under a pressure of Mpa for 10-12 min. Thus dry mixed powder mixture was hot pressed at 150°C-250°C for 10-30 minutes under a pressure of 0.5-15 MPa. The temperature, time and pressure will vary according to materials (or ingredients) added, its bonding and other characteristics and shall be carefully chosen.

Post curing: There intermittent breathings were also allowed during the initiation of curing to expel volatiles. The pads were then removed and were then post-cured in an oven at 100°C-350°C for 1-10 hrs. to relieve the residual stresses in the sample pads.

Finishing: Finally, finishing operation was done by grinding, sizing etc. Thus surfaces of the pads were then polished with a grinding wheel to attain the desired thickness and to remove the resinous skin [13,53,54].

The above said four steps are same for NAO type whereas for semi-metallic type friction materials only hot pressing & curing temperature and time are slightly varied.

2.8.2 Manufacturing technique for sintered friction materials

The metal powders namely matrix which provides the basic strength, must have a sintering activity which is as high as possible. Because of addition of non metallic powder components which are added and which do not take much action in sintering process. They should also form a sufficiently stable structure. For this reason spongy and dendirtic powders with particle size below 150um are preferred since they have high surface area. Spongy iron powders which are produced by reduction of oxides are mainly used for Iron based friction material. For copper base material electrolytic powder is used. Further, copper alloys like brass, bronze and Ti are also used since they forms transient liquid phase during sintering. Mixing should be done carefully.

Friction materials are composite materials consisting of metallic and nonmetallic constituents. Their manufacturing is not possible by the conventional route in which miscibility plays main role of different constituents in the liquid state. This limitation can be overcome by using powder metallurgy technique in which different powders can be mixed irrespective of their miscibility limitations. The composition and final properties can be controlled by powder metallurgy route as different metallic and nonmetallic constituents otherwise immiscible can be properly blended in powder form to develop properties desired.

In sintering technique following are the basic steps in the production technology of friction components.

1. Preparation of powders and the load bearing steel frames,
2. Blending of the components,
3. Compaction of the performs of friction components,
4. Sintering the products under pressure in a protective atmosphere,
5. Finishing operations (polishing, groove cutting etc.) [7]

The finishing operation will be same for the elements either prepared by sintering technique or hot forging technique.

All powders are screened through a sieve of required mesh size before mixing since many of the powders used tend to agglomerate and this is most undesirable. Mostly fine size powders are preferred to achieve uniformly distributed microstructures. Mixing can be carried out in many ways. Generally this is carried out in conventional types equipment such as double cone or V- cone blenders or ribbon type mixers. But using pot mill mixer is very much beneficial because in the mixing itself we can achieve mechanical alloying of different elements.[2,3]

Compaction is done in a large hydraulic press. Iron based materials are compacted in the pressure range of 400 to 800 MPa. Copper based products the compacted pressure in the range of 150 to 300 MPa.

Sintering is carried out in a number of ways like pressure-less sintering, sintering under pressure, liquid phase sintering, electric discharge and electric arc sintering, double sintering with intermediate repressing, sintering in conjunction with supplementary heat treatment, etc. The backing plate can be joined with friction element either by brazing or welding, or by sintering the two components together under pressure.

The sintering temperature of the copper based components is usually in the 650°C to 900°C range and in the case of the iron based ones; it is the 1030°C to 1070°C. The sintering time of the friction components depends on the chemical composition of the material and the required final density. In the case of the copper-based components it varies from 15 to 20 minutes up to 4 hours, and in case of iron based components, it amounts to 3 to 4 hours. Sometimes, raising the sintering time and temperature increases the wear of iron-phosphorous base materials and slight increment in friction; pressure applied during sintering has no effect upon the wear of the material but results in higher coefficient of friction [133].

During sintering, the stack of disc is subjected to a load using hydraulic, pneumatic, or mechanical devices. For copper base products, the pressure amounts to 0.5 to 1.0 Mpa and for iron-base components it amounts to 1.0 to 1.5Mpa. The sintering operation is carried out in a protective atmosphere under pressure in conveyer furnaces or in special continuous furnaces in which the shaft is positioned vertically so that the pressure can be applied on the pile of discs.

The finishing operation may include sizing or coining, repressing, lathe turning, or polishing, groove making, shaping conical or cylindrical by forging etc. Iron base materials can be heat treated for improving the properties of the layer. Annealing is carried out at 900°C for decreasing the hardness of the friction layer. Quench hardening is conducted from a temperature 900°C to 950°C in oil or hot water followed by tempering 500°C

Fig. 2.2 and 2.3 are the illustrative flowcharts for manufacture of copper and iron based brake pads respectively employing sintering technology.

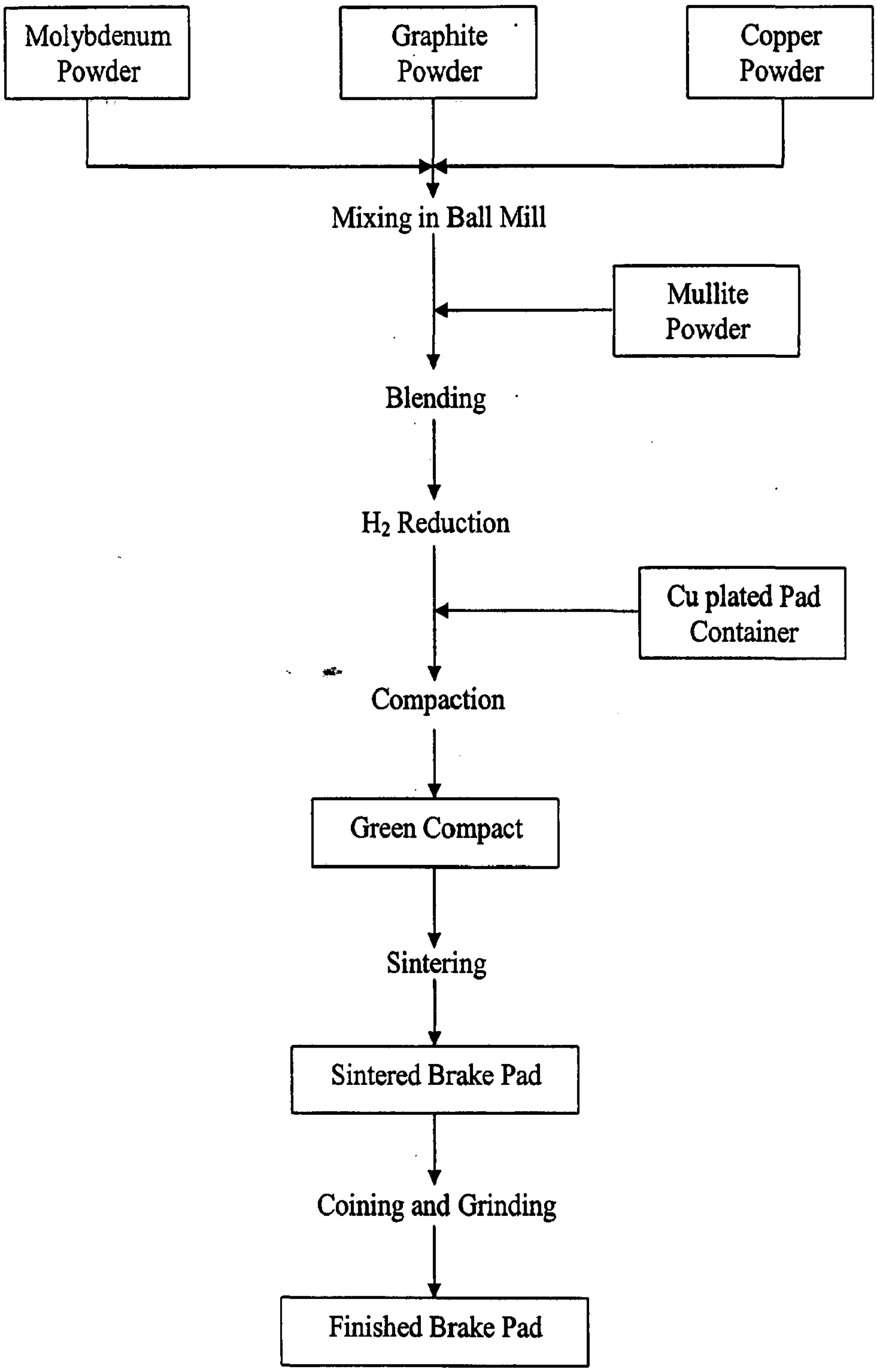


Fig. 2.2 P/M process for the manufacture of copper based brake pad [25]

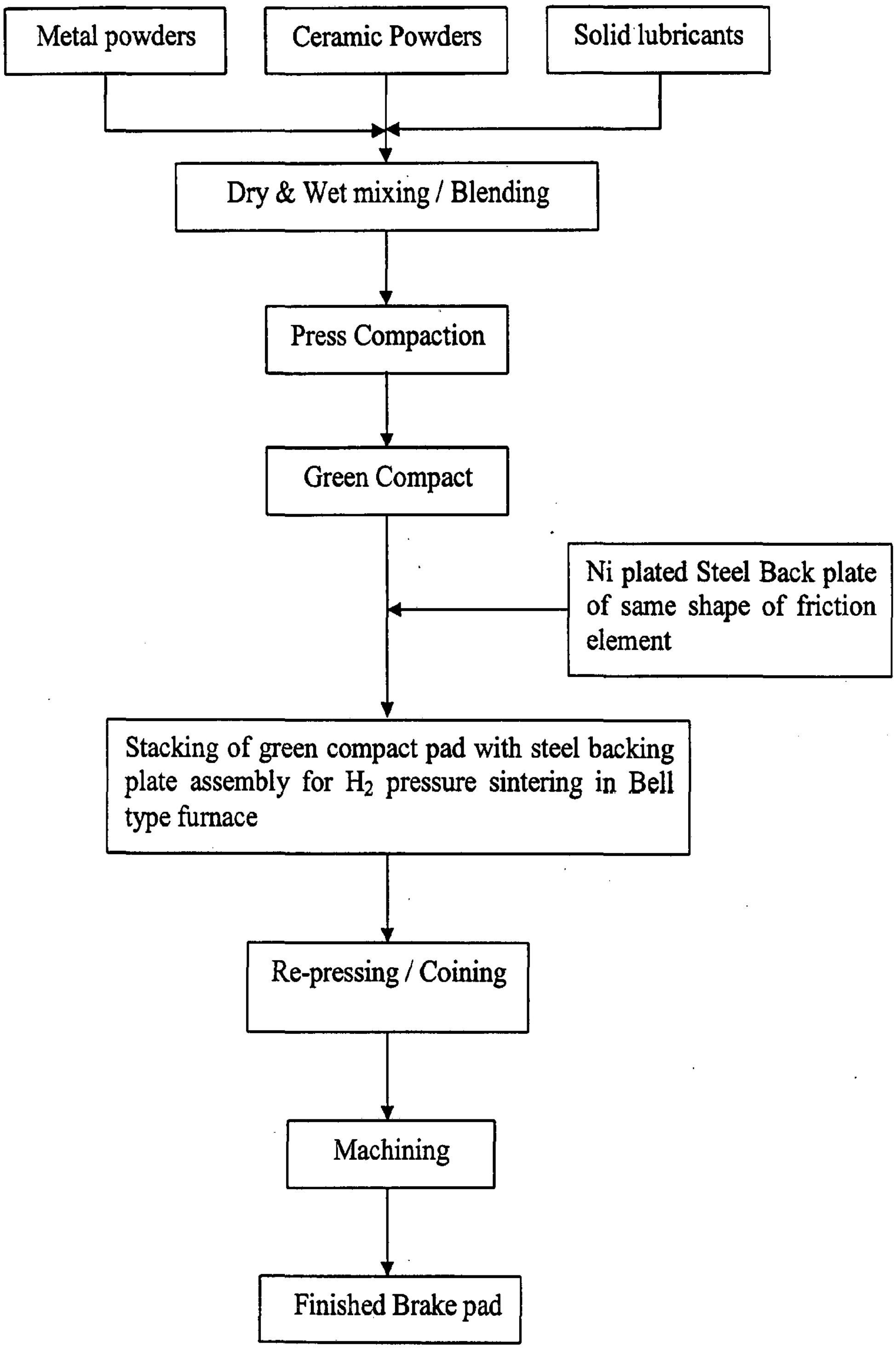


Fig. 2.3 P/M process for the manufacture of iron based brake pad [25]

2.8.3. Manufacturing Technique of Carbon/Carbon Friction Materials

These materials are also produced by compacting and sintering route but containing predominantly graphite based powder. The friction and mating part both are graphite based and are essentially lubricating type of materials with very low coefficient of friction. These are excellent friction materials for heavy duty applications due to high temperature stability of ceramic graphite. However, this type of friction materials is beyond our scope of the present investigation [RR1].

2.9 CHARACTERIZATION OF FRICTION MATERIALS

The different characteristics of friction materials namely physical, frictional, metallurgical and thermal properties are briefly described below.

2.9.1 PHYSICAL PROPERTIES

Apart from the values which directly concern the

metal facings there are other physical characteristics which influence their performance of a facing in service and are therefore taken into consideration at the design stage Some of these shown in Table 2.7 below. The heat resistance of these materials, as shown by the softening temperatures, is very much higher than for conventional organic facings, giving greater stability at high running temperatures and freedom from fade [20].

Table 2.7 Physical characteristics of sintered friction facings

Property	Bronze	Bronze-graphite	Bronze-ceramic	**Iron**	**Iron-graphite**	**Iron-ceramic**
Heat capacity, cals/gm/°C	0.102	0.102	0.118	0.121	0.119	0.119
Thermal conductivity, cals/sec/sq. cm/cm/°C	0.0340	0.0350	0.0300	0.0295	0.0300	0.0284
Softening temperature, °C	845	845	870	1180	1100	1180
Compressive crush strength, lb/in^2	12100	22700	7620	64800	22100	25750
Transverse rupture, lb/in^2	9200	11800	7300	41400	14300	20800

2.9.2 FRICTIONAL PROPERTIES

The coefficient of friction is probably the most important single property of a facing material, but its application to the design of working assemblies requires careful interpretation. The data quoted in the Table 2.8 below are determined under standardized conditions [1,20]. A new specially designed equipment for evaluating tribological performance of ceramic-based composites for braking applications were developed [69, 122] As the final conclusion from the author, if the speed increases wear rate of the sintered iron increases [49,50,126]

Table 2.8 Properties of some sintered friction materials

Type	Grade No	Coefficient of friction				Permissible facing pressure		Typical applications
		Dynamic		Static				
		Oil	Dry	Oil	Dry	Oil, psi	Dry, lb/in²	
Bronze	Durasint S1	0.08	0.31	0.16	0.29	75-600	50-300	Main drive, steering & powdershift clutches
Bronze-ceramic	Durasint S14	-	0.35	-	0.48	-	50-250	Heavy duty dry industrial clutches
Bronze-graphite	Durasint S73	-	0.21	-	0.23	-	30-300	Torque limiting and safety clutches (dry)
Bronze	Ferodo SM1	0.07	0.31	0.11	0.37	100-500	50-300	Main drive, steering & powdershift clutches
Bronze	Ferodo SM6	0.09	-	0.11	-	100-500	-	Automatic transmission, power and steering clutches in oil
Iron-ceramic	Durasint S92	-	0.39	-	0.45	-	30-500	Disc brakes and dry main drive clutches
Iron-graphite	Durasint S210	-	0.30	-	0.30	-	25-150	Dry main drive and steering clutches

2.9.2.1 Calculations for Sub-scale dynamometer test parameters [147, MIL D 5013]

<u>Input parameters</u>

1. **Energy absorbed per brake stop (E_s):**

   The kinetic energy absorbed per stop (E_S) and the resulting heat produced in the friction material is the major factor influencing brake service life.

   The following formulae are used to calculate the kinetic energy absorbed by the brake per stop (Es).

   (a) For a caliper brake, the kinetic energy absorbed by the brake per stop is given by,

   $$Es = WR^2N^2 / 5872,$$

   Where E_s = energy absorbed per stop, ft. lb (N.m);

   W = weight of body stopped,

   R =radius of gyration, ft (m);

   N = number of turns to stop.

   Some times, the value of inertia (WR^2) is also mentioned by the machine builder.

   (b)The kinetic energy absorbed is also calculated by,

   $$Es = \frac{1}{2} I \omega^2$$

   Where I = Inertia, (provided by the machine builder)

   ω = angular velocity = $2\pi N/60$

   (c) Kinetic Energy = CWV^2, ftlb, according to [MIL W 5013]

   Where C = 0.032 for nose wheel of aeroplanes and for all helicopters

   C = 0.026 for tail wheel airplanes

   W = Weight of aircraft in pounds under the loading conditions

   V = Power-off stalling speed of the aircraft in mph at the weight W

   A speed of 40 mph shall be used for helicopters, unless otherwise specified.

2. **Speed, Brake force / brake pressure:**

The rotational speed of tire is the same as that of the brake where it is fitted. Thus, the speed (rpm) can be estimated from the vehicle speed at the time of application of brakes. For example, if the landing speed of aircraft is 280km/hr, brakes are applied say at 240km/hr, correspondingly the speed in rpm is ((240x1000)/60)/πD, where D is wheel diameter for the vehicle.

Brake force / brake pressure is strongly dependent on vehicle design specifications; the number of brake cylinders, stroke length, and diameter of piston will determine the brake force/pressures.

The kinetic energy, rotational speed, brake force/pressure as estimated above, are set as the testing input parameters for sub scale inertia dynamometer test of the brake pad material/element.

<u>Output parameters</u> [147]

1. **The brake torque,**

$$T = 5250PK/s, \text{ lb.ft (N. m)}$$

Where, T = brake torque which the brake handles,

P = hp absorbed (kw),

K = a safety factor between 1.5 and 5 as the duty cycle of the brake increases,

s = brake rotation speed, rpm.

For example, if P= 5 kw, K=5, s=3600rpm then

T = 5250 (5) (5) /3600 = 36.46 lb.ft (49.4 N.m)

2. **The average brake torque required to stop the vehicle load,**

$$T_a = Wk^2n / (308t), \text{ lb ft}$$

Where, T_a = average torque required to stop the load,

Wk^2 = Inertia, load including brake rotating member, lb.ft^2 (kgm^2),

W = weight of body stopped, lb (kg),

k = radius of gyration, ft (m),

n = shaft speed prior to braking, rpm,

t = required or desired stopping time, s,

For example, T_a = (200) (1800) / [308 (40)] = 29.2 lb.ft. or 351 lb.in (39.7 Nm)

A service factor varying from 1.0 to 4.0 is usually applied to the average torque to ensure that the brake is of sufficient size for the load.

Applying a service factor of 1.5 for this brake yields the required capacity = 1.5(351) = 526 in.lb. (59.4N.m)

3. **No. of Revolutions prior to stopping,** run down revolutions R_s = (tXn) / 120

   Where, R_s = number of revolutions prior to stopping;

   Other symbols as given above;

   For example, R_s = (40) (1800) / 120 = 600 r.

4. **Stopping distance,**

   $$t = (2)(\pi)(k)(R_s)$$, t and k both are either m or in ft.

5. **The heat the brake must dissipate,**

   $$H = 1.7FWk^2 (n / 100)^2, \text{ ft.lb / min}$$

Where, H = heat generated at friction surfaces, ft.lb / min

F = number of duty cycles per minute,

Other symbols are as described earlier,

For example, H = 1.7 (1) (200) $(1800/100)^2$ = 110200 ft.lb/min. (2490.2 N.m/s)

6. **Required radiating area of the brake,**

   $$A = 42.4 \text{ hpF} / K$$

   Where, A = required brake radiating area, in^2,

   hp = power absorbed by the brakes,

   F = brake load factor = operating portion of use cycle,

   K = constant = Ct_r, where C = radiating factor (a value for different temperature rise); t_r = brake temperature rise, ^{o}F; Assume C = 0.00083 for $t_r = 300^{o}F$;

   For example, A = 42.4 (20) (0.5) / [(0.00083) (300)] = 1702 in^2 (10980.6 cm^2)

7. **Heat produced in the brake**

The heat produced in the brake by the energy absorbed is found from $H = E_s$ / 778.3,

Where H = heat absorbed per stop, Btu (kJ)

8. **The temperature rise of the brake** is

$$T_r = H / 0.12W,$$

Where T_r = temperature rise per stop, °F (°C)

9. **Average disk temperature per stop,**

$$T_d = HT_a / 2.25A,$$

Where T_d = disk temperature per stop °F (°C);

T_a = average disk temperature ;

A = disk surface area, ft^2 (m^2),

In this expression the factor 2.25 is the cooling index used when the disk is stationary during cooling- the usual condition following an emergency stop. However, if the disk rotates during cooling, a factor of 4.5 should be used instead.

10. **The peak temperature of the brake,**

$$T_p = T_d + 0.5T_r;$$

Where, the temperatures are in either °F or (°C).

11. **The brake service life** (L), in number of stops for a brake, L = (1.98 x 106)ZY / E_s, where the service factor, Z, is found from standard curves available from brake manufacturers and friction-material suppliers; Y = total friction material volume, in^3 (cm^3)

2.9.3 METALLURGICAL PROPERTIES

The microstructures as shown in Fig. 2.4 depict the non-metal components namely SiO_2 and C encompassed by the metal matrix. When observing the friction layer-steel base interface, the formation of a solid solution of copper and nickel is observed and at some places the formation of a solid solution of copper and nickel with the iron from the matrix was also noticed. It is also registered that the thickness of the intermediary layer is restricted. A deeper diffusion of the solder into the steel base, bearing in mind the thickness of the steel base 1.2 mm., would weaken the mechanical properties of the steel base. On the other hand, deeper penetration of the solder into the friction layer would cause considerable changes in the structure of the friction material. This would result in a change in the mechanical and friction properties in that part of the friction layer and would completely reduce the expected life of the friction pads.[105,108]

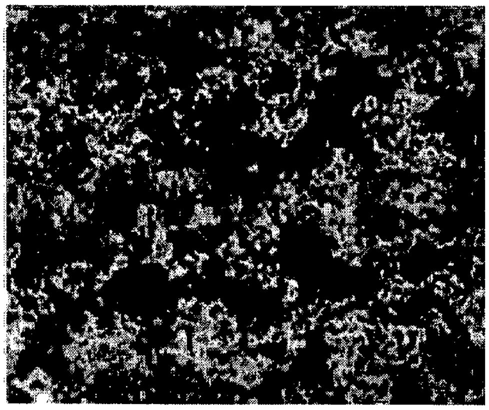


Fig.2.4 Microstructure of sintered iron base friction material

2.9.4 THERMAL PROPERTIES

The influence of the temperature on the wear and friction of some brake pads has been described under thermal characteristics. During braking operations, a temperature in the order of 1000°C has occasionally observed. Hence there is a need to study and understanding of the chemical-physical decomposition processes that occur when a friction material is exposed to severe thermal conditions. Differential thermal analysis (DTA), thermo gravimetric analysis (TG), and evolved gas analysis (EGA) have been used to study their effects. By means of the combined use of DTA and TG thermal characteristics are studied for the investigation of brake pad and its wear residues produced during the long service of a largely used automobile are carried out in order to study the chemical and physical changes suffered by the combination of heat and mechanical actions and to estimate the brake pad contact surface temperature. [57,73,121]

2.10 REVIEW OF PATENTED LITERATURE ON FRICTION MATERIALS

This review on patents purely confines to sintered iron base friction materials/brake elements only. However, in the present investigation, Hot Powder Forging process and the product is first time developed and patented literatures is not available elsewhere.

US Patent 7094473 comprise of wear resistant iron based sintered contact material applied to sealing material or like for use in rotating parts of construction machines etc. with a view to achieving improved seizure resistance and preventing abnormal wear to attain increased wear. It is composed of sintered contact material sintered bonded to a backing plate and is applicable to floating seals used for encapsulation of lubricating oil, thrust washers for use in the joint ofa work implement, and end faces of a crawler track bushing in a chassis.

US Patent 6439353 cited are aircraft wheeling segments of stator brake disks and rotor brake disks. The pads are made of sintered metal and the rotor brake disks are made of ceramic or ceramic composite. This patent mainly describes on brake designs aspects rather the technique of producing the friction materials

US Patent 6143051 describes a method of preparing a friction material, where in a mixture of iron fibers, iron particles, graphite particles and metallic binder is cold pressed at a pressure of at least 100 MPa to form compacts which are sintered at 800-1140 ^{0}C for a long time. It does not however, include ceramics components which are needed for heavy duty brake elements.

US patent 6110268 describes a method for manufacturing a fiber reinforced ceramic brake member/ brake lining where a mixture of carbon particles, metal particles with polymer binding agent, silicon carbide or titanium carbide particles as abradants and solid lubricants are cold pressed into green compacts and then sintered in vacuum or protective atmosphere.

US patent 4576872 describes a method of manufacturing a friction element which beds-in quickly and which has a 'feel' similar to a resin based element where the powdered metallic friction material is subjected to resistance sintering, so as to produce a a sintered substrate and un-sintered or partly sintered surface layer.

US Patent 4415363 comprises friction lining material for a cast iron mating surface. The friction materials lining layer has iron as base and reacts with its alloys and hold substantially equal weight percentages of graphite and coke in a fixed position. The friction layer has constant wear rate upto 300°C and linear wear rate between 300-500°C. This technique also manufactured by compacting and sintering route only

US Patent 4391641 claims an iron base, sintered powder metal friction material for railroad braking use, formed by solid phase sintering and consisting essentially of, by volume, 10-70% carbon in the form of coke or graphite; 0-2.5% sulfur, 0-10% alumina; 9-40% of a metal powder additives of copper, manganese, ferrochrome and chrome carbide compounds and the balanced iron. Two dynamometer test procedures UIC (European) and AAR (USA) are used for determination of friction characteristics. The technology and the materials so developed exhibit low metal pickup. Here, the application is narrow and only suitable for railways and also bonding between friction materials and backing plate is not provided

US Patent 4350530 describes Fe-based sintered alloy for friction materials containing 3 to 15% of bismuth of Bi-Pb alloy containing 5 to 100%bismuth, provides stable friction coefficient over wide ranges of temperature zones with excellent wear resistance. It states that Bi or Bi-Pb alloy can produce desired lubricity for various service temperature zones. Two stage sintering is recommended where the bonding between friction material and the backing plate is due to second stage pressure sintering.

US Patent 4311524 comprises sintered iron based friction materials and limits the application in friction devices operating under liquid lubrication conditions at medium performance modes; listed composition of the friction materials fades under severe energy levels and are not suitable for heavy duty applications. The patent does not describe the materials for use in dry operating conditions. It also does not spell about the bonding between friction elements and backing plate.

US patent 4280935 describes 20-60 wt.% of a high carbon iron powder instead of a ceramic powder in the conventional friction material and thus improving in wear resistance at high temperature by further adding 0.5-10.5wt. % of antimony trioxide as a flame retarding material.

US patent 4278153 describes friction modules with the grid reinforcement in either a mold or with in the brake disc cup that too using the sintering in brake manufacturing.

US patent 3341931 describes a method of producing railroad brake shoe, in the form of a sintered body of powdered metal including iron and graphite, by subjecting the sintered body to repeated pressure at elevated temperature.

US patents as sited above do not cover the joining of friction material with that of baking plate and the perfect ness of joint or the joint strength. Further, all these patents comprise of compacting and sintering in manufacturing a brake element, which is not involved in the present method of manufacturing of brake elements.

IP Patent application No.2420/DEL/2006 comprise of a novel low cost process for manufacturing Cermet friction materials/ composites/brake elements using hot powder forging with built in backing plate for medium to heavy-duty applications.

IP Patent application No.2421/DEL/2006 Development of hot powder forged iron based cermet brakes with built in backing plate and the new friction material there of, suitable for use in light to heavy duty automobiles, rails and aircrafts.

IP 198715/2002 deals with the preparation of metal-ceramic (Fe-based and Cu-based) friction materials with cup type or flat plate type steel baking frames that too following compacting and sintering route only. The baking plate is joined by pressure sintering.

Chapter 3

FORMULATION OF PROBLEM

3.1 SCOPE OF THE PRESENT THESIS

The existing or presently practiced manufacturing technology available world over for Metallo-Ceramic brake friction materials is conventional P/M. i.e. compacting and sintering technique. Friction materials so produced have much more wear resistance, better frictional and other properties such as thermal shock resistance, fatigue strength, shear strength, compressive strength etc.

The compacting and sintering is the only technique followed till now for manufacturing iron base friction materials and there is no other alternate technology available for manufacturing the same. Minor modifications such as double sintering, repressing and pressure sintering etc. are there but have not contributed to significantly enhance performance parameters of such friction materials.

The scope of the present investigation is that developing new friction materials by a new technology called 'Hot Powder Forging'. The hot powder forging significantly differs from the existing technique where simultaneous application of pressure and temperature for a short period of time causes material to severely deform. Thus the purpose of compacting and sintering is fulfilled in a single step only. Further, the brake elements are developed with built-in backing plates, which have better bonding with the friction material layer on it. The main motto of the present investigation is to adopt this technique for manufacturing iron base friction products for brake application.

The 'Hot Powder Forging' technique used in the present investigation has already been used for developing iron phosphorous based soft magnetic materials, ODS superalloys in the past four to five years in the department and same were patented earlier.. However, the technique in the present case differs from the above mentioned past material processing technique where the steel capsule cover after forging is removed by machining to characterize the inner part of the material. In the present work, the capsule cover becomes part of brake pad material i.e. it serves as backing plate. This is likely to produce better bonding between backing plate and friction material in comparison to compacting and sintering technique.

3.2 LIMITATIONS OF THE EXISTING TECHNOLOGY

The compacting and sintering technology for the manufacture of brake pads involves complicated process variables, complicated processing steps, and also it has its own limitations. **Kolpakov Ya V. et al** [74] has critically mentioned some problems in the manufacturing iron base friction material and suggested few modifications from the earlier practiced process based on sintering technique. These limitations are summarized as follows:-

1. Bonding of metallic and nonmetallic constituents is poorer resulting in frequent breakage during manufacture and usage.
2. Poor density level of the resulting product due to limitations of compacting and limited extent of pressure application during pressure-sintering,
3. Poorer thermal conductivity due to high level of porosity in the product resulting in overheating of the product in actual application.
4. Inadequate joining of backing plate with friction element due to improper wetting characteristics at the interface. Joining is non-uniform throughout the entire area of the brake pad.
5. Brake fading (stable coefficient of friction (COF) with rise in temperature) owing to high temperature generation.
6. Poor quality of product owing to segregation along prior particle boundaries (PPB's).
7. The friction material is anisotropic in nature towards compacting pressure direction and thus it may results in limited or insufficient shear strength to withstand frictional forces under actual conditions.
8. The resulting product also suffers from wide variations in final characteristics due to large number of complex variables involved.
9. Substantial rejection rate in compacting and sintering due to brittle nature of the product and also due to improper joining of backing plate and friction element.
10. Higher content of abrasive constituents adding further to the cost to compensate for poorer density of products as achieved in the existing technology.

11. Large consumption of hydrogen gas during sintering.
12. Costly raw materials owing to precise requirement of cold compacting process involved.
13. High cost of die due to different brake pad shape and sizes. Die wear is also an associated problem.
14. Costly manufacturing technique due to number of complex operations involved.
15. Heavy capital investment in the form of costly custom built equipments.

3.3 ALTERNATIVE TECHNOLOGY

The Hot Powder Forging technique evolved in the present investigation employed for the first time to produce brake pads differs from the existing technique. It can be briefle described as-

The hot forging technology of the present investigation is likely to improve product performance in following manner-

1. Bonding of metallic and non-metallic constituents are always better than sintered products due to simultaneous application of pressure and temperature; simplifies the process.
2. Powder specifications are no more rigid as shaping of the product is achieved by simultaneous application of pressure and temperature unlike cold compacting.
3. When the material is get deformed the powders are plastic-like soft in nature hence density of the final product can be increased to very high range if desired. Hence, any level of density is achievable.
4. Owing to higher density achievable, thermal conductivity of the product likely to improve and thus providing lesser damage to the product during heavy duty applications.
5. Brake pads with in built backing plates are produced, eliminating the problem of joining of backing plate with Brake pads. Thus it has improved the performance of the brake pad material and significantly reduced the overall production cost.
6. Joining of backing plate is also simultaneously achieved in one operation itself where high forging force and temperature make a perfect joint.
7. Effective material designing is possible by substantially reducing ceramic content without sacrificing end properties. This results in economy of manufacture.

8. Brake fading is also reduced to very low levels and it is always expected to be better than their sintered counterparts.
9. Product is much cleaner prior to deformation, due to the flow of hydrogen gas in loose powder mixture. Hence joining of particles during shaping is better than sintered counterparts. There is complete absence of prior particle boundaries (PPB'^s) as well as impurity segregation owing to heavy deformation of particulate matter during shaping. Some residual impurities if present may get uniformly distributed in the iron matrix. PPBs are possibly removed only by high rate of forming method like forging.
10. The fine ingredients present in the powder mixture is uniformly distributed and the side walls of the product is restricted to standard size by using channel die set up and application of compressive load due to this side wall restriction is constant and hence the product may result in isotropic in nature.
11. Brittleness of the final product does not adversely affect the hot forging process.
12. The problems associated with the use of dies in compacting and sintering problems such as dimensional instability, swelling and warpage are completely eliminated. The cost of die related toolings are substantially reduced.
13. Better scope of designing new set of materials and thereby delivering better combination of final properties of brakes.
14. Consumption of protective gases involved in sintering furnace is significantly reduced due to lesser area of processing.
15. The cost of raw materials (Fe-powders etc) is remarkably reduced as the powders do not require stringent characteristics as being required in Fe-based sintered brake pads.
16. Only simple equipments are involved which rendering low capital investment; whereas compaction presses, sintering furnaces are costly in sintering technique.
17. Simplified technology.

Thus the limitations of existing technology as mentioned in 3.2 are successfully overcome.

The present investigation is now formulated with the aim to exchange sintered iron base products with hot powder forged iron base friction products where it have lower cost per brake pad, improved abrasive, wear resistance, superior performance and longer life.

Further, the unique features of Hot Powder Forging technique are

- Better control of properties by way of improved control over the density of the product.
- Process provides for effective cleaning of powder particle surfaces prior to forging thereby allows use of economical and poor grade powders.
- Provides much stronger joint between friction element and backing plate than the one obtained by sintering technology- established through Ultrasonic Test.
- Does not require any specialized training or skilled labour to manage the process.
- Only simple indigenous equipments are required. No imported equipment is needed.
- Improved economy in running cost and improved saving in fixed capital investment.

3.4 OBJECTIVES OF THE INVENTION

Powder forging technology for the manufacture of metallo-ceramic brakes is developed with the aim to overcome the problems associated with presently practiced compacting and sintering technique followed by methods proposed leading to improvement and thus fulfilled the following objectives.

1. To adopt the hot powder forging technique in manufacturing the friction materials to overcome the difficulties of present process.
2. To obtain new set of iron-based friction materials
3. To produce friction element with built-in backing plate
4. To produce brake elements in desired shapes and sizes for different applications without using compacting dies.
5. To produce brake pads with in built backing plates with adequate adherence to eliminate the problem of joining backing plates with braking pad material.
6. To obtain desired density and superior performance in heavy-duty applications.
7. To allow the use of economical powders as compared to powders required in existing technology.

8. To reduce ceramic content without sacrificing end properties, in turn resulting in economy and simplification of chemistry.
9. To improve thermal conductivity of the product thus extending life of the elements.
10. To reduce brake fading
11. To characterize the friction product and compare its performance vis-à-vis their compacted and sintered counterpart.
12. To improve upon the quality of product as produced by sintering technique.
13. To reduce failure rate of the product due to breakage and warpage of the product.
14. To economize processing with improved product performance.
15. To avoid use of sophisticated and costly custom built equipments.
16. To develop less costly technique.

Chapter 4

EXPERIMENTAL WORK

Friction material's are very complex multiphase composites. Normally an iron based metallo-ceramic friction material contains 6 to 9 constituents. There are two principle requirements for these iron base friction pads one to achieve improved wear resistance and second to obtain high and stable coefficient of friction. In the present investigation, the iron based metallo-ceramic friction materials have been produced by a new 'Hot Powder Forging' technique.

4.1. Hot Powder Forging

The existing compacting and sintering process basically involves four steps powder mixing, cold compacting in heavy presses, pressure sintering under controlled atmosphere and finally finishing which includes grinding, coining, etc. Powder Forging (P/F) is the process of making the more dense products by use of metal preform with further deformation to yield final shape by single or multiple strokes. Here the preform is forged thus the porosity is closed up and eliminated by the action of plastic deformation. In the present investigation, Hot Powder Forging differs from the preform forging process that the powder mixtures are loosely packed under closed steel cover in hot condition under hydrogen atmosphere and then deformation by operation is carried. Hence, the process employs high rate of forming where the material (powder mixture) undergoes severe plastic deformation as well as consolidation under application of impact load at high temperature; purpose of compacting and sintering both are thus fulfilled simultaneously in a single step.

The different ingredients namely metallic powders, ceramic powders, abrasive powders, and solid lubricants are chosen, these powders are mixed/blended in wet/dry media and encapsulated/filled in specially designed mild steel capsule (inner side being copper coated). This powder filled steel capsule is heated at 1050°C in hydrogen atmosphere and forged under hot condition followed by homogenization treatment at 1050-1100°C to allow inter diffusion of different constituents. The mild steel skin wherever not required, is removed by machining. However, it is predominantly retainied along with friction element as its backing plate. The flow diagram of the proposed method of forming friction material based on 'Hot Powder Forging' technique is given in the Fig. 4.1.

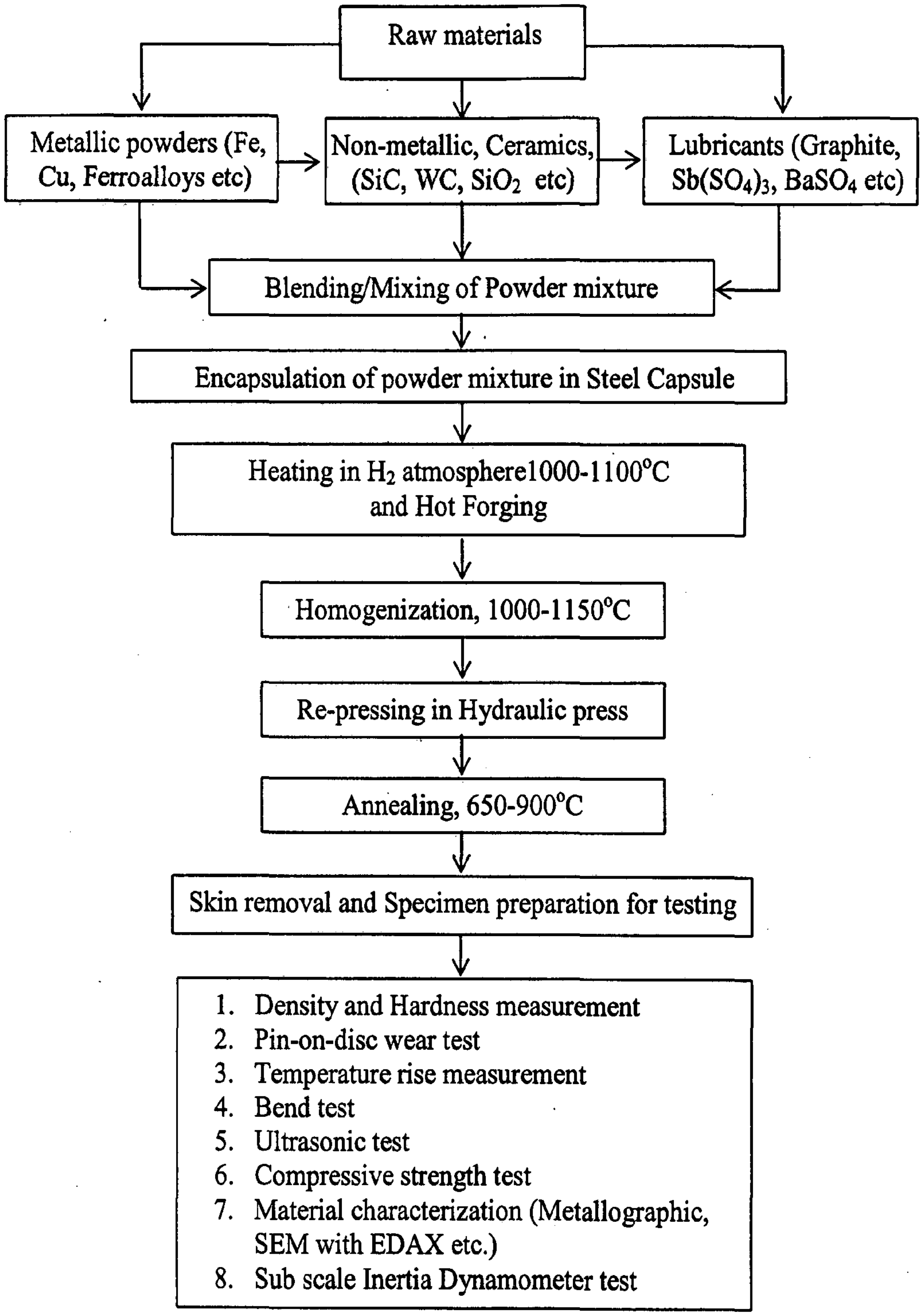


Fig. 4.1 Process Flow Chart

4.1.1 Raw Materials

The different raw materials/constituents namely, metallic (Fe, Cu, Sn, Zn, Al etc.) powders, ceramic (SiC, Al_2O_3, WC, SiO_2 etc.) powders and solid lubricants (graphite, $BaSO_4$, BN, $CaSO_4$, Sb_2O_3, etc.) are chosen from the literature available in accordance with improved wear resistance, frictional stability, thermal conductivity, higher strength and so on. A total of 16 different constituents of the friction material has been formulated in the present investigation and is shown in Table 4.1.

Since the materials are iron base, first of all the iron powder was analyzed using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-Unit). It was found that electrolytic grade of iron powder, which was used in the present investigation, contains 0.016%C, 0.012%S, 0.007%P, and 0.075%Si. Sieve analysis was carried and iron powder with –120 μm was chosen for subsequent use in the present investigation.

Copper addition to the iron base sintered friction materials improves strength by forming a liquid phase and precipitation hardening thereafter. Further, copper improves thermal conductivity and upto 10% addition it increases COF. [54]. Addition of nickel improves strength and frictional properties under low friction powers, whereas at higher conditions, high temperature evolved in rubbing surface where phase transformation of austenite is formed. It was concluded that addition of nickel content is independent of frictional properties. Low melting non-ferrous metals can lower the wear of iron-graphite system and also it may improve lubricating capacity under higher load conditions due to the presence of liquid phase. Addition of phosphorous improves wear resistance. Addition of phosphorus in the manufacturing of iron-graphite base friction composites, is in the form of Ferro phosphorus. Ferro phosphorous addition is simpler, more economical, and more suitable and safer for the workers' health.[54]. Further, Ferro alloys like Fe-W, Fe-Mn, Fe-Ni, Fe-Cr, Fe-Si are also added to improve mechanical properties and wear resistance.

Friction additives such as silica and alumina improve frictional stability but higher addition may decrease compressive strength.[118]. Addition of lubricants may reduce wear, seizure, scoring but improves frictional stability and engagement of brakes.

Table 4.1 Nomenclature of Friction Materials

Symbol	Chemistry (wt.%)				Processing parameters*		
	Common constituents			Others	Heat Treatment	Density	Hardness
	Fe	Cu	Graphite			gm/cc	BHN
FM01N	76.2	6	5	P- 0.8, Al -3.5, Asbestos-2.5, B_4C- 4.0, SiO_2-2.0	Repressed once and Normalized thereafter	4.96	124
FM02N	80.7	6	6	P-0.8, Al-1.0, Asbestos-2.5, B_4C -3.0		5.99	342
FM03N	82.5	7	8	P-0.5, Asbestos-1, B_4C -1		5.83	146
FM04N	78.5	7	8	P-0.5, Sn -3, $CaSO_4$-1, Zn -2		6.37	75
FM05N	78.5	7	8	P-0.5, Sn -2, $CaSO_4$-1, Zn -3		6.35	60
FM06N	81.3	7	5	P-0.7, Sn-2.5, $CaSO_4$-1, Zn-2.5		6.69	186
FM07N	78.7	7	6	P-0.8, Sn -3, $CaSO_4$-1.5, Zn -3		6.46	92
FM08N	82.2	7	6	P-0.8 Sn -3, $CaSO_4$-1		6.67	120
FM09N	78.2	7	6	P-0.8, Sn -3,SiC -4, $CaSO_4$-1		5.92	171
FM10N	78.5	6	6	Sn -3, SiC -4, $CaSO_4$-1, Ceramic Wool-1.5		5.68	112
FM11N	78.9	6	6	P-0.6, Sn -3, SiC -3, $CaSO_4$-1, Ceramic Wool -1.5		6.06	121
FM12N	81.0	5	5	P-0.4, Sn -2.5, SiC -4.5, Sb_2S_3-0.8, Ceramic Wool -0.8,		5.96	145
FM13N	80.05	5	5	P-0.45, Sn -2.5, , WC -5, Sb_2S_3-1.2, Ceramic Wool -0.8		6.67	116
FM14AA1	70.3	10	7	P-0.7, Sn -1, SiC -6, Sb_2S_3-5	Repressed once and annealed at 1050°C, 2hrs time	5.26	132
FM14AC3	70.3	10	7	P-0.7, Sn -1, SiC -6, Sb_2S_3-5	Repressed thrice and annealed at 680°C, 5hrs time	5.78	112
FM14AB1	70.3	10	7	P-0.7, Sn -1, SiC -6, Sb_2S_3-5	Repressed once and annealed at 710°C. 5hrs time	5.56	97
FM15AB1	70.3	10	7	P-0.7, Sn -1, SiC -6, $BaSO_4$-5	Repressed once and annealed at 710°C 5hrs time	6.05	67
FM15AB3	70.3	10	7	P-0.7, Sn -1, SiC -6, $BaSO_4$-5	Repressed thrice & annealed at 710°C 5hrs time	6.10	83
FM16AB1	68.5	11	6	P-0.5, Sn -2, SiC-3.5, $BaSO_4$-5, BN-1.5	Repressed once and annealed at 710°C 5hrs time	5.33	167
FM16AB3	68.5	11	6	P-0.5, Sn -2, SiC-3.5, $BaSO_4$-5, BN-1.5	Repressed thrice and annealed at 710°C 5hrs time	5.38	178

*Forging temperature- 1050°C; Homogenization temperature 1050°C, ½ hr soaking period; Repressing temperature being 1050°C, Density and hardness values reported are corresponding to end portions of forgings.

4.1.2. Blending/Mixing of Powder mixture

Once the chemistry was fixed, blending/mixing of these powders were carried in Ball Milling and in Double Cone Blender. It was planned to have a sequence of mixing of the various ingredients, i.e., to mix the metallic ingredients and ceramic ingredients separately as individual mixes and then finally mix them together along with lubricant additions. Firstly, all the metallic powders like Fe, Ferro alloys, Cu, Sn, Al, P etc. were taken according to their weight percentages and then mixed in double cone blender for about 6-10 hrs depending upon its volume, flow rate, apparent density etc. This constitutes metallic powder mixture. Secondly, ceramic powders like SiC, WC, SiO_2 etc and low dense powders such as $BaSO_4$, Sb_2S_3 are mixed under wet media with alcohol based solution (preferably ethyl alcohol) with steel balls in the ratio of 1:1:0.5. This wet mixture is dried in oven at 100-120°C for about 1-2 hrs. The purpose of wet mixing is to coat SiC powder so that it easily mixes with other constituents. Ceramic powders mixture so prepared is now added to metallic powder mixture and then mixing is carried in ball mill for about 2 hrs. Lubricants such as graphite or any other high temperature lubricant like BN, $CaSO_4$, is mixed subsequently in double cone blender for about 2 hrs. Thus, entire procedure of mixing is developed to obtain uniform distribution of constituents with widely differing characteristics. Now the powder mixture is ready for next step.

4.1.3. Encapsulation of powder mixture in Steel Capsule

A mild steel capsule was specially designed for producing iron base friction pads and is shown in Fig. 4.2. The center steel pipe, cup portions and the two end tubes are welded properly such a way that there should not be any leakage or brakeage during forging operation. The inner side of steel pipe is copper coated with a thickness of 150-300μm by displacement method using copper sulphate solution. Priorto coating the steel tube is thoroughly cleaned by diluted sulphuric acid for any contaminants sticking at the inner surface. The aqueous solution of cupric sulphate (50 gram of $CuSO_4.5H_2O$ was dissolved in 1 litre of distilled water and 10 ml of conc. H_2SO_4 was added) was filled in the steel pipe (capsule center part) by closing one end. The copper sulphamate solution makes following reaction with iron content of steel part.

$$Cu\,SO_4 + Fe \rightarrow Cu + Fe\,SO_4$$

The purpose of copper coating is to improve joint between steel pipe with friction layer during forging operation. Hence, the forged slab cover (steel) pipe act as a backing

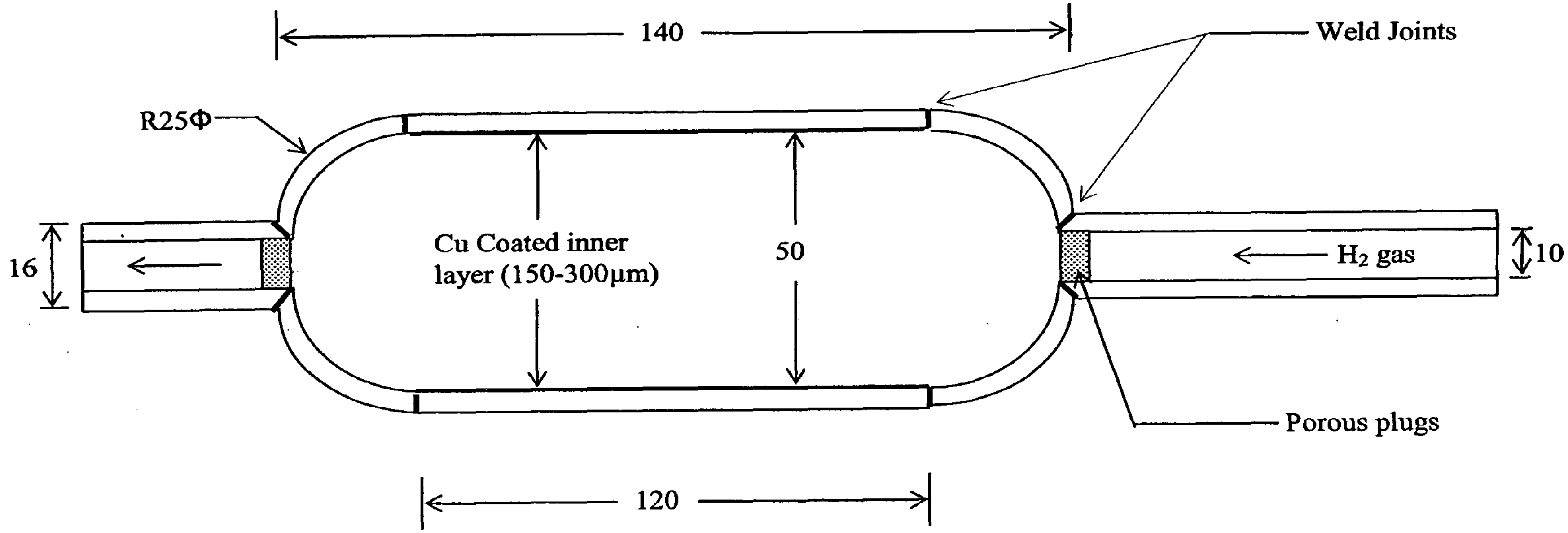


Fig. 4.2 Steel capsule

plate for the friction pad so produced. Thus friction composites/pads are produced with built-in backing plate in single operation only. Whereas in sintering process, the compacted preform is joined with separate steel plate of same or similar size under pressure sintering. There is wide flexibility of changing the center copper coated steel pipe with carbon steel or high strength low alloys steel pipes etc. for different low, medium and high energy aircraft braking applications in the existing process of forging.

The powder mixture is encapsulated/filled into steel capsule via closing one end by means of porous plugs (ceramic wool). Once the powder mixture is filled, the other end is also closed by porous plug. The quantity of powder mixture filled is maintained at constant level which depends upon volume or size of steel capsule.

Since powder filling involves manual operation care must be taken to ensure proper quantity of powder mixture inside the steel capsule commensurate with its inner volume.

4.1.4. Heating and Hot Forging

The powder filled steel capsule as shown in Fig.4.2 is now checked for hydrogen flow from one end to the other end to ensure proper hydrogen flow by igniting at other end portion and thus creating a positive hydrogen atmosphere inside the steel capsule. This was performed prior to heating. Now, this steel capsule with hydrogen flow is on inserted in a tubular furnace which is already heated and maintained to in the range 1000-1100°C. The capsule is soaked for 0.5 to 1.0 hr in order to heat the powder mass uniformly reducible impurities of the powder mass and thereby clean it prior to forging. The hydrogen pressure regulator is adjusted from time to time in such a way that a constant flame length is maintained. The capsule is also slowly rotated about its longitudinal axis.

At the end of soaking time, the hot steel capsule is transferred in a channel die set up of forging press. Forging is carried out in friction screw press of 200 metric ton capacity. Two to four blows tare performed till red hot condition of 850°C approximately remains. The impact force of the order of 150-230 tons with ram speed of 250-350 mm/sec is maintained. Dry H_2 gas supply through encapsulated powder mix automatically terminates till the first blow of the forging hammer. In this process since the powder mass is cleaned of impurities prior to forging, powder characteristics are of little consequence as regards to the final quality of forged product. This aspect is absent in existing technology of compacting and sintering. Furthermore, simultaneous application of temperature and impact force of high magnitude ensures removal of prior particle boundaries (PPB's) in the product.

Now the steel cylindrical can (capsule) get deformed heavily into a flat forged slab. The percentage of deformation interms of cross-sectional area is about 50%.

4.1.5 Homogenization,

Homogenization treatment is carried out at 1000-1150°C for 1/2-1 hr in a muffle furnace followed by air cooling to ensure uniform distribution of alloying elements throughout the cross-section of forged component. Further, this treatment allows inter diffusion of metallic and some ceramic constituents which results in elimination or decrease the chemical segregation.

The samples from FM01N to FM13N are processed up to above mentioned steps and then directly skip into section **4.1.8.** Remaining samples from FM14... to FM16...were further processed as per following two sections 4.1.6 and 4.1.7 respectively.

4.1.6 Re-pressing in Hydraulic press

It was planned to estimate the role of density on frictional response and thus the forged slab is further repressed at number of times to increase the densification of product. The homogenized forged slab was hot pressed in a hydraulic press of 60Tonne capacity at 1050°C for 10 minutes. The number of repressing will depend on density of forged slab required. Thus wide range of density could be achieved.

4.1.7 Annealing

Heating to and holding at a suitable temperature and then cooling at a suitable rate with the aim to reduce hardness, improving machinability, facilitating cold working, producing a desired microstructure and also to obtain desired physical, mechanical and frictional properties. In some of initial samples the hardness values are high. With the aim to further reduce the hardness, to improve ductility of the friction materials, annealing was carried out at 650-900°C for 2-5 hrs in the muffle furnace.

4.1.8 Skin removal and Specimen preparation for testing

The slab material so processed from the above sections has mild steel skin (steel capsule cover) on both sides of friction powder compact. This mild steel skin wherever not required can be removed by machining using shaper, grinder etc. While the slab material was machined near to interface layer (copper coated), a hard and poor machinability layer was observed and the tool tip gets blunted at this portion. This indicates that the copper layer gets highly diffused on either sides of friction material as well as steel baking plate. This is due to severe deformation of powder mixture with steel part by simultaneous application of high pressure and temperature. Thus relative tough maching of the interface layer confirms that the joint strength between friction layer and backing plate may be higher than the sintered product. The specimens are prepared with different shapes and sizes with or without backing plate for different characterizations.

4.2 Characterization of Friction materials/pads

The friction materials/composites so produced with built-in backing plates are characterized for physical, frictional and metallurgical properties namely density, hardness, pin-on-disc wear test, temperature rise, microstructures, SEM with EDAX analysis and sub-scale brake inertia dynamometer tests were carried. The bond quality between friction material and backing plate was also checked by bend test and ultrasonic test. The fractured surface of bend test samples was examined by SEM microscope. For density and hardness, compressive strength, wear test, temperature rise tests only friction element was prepared. For dynamometer test, bend test, ultrasonic test and metallurgical analysis brake pad (friction element with backing plate) was used.

4.2.1 Density and Hardness measurement

Densities of the friction material were estimated by measuring the volume of the given piece of the material by water displacement method based on Archimedes principle and its weight in air using a chemical balance. Prior ot density measurement the sample is wax coated to seal surface porosity if any.

Hardness measurements were carried using Brinell's hardness testing machine employing a 31.25 kg Load with ball diameter of 2.5mm and kept constant throughout the experiment for all friction materials. The load was applied for 30 seconds on a sample. At least 5 indentations were made on each sample; average hardness was reported.

4.2.2 Pin-on-disc wear test

An initial laboratory level based pin-on-disc wear test was performed under different set of parameters (applied load, sliding speed, and sliding time/distance) according to ASTM G99 standard test procedure. The pin circular or square or rectangular cross section can be used to clamp between the fixed jaw and the removable jaw. A pin made from friction material of squire size of 30mmX7mmX7mm was used in the present study. The counterface disc is made of EN-32 steel hardened to 45 HRC. To ensure proper contact between the test piece and the steel disc, test pin adjusting screw is provided. Normal loading on the test piece is provided by the slotted weight, which are hanged on pan. This load is transferred through the frictionless wheel to the specimen holder. Electric motor is directly connected to the steel disc and the speed of the disc can be controlled by variable regulator.

The pin on contact side of the disc was rubbed on polish paper of 1/0, 2/0 before clamping and counter disc is also made smooth surface finish by the polish paper of 2/0 at each cycle. The load applied is 5kg and 8kg with specific pressure of $100N/cm^2$ and $160N/cm^2$ respectively. Sliding speed of 9m/s (1140±10 rpm at a track radius of 75mm) was kept constant for the whole experiment. Sliding time is varied from 10 to 50 minutes with the interval of 5 minutes. The wear loss after each cycle, the frictional force generated at every 1 minute was recorded.

The noise generated during the wear process is also recorded by means of special microphone based noise level meter in decibels (dB). This gives an idea about the noise behavior of friction materials during the test.

4.2.2.1Temperature rise measurement

Measurement of rise in temperature of the wear surface as a function of time and during wear test was carried out using a thermocouple made of Chormal-Alumel wire is placed at 5mm away from the wearing surface by making hole of 2mm diameter with 3mm depth approximately. The rise in temperature is recorded till the temperature at the wear surface becomes stable. Care must be taken while brazing thermocouple bead inside the hole at friction material. Simultaneous measurement of coefficient of friction and temperature rise during the test would provide brake fading characteristics.

4.2.3 Subscale Dynamometer test

The laboratory qualification test on individual samples of the newly developd hot powder forged friction materials were carried in sub-scale brake inertia dynamometer tests. However, to qualify the brake pads for airworthiness, actual field trial performance and full scale dynamometer are required. The brake inertia dynamometer tests were carried where these newly developed friction pads are fitted with a caliper brake assembly and subjected to repeated cycles of real time brake performance tests on a brake dynamometer simulating the actual aircraft brake energy conditions. Pair of two brake pad samples were tested at a time in subscale dynamometer with different parameters (K.E., Brake speed, Brake force etc.) under near actual conditions of AN-32 military transport aircraft, MIG 21/27 fighter aircrafts. Once reaching the speed of brake disc at the required level, brakes are applied with appreciable pressure and thus disc is stopped. The responses are run down revolutions (revolutions prior to stopping), run down time (stopping time), brake torque (mean and peak), drag force (mean and peak), COF, temperature of brake pad/disc were calculated and recorded for each cycle. The number of cycles was 50.

For an aircraft, there are three brake energy conditions for which the parameters are varying and are calculated, fixed accordingly. First, normal landing conditions which refers to normal aircraft condition which corresponds to the normal landing speed of the aircraft. Second, rejected take off (RTO) conditions which are refers that when the aircraft take off from the runway, due to technical fault or some other reason the aircraft would like to land immediately. In such cases, the brake pads are able to withstand higher applied pressures, operating temperatures, and hence able to stop with particular short distance within runway. Third, overload conditions, which refer to extreme beyond loading conditions. In all of these conditions, the input parameters of dynamometer tests will vary and new calculations were made and fixed.

In the present investigation, sub-scale dynamometer tests were carried under RTO brake energy conditions and the specifications of dynamometer is as follows.

1. Make : Dynaspede Integrated Systems Pvt. Ltd.
2. Inertia : 14-54 Kg.m2 (Stepless by electrical simulation)
3. Maximum energy : 1.2 Laks kgfm = 1.18 MJ
4. Speed : 100-2000 rpm
5. Braking force : 50-1000 Kgs
6. No of disc : 2 (alloy cast iron and alloy steel)
7. Disc diameter : 500mm
8. Maximum no. of cycles : 200
9. Acceleration time : 30sec
10. Noise level : 85 dB

4.2.4 Metallographic analysis

The microscopic examinations of so produced friction composite (hot powder forged friction materials) are analyzed through optical microscope. Microstructures of backing plate, interface layer and friction element have been studied and compared with sintered friction pad structures of MIG-21 brake. Pore morphology and microstructures, the distribution of graphite flakes, copper rich phase, and ceramic constituents such as SiC, SiO_2, Al_2O_3 etc. with the iron matrix, ferrite content, bond quality, thickness of plating (Ni or Cu coating), back plate structure, presence of porosity and their influences, are analyzed. Specimens (about 15X15mm surface area) having cross section of backing plate and friction element are cut from the selected composition and these samples are mounted by hot mounting using thermosetting based plastic granules. Metallographic specimens were prepared as per the ASTM E3, E407 standard test procedures. Conventional polishing techniques, such as grinding on emery papers up to 4/0 grade and polishing on cloth are used in the preparation of these samples for optical metallographic examination. Particle size of the abrasive being used in the formation of slurry for polishing, wheel speed and policing time play a significant role in clearly revealing pores and grain boundaries of a sintered ferrous material. During cloth polishing, the polishing cloth (3-6 μm grade) with fine grains and abrasive slurry of 1 to 0.1 micron alumina powder are used. In order to reveal the morphology of pores, microstructures are studied in unetched condition, as being also suggested earlier. Microstructural examination is also carried out in etched condition after etching with freshly prepared etchant, nital (2% nitric acid and methanol). Sometimes, repeated etching and policing is applied in order to reveal pores and grain boundaries clearly. REICHER-JUG MeF3 and OLYMPUS PME-3 microscopes were used in this study.

4.2.5 SEM with EDAX

The surface morphology of the friction material, backing plate, and interface layer are analyzed through SEM. X-ray elemental mapping of different constituents present in the samples have been done to check homogeneity of the constituents in friction elements. To identify the element wherever required was carried with the help of point/surface area analysis of EDAX analysis. QUANTA FEG 200 FEI Netherland make was used in the present study.

4.2.6. Bend Test

A three point bend test is used with the aim to check the joining strength of friction material with backing plate. Hounsfield H25K-S Universal Testing Machine with three rollers of 25mm diameter with span length of 50mm was used. The sample (of about 58mmX17mmX7mm in size) was placed facing the friction material on two roller (bottom) supports and back plate on single roller (top) side. Once the sample is bent, the angle of bend and load at which friction material cracked upto interface layer or upto steel back plate are calculated. The fractured section is also viewed under stereo microscope to detect crack etc. at the interface between friction material and backing plate.

4.2.7 Ultrasonic Test

The bond quality of the friction material with the backing plate is also identified through non-destructive method of Ultrasonic test of pulse echo principle. An Ultrasonic instrument (USM 35 model of Krauntker, Germany) equipped with Transmitter Receiver (TR) probe of 10mm diameter with 4 MHz frequency range was used to identify any defect at the interface between backing plate and friction element. Initially, the equipment is properly calibrated with standard step block (provided by the make of the instrument) by considering the brake pad thickness. A clear echo is seen through screen; adjust gain/sensitivity to get reflection from plate to full height on the screen and thereafter image is stored. Then the brake pads are subjected to testing by applying couplant on steel back plate side and thereby placing probe gently on it. The peak signal may be seen through screen as initial, intermediate and bottom signals and thereby examining acceptable or rejectable signal patterns.

Chapter 5
RESULTS AND DISCUSSTIONS

In the present investigation, total of sixteen formulations were developed based on iron as a main constituent for heavy duty friction materials. Iron varied from 68.50 to 82.25%, copper varied from 5 to 11% and graphite varied from 5 to 8%. Other constituents were Phosphorous, Aluminium, Asbestos, Boron carbide, Silica, Calcium sulphate, Tin, Zinc, Silicon carbide, Ceramic wool, Antimony sulphide, Tungsten carbide, Barium sulphate and Boron nitride in varying percentages. Processing parameters were as follows.

Forging temperature – 1050°C,
Homogenization temperature – 1050°C, and
Repressing temperature – 1050°C

Thereafter, the samples are either normalized or annealed in the temperature of 680°C to 1050°C. Based on above chemistry and processing parameters, Table 5.1 provides complete details of nomenclature of friction material developed in the present investigation. This table also gives an idea of density of the final product ranging from 4.96 to 6.69 gm/cc and hardness from 60 to 342 BHN. Based on the chemistry and processing parameters symbols are also assigned to each type of friction materials developed in the present investigation.

Following tests were conducted to characterize the friction materials developed in the present investigation.

1. Density and Hardness
2. Pin-on-disc wear test at different loads and sliding speeds using heat treated steel disc having hardness of 45 Rc.
3. Sub-scale dynamometer test with varying energy, speed, and brake force.
4. Optical microscopy to identify the distribution of different constituents as well as interface structure examination with back plate.
5. EDAX analysis to confirm distribution of different constituents.
6. Bend test to asses the joining of friction material and backing plate.

7. Ultrasonic flaw detection to establish quality of joint between friction layer and backing plate.

Investigations were carried out in detail in selective cases only where there is a scope for further exploitations towards application of friction elements developed in the present investigation for heavy duty military aircrafts such as MIG 21, MIG 27, as well as military transport aircraft AN-32 for which entire.work of the thesis is concentrated.

In the following sections, it is proposed to discuss the details of the results obtained. Results have also bee compared with the performance of sintered samples for equivalent test parameters.

5.1 Density and Hardness

Density and Hardness of Friction Materials are reported in Table 4.1. Both these parameters depend upon extent of repressing and normalizing/annealing treatments thereafter. They also indirectly depend upon, chemistry of friction materials. The technology developed in the present investigation is capable of developing these parameters in wide ranges which is not possible in sintering technology. Accordingly, the technology developed has capability to control these parameters in very precise manner and therefore it is possible to develop friction layers for different ranges of application (light to very heavy duty) by merely controlling these two parameters. And thereby easing the restriction of chemistry choice. It will be established in subsequent sections that density is a very dominating parameter to decide the suitability of friction `element which can be employed in AN 32 to MIG 27 aircrafts. Literature surveyed in the present investigation has not given any indication about the role of density on varying ranges of applications. All the literature cited in the present investigation emphasizes more on chemistry and there is no systematic approach to the selection of chemistry for various ranges of applications.

5.2. Wear studies on Pin-On-Disc Machine

Pin-on-disc wear test were carried out in all the samples made in the present investigation for preliminary assessment of suitability of test materials. Based on pin on disc results, certain samples were omitted from Dynamometer testing.

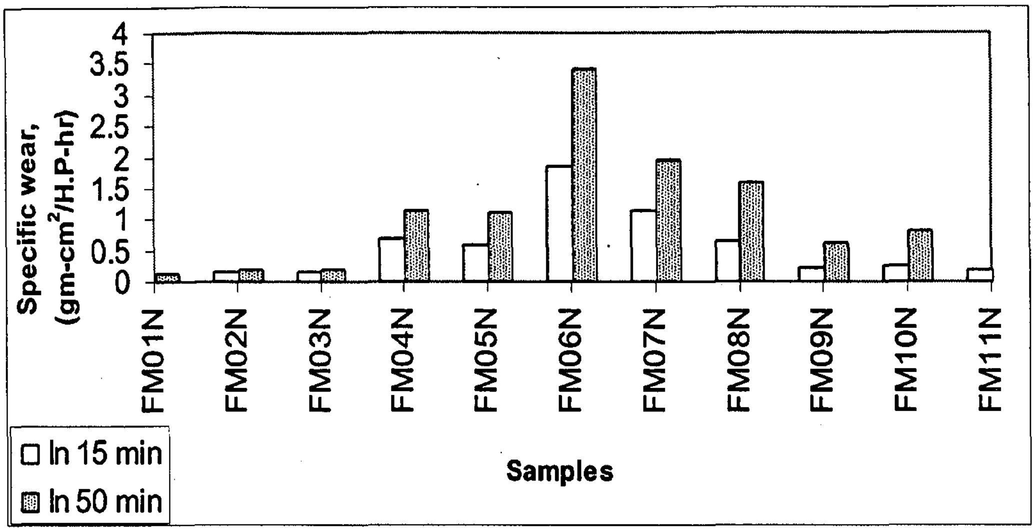
The pin on disc tests were performed on the pin size of 7mmx7mm with sliding speed of 9m/s and load 5 kg and 8 kg respectively. Tables 5.1 and 5.2 provide the summary results of these samples. Grey Cast Iron (GCI) and MIG 21 sample were also included for the purpose of comparison. It may be noted that the wear in case of GCI is excessively high in comparison to friction materials developed in present investigation. It is justifiable since GCI does not contain wear resistant constituents in it. Wear in case of MIG-21 is also on the higher side in comparison of our samples made in the present investigation. And therefore complete test could not be carried out in MIG 21 samples (owing to limited thickness available with the finished sample). Accordingly in the tables, some of the columns are blank and at few places, time of wear is indicated in parenthesis which happens to be lesser than the time planned for the experiments. Fig. 5.1 to 5.4 are graphical representation of these samples tested in Pin-on-Disc. It may be inferred from these graphs that upto sample no. FM09N the wear is gradually increasing from very low value to higher values thereafter it shows a significant drop in the amount of wear. This is possible because there is simultaneous role of wear resistant constituents and lubricants. In the initial composition only Phosphorous is present which develops wear resistance but in later compositions, more wear resistant constituents were incorporated such as Silicon carbide, Silica, Alumina etc. This is apparent because wear resistant materials, like silicon carbide, Silica etc. first increase COF and lubricants improve the engagement. Combined effect of these two types of constituents optimizes the net wear loss. The noise level during the test is not significantly altered in all the cases. This is because of the fact that the noise level is related to met metallic content of the brake elements which in our case varies from 82% to 90%.

Table 5.1 Pin-On-Disc Wear Test results at 5kg Load($100N/cm^2$), 9m/s Sliding Speed

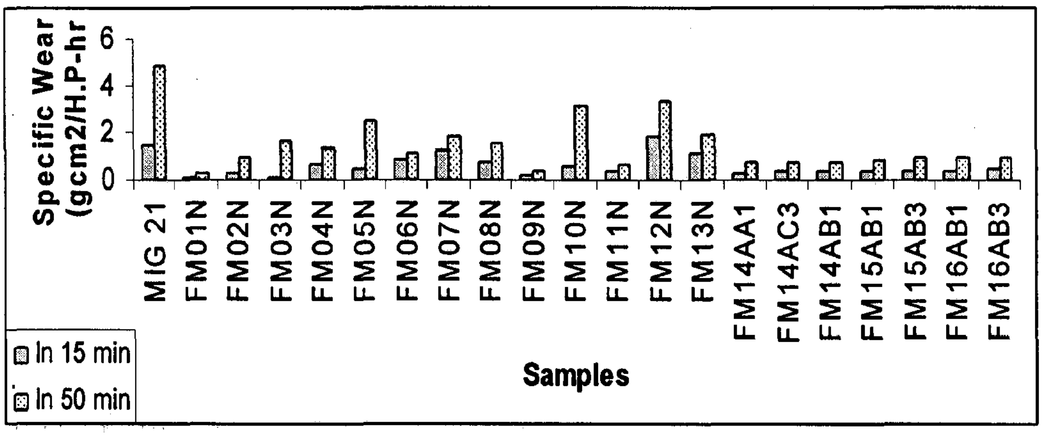
Samples	Cumulative Wear loss, gm (min.)		Specific wear, (gm-cm^2/H.P-hr)		COF			Temperature		Noise level, dB	
	15'	50'	15'	50'	Max	Min	Avg	oC	Sec	Max	Min
GCI	3.80(2.5)	6.83(5)	75.2	67.9	0.40	0.20	0.30	290	540	99.4	99.0
MIG-21	0.612	-	2.03	-	0.54	0.48	0.51	286	270	98.5	96.1
FM01N	0.027	0.13	0.09	0.13	0.60	0.54	0.57	149	600	99.1	97.0
FM02N	0.049	0.18	0.16	0.18	0.54	0.40	0.47	179	590	99.8	98.7
FM03N	0.046	0.21	0.15	0.21	0.54	0.48	0.51	163	470	100.3	98.4
FM04N	0.203	1.13	0.67	1.13	0.40	0.40	0.40	81	1500	96.4	94.8
FM05N	0.174	1.09	0.58	1.09	0.34	0.34	0.34	92	1400	98.5	95.7
FM06N	0.557	3.45	1.85	3.43	0.54	0.48	0.51	131	1540	96.8	94.2
FM07N	0.342	1.97	1.13	1.95	0.48	0.40	0.44	86	1620	94.4	94.0
FM08N	0.200	1.60	0.66	1.59	0.54	0.48	0.51	86	820	100.1	95.8
FM09N	0.072	0.61	0.24	0.61	0.48	0.40	0.44	93	970	93.1	92.6
FM10N	0.079	0.82	0.26	0.81	0.54	0.40	0.47	86	1800	101.5	92.5
FM11N	0.062	0.59	0.21	0.59	0.54	0.48	0.51	84	1330	91.8	89.4

Table 5.2 Pin-On-Disc Wear Test results at 8kg Load (160N/cm^2), 9m/s Sliding speed

Samples	Cumulative Wear loss, gm (min.)		Specific wear, (gm-cm^2/H.P-hr)		COF			Temperature		Noise level, dB	
	15'	50'	15'	50'	Max	Min	Avg	°C	Sec	Max	Min
GCI	4.80(2)	-	69.65	-	0.33	0.29	0.31	115	120	99.8	98.6
MIG 21	0.96(10)	-	1.46	4.86	0.54	0.46	0.51	235	390	96.6	95.8
FM01N	0.042	0.51	0.087	0.31	0.50	0.46	0.48	162	860	102.4	100.1
FM02N	0.09	1.56	0.29	0.97	0.44	0.40	0.42	170	960	100.2	98.0
FM03N	0.048	2.56	0.10	1.59	0.50	0.44	0.47	155	1200	99.5	97.2
FM04N	0.31	2.14	0.65	1.33	0.29	0.29	0.29	89	1100	96.1	95.2
FM05N	0.23	3.94	0.48	2.45	0.29	0.29	0.29	102	900	98.9	101.1
FM06N	0.26	1.90	0.86	1.18	0.50	0.44	0.47	131	1260	95.1	97.1
FM07N	0.58	2.89	1.20	1.79	0.42	0.38	0.40	92	1240	96.1	95.2
FM08N	0.73	2.47	0.74	1.53	0.38	0.29	0.34	156	800	107.2	102.1
FM09N	0.19	1.36	0.19	0.41	0.33	0.24	0.29	120	700	100.1	96.2
FM10N	0.52	.10	0.53	3.16	0.46	0.33	0.39	111	750	110.5	95.5
FM11N	0.34	2.22	0.34	0.68	0.42	0.33	0.38	141	700	104.4	94.5
FM12N	1.81	7.68	1.83	3.34	0.50	0.38	0.44	91	730	96.4	94.8
FM13N	1.16	6.21	1.18	1.89	0.42	0.33	0.38	97	770	95.1	93.9
FM14AA1	0.15	1.19	0.31	0.74	0.29	0.29	0.29	94	870	94.1	90.5
FM14AC3	0.17	1.27	0.35	0.78	0.29	0.29	0.29	99	920	93.2	90.6
FM14AB1	0.17	1.27	0.35	0.79	0.29	0.29	0.29	102	950	93.1	91.3
FM15AB1	0.18	1.40	0.37	0.87	0.44	0.40	0.42	112	850	94.6	91.1
FM15AB3	0.20	1.48	0.41	0.92	0.44	0.40	0.42	110	840	95.2	93.6
FM16AB1	0.18	1.46	0.37	0.91	0.50	0.44	0.47	97	920	92.1	90.5
FM16AB3	0.21	1.53	0.43	0.95	0.50	0.44	0.47	105	910	94.3	91.6

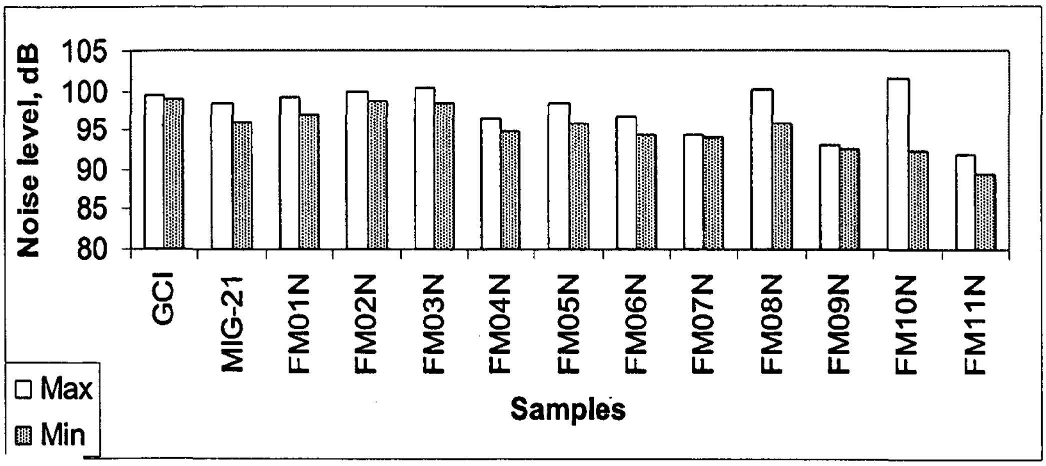


(a)

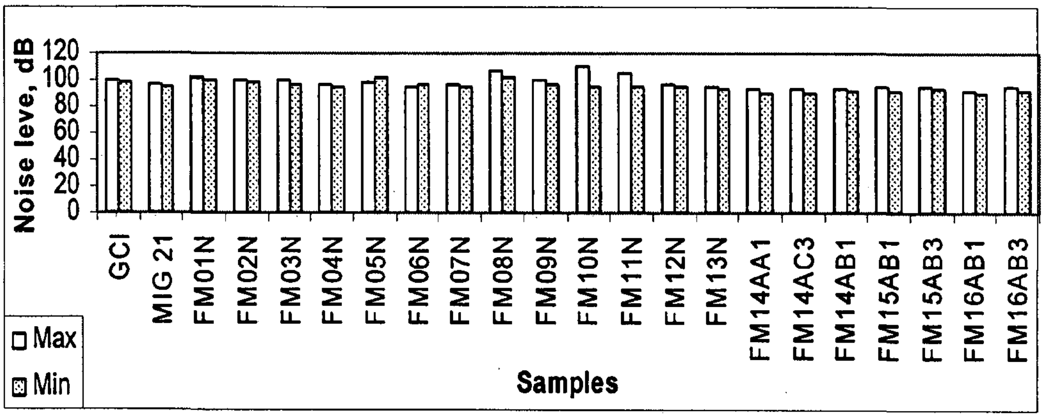


(b)

.Fig. 5.1. Specific wear at (a) 5kg load, (b) 8 kg load of various samples.

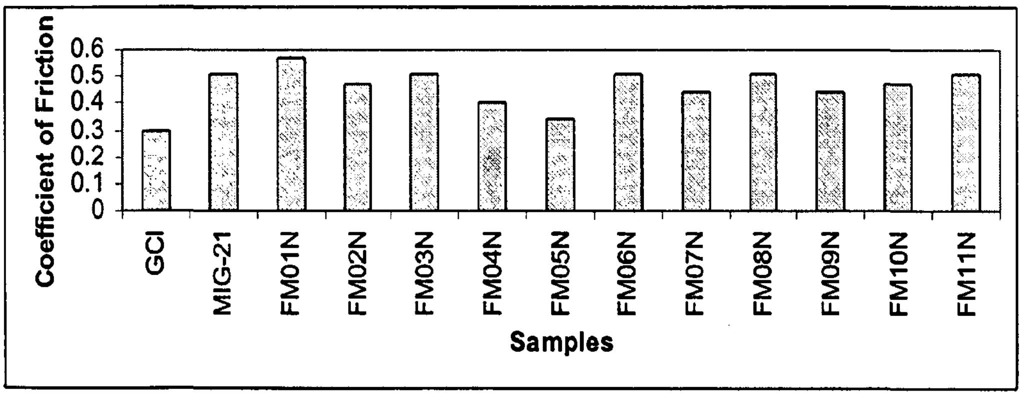


(a)

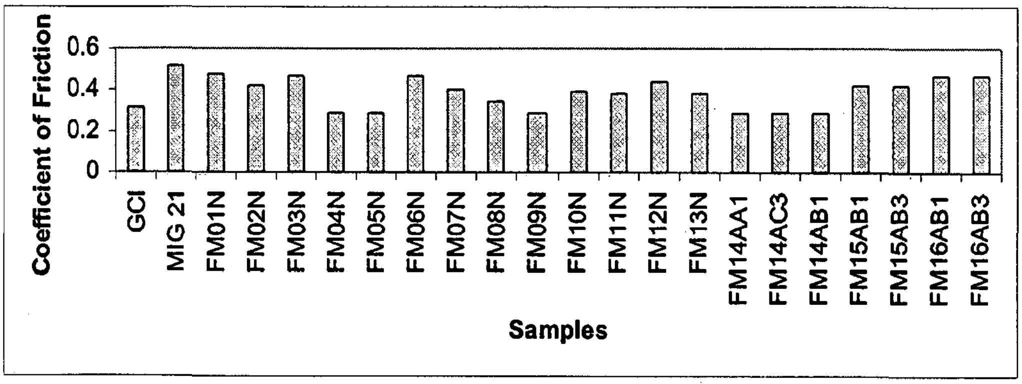


(b)

Fig.5.2. Noise level (a) at 5kg load and (b) at 8 kg load of various samples

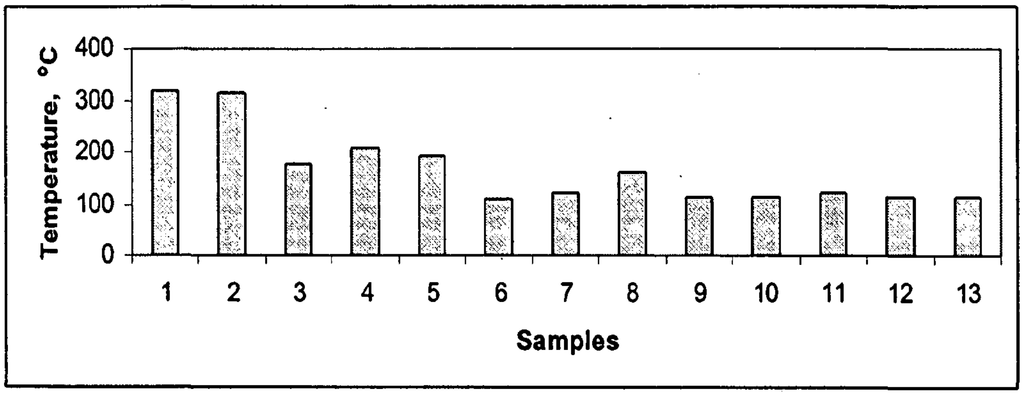


(a)

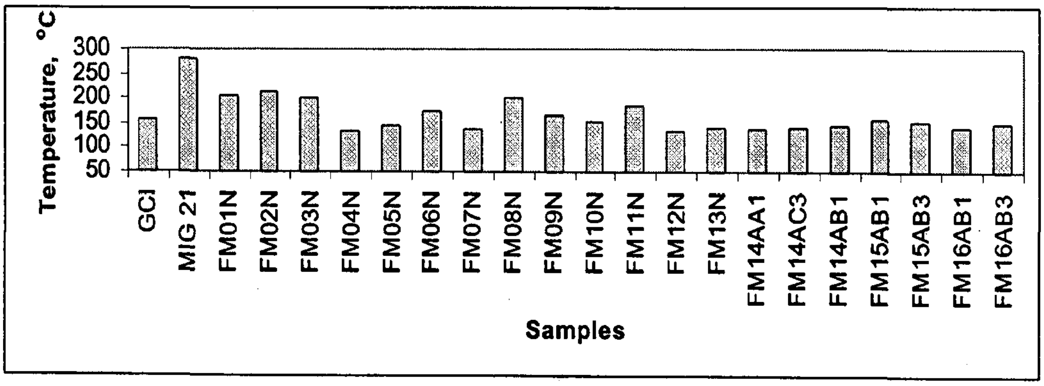


(b)

Fig.5.3. COF at (a) 5kg load and (b) 8 kg load of various samples



(a)



(b)

Fig.5.4. Temperature at (a) 5kg load and (b) 8 kg load of various samples

5.3. Sub scale inertia dynamometer tests

Sub scale dynamometer tests are one of the most important tests to assess the suitability of brake pads for actual applications. Since the present investigation has been aimed at applications relating to military aircrafts, it was imperative to test the pads developed in the present investigation at HAL Bangalore where only such a facility is available. They readily provided us this facility. The detailed computer generated result sheets corresponding to our samples are available in Annexure-I of the thesis. These tests were carried out employing cast iron wheels as inertia wheels having specifications given in Table 5.3. No effort has been made to assess the wear in of these wheels during testing although this aspect is also important for applications other than aircraft brakes.

Table 5.3 Specifications of Inertia wheels

Diameter	Thickness	Composition	Heat treatment	Hardness
500mm	25±1mm	C-3.20 to3.80 Si-1.60 to 2.30 Mn-0.60 to 1.0 Cr-0.15 to 0.45 Mo-0.20to 0.50 Ni-0.80 to1.40 S-0.10%Max P-0.30%Max	Soak at 550oC for 3 hrs. and air cool in furnace	163 to 217 BHN

The tests were conducted for the purpose of different military aircrafts' applications. Table 5.4 provides the details of the test input parameters including the model of aircraft where brake pads can be employed.

Table 5.4 Test input parameters

Brake pad contact area: 25.8 cm^2 [As shown in Fig. 5.4 (A)]

Applications	Test Parameters		
	Kinetic energy, kgfm	Brake Speed, rpm	Brake Force, kgf
AN 32 Rotor	17300	1000	150
MIG 27 Stator	32000	1360	135
MIG 27 Rotor	36123	1445	135

This table has been arrived at on the basis of calculations as indicated in the literature review section 2.7.3 for Rejected Take Off (RTO) conditions of these aircrafts and their vehicle dynamic parameters such as velocity, momentum etc at RTO. Rejected

Take Off conditions mean extreme energy developed by the vehicle just prior to take off. This condition is regarded as the most extreme condition of the vehicle where brake assembly has to absorb that quantum of energy within the available air strip length. The test parameters for assessing the performance of brake pads can also be evaluated from the same model calculation as given in section 2.9.2.1 of literature review. These are provided in table 5.5 for the purpose of evaluating performance of our brake pads with varying chemistry. It may also be mentioned that most of the sintered brake pads also observe these parameters as given in the table 5.5.

Table 5.5 Test output parameters

Application	Test parameter					
	RD Time, sec		COF		Maximum Wear (for 50 cycles)	
	Min	Max	Min	Max	in grams, gm	in thickness, mm
AN 32 Rotor	6	12	0.18	0.40	14	1.25
MIG 27 Stator	-	25	0.12	0.35	20	1.5
MIG 27 Rotor	-	18	0.20	0.45	10	0.70

Note: Some of the graphs appearing under this section have shaded regions. These indicate permissible ranges of the parameter shown in these graphs as per the output parameters indicated in this table.

The different test parameters as obtained from sub scale inertia dynamometer tests are as follows.

1. Run Down time:- This parameter relates to the time required for a pair of brake pad in absorbing the energy fed from the dynamometer. This time should preferably be on the lower side for efficient brake application.
2. Run Down Revolution:- This is also a parallel parameter corresponding to the one above. However, it is actually number of revolutions of inertia wheels to get stopped by the pair of brake pads. Like RD time, RD revolutions also should be on the lower side for efficient braking.
3. Coefficient of Friction (COF):- This is the ratio between input energy and observed energy by the pair of brake pads under dynamic conditions of inertia dynamometer. This should be preferably on the higher side for efficient braking. But at the same time, not too high also, resulting into jerky application of brakes.

4. Brake torque:- It is the force developed by the brakes under dynamic conditions and it is parallel to the COF. This parameter also like COF, should be moderate.
5. Wear:- wear has been reported in two units one corresponding to thickness of brake pad and other corresponding to weight loss for 50 cycles of braking operation. This parameter should be also moderate.
6. Temperature rise:- During braking operation, temperature of brake pad always rises. This rise might adversely affect the test parameters described above. It should be therefore moderate only. However, on account of defect in brake assembly, temperature data could not be obtained. But it has already been qualitatively ascertained that the temperature rise during testing of brake pads of has been moderate only, and, that, it has not significantly affected other test parameters. It is further to state number of test cycles and temperature rise are parallel parameters meaning thereby greater number of cycles indicate greater temperature rise.

5.3.1. Testing under low energy range (for AN 32 rotor Aircraft)

Fig.5.5 shows the test performance of six combinations of chemistry starting from FM08N to FM13N for AN 32 aircraft application. The shaded regions in these figures indicate maximum and minimum ranges of test parameters as described in the note below Table 5.5

Experimental points in these figures have not been shown for the sake of clarity and the curve smoothening has been done through Microsoft Excel. This has been done just to get a clearer picture of the performance. Shaded regions in these graphs wherever, shown, are corresponding to Table 5.5 which decides the suitability of application of brake pad developed in the present investigation.

There is a general trend in these figures such that a property changes are more severe upto 8 No. of cycles of the test. Thereafter, the property tends to stabilize. This is possibly because of the initial mechanical adjustments of stationery brake pads with moving inertia wheel during testing.

(a)

(b)

(c)

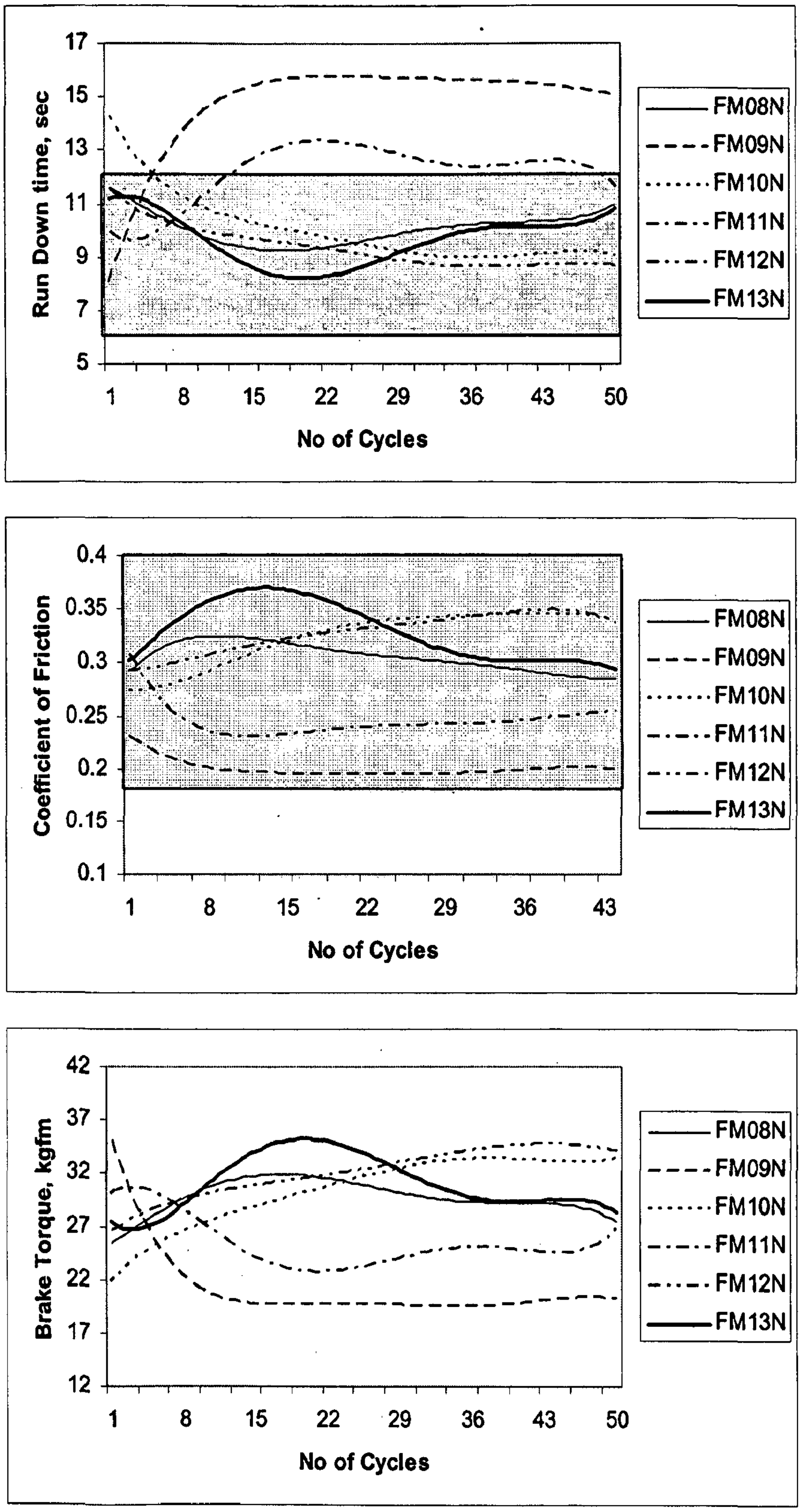


Fig.5.5 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque for test parameters corresponding to AN32 aircraft rotor application.

It can be easily inferred from these figures that with exception of FM09N (which has performed worst), all the combinations tested in the present investigation are suitable for AN-32 application. However, preference is in the following order:-

FM12N > FM10N > FM13N > FM08N > FM11N.

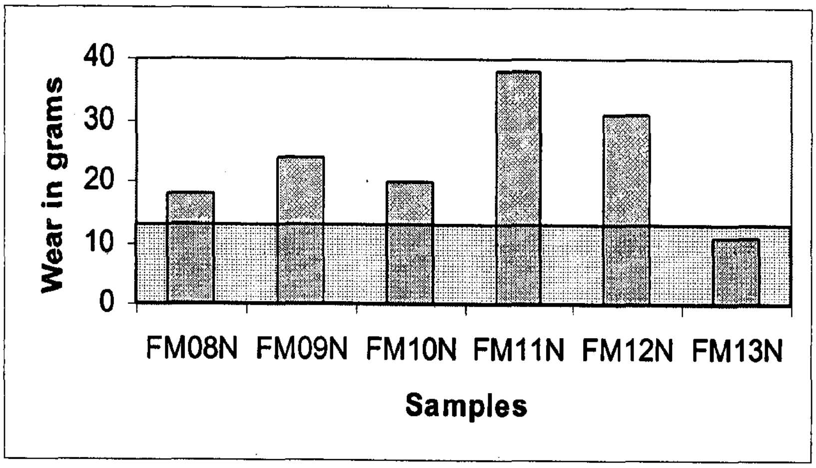
It may further be mentioned that the region for poor performance of FM09N, is due to higher hardness and lower density combination only There appears to be nothing wrong in the choices of chemistry of the pads.

All these samples could have given even more improved performance, if they were given annealing treatment instead of normalizing treatment. This is on account of the fact that annealing would lead to coarse grain microstructure which will offer better grip for the brake pads and hence would provide better performance.

The most significant aspect of these samples relate to stable performance with increasing number of cycles. In this context, brake fading tendency in our pads is completely absent. It is also noteworthy to mention that for application like AN 32 aircraft a high dose of abrasives in the chemistry formulation is not necessary. Mere addition of 0.8% Phosphorous takes care of abrasive resistance of the pads, and, accordingly, a very simple chemistry like FM08N is qualified for such an application. This aspect has emerged out from the present investigation only and has not been reported sofar.

Fig.5.6 depict wear in grams and as well as in thickness for 50 number of cycles in respect of combinations FM08N to FM13N. The shaded region in these figures pertain to permissible ranges of wear. It may be inferred that FM11N and FM12N show fairly high wear. Other formulations namely FM08N to FM10N and FM13N are qualifying in accordance with wear criterion based on thickness.

(a)



(b)

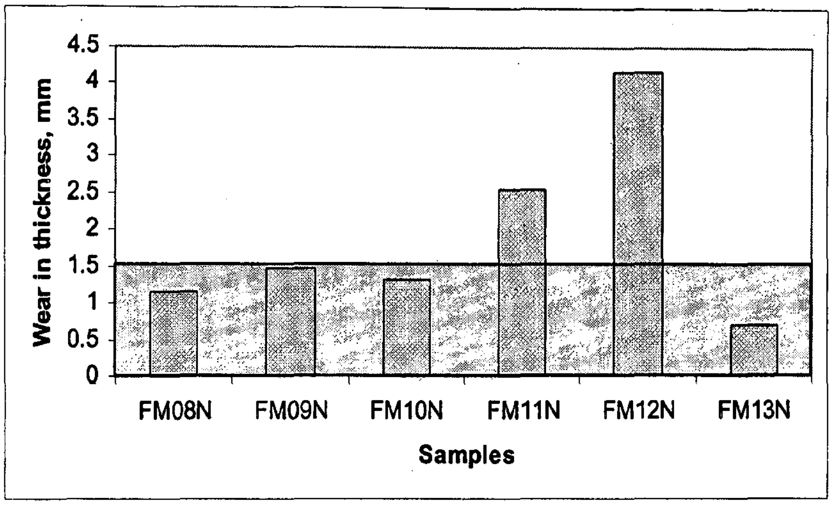


Fig.5.6 Variations in wear data (a) in grams, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to AN32 aircraft rotor application.

5.3.2. Testing under high energy conditions (for MIG 27 stator)

Fig.5.7 represents results corresponding to MIG 27 stator application. The symbols and terms employed have usual meanings as described in previous sections. Here an additional curve corresponding to MIG 21 sintered pad has also been shown but owing to limited thickness of the sintered pads, tests could be performed upto 21 cycles only. It is obvious from these figures, that all the formulations starting from FM08N to FM13N are suitable for such an application as the properties in every case fall within the shaded regions.

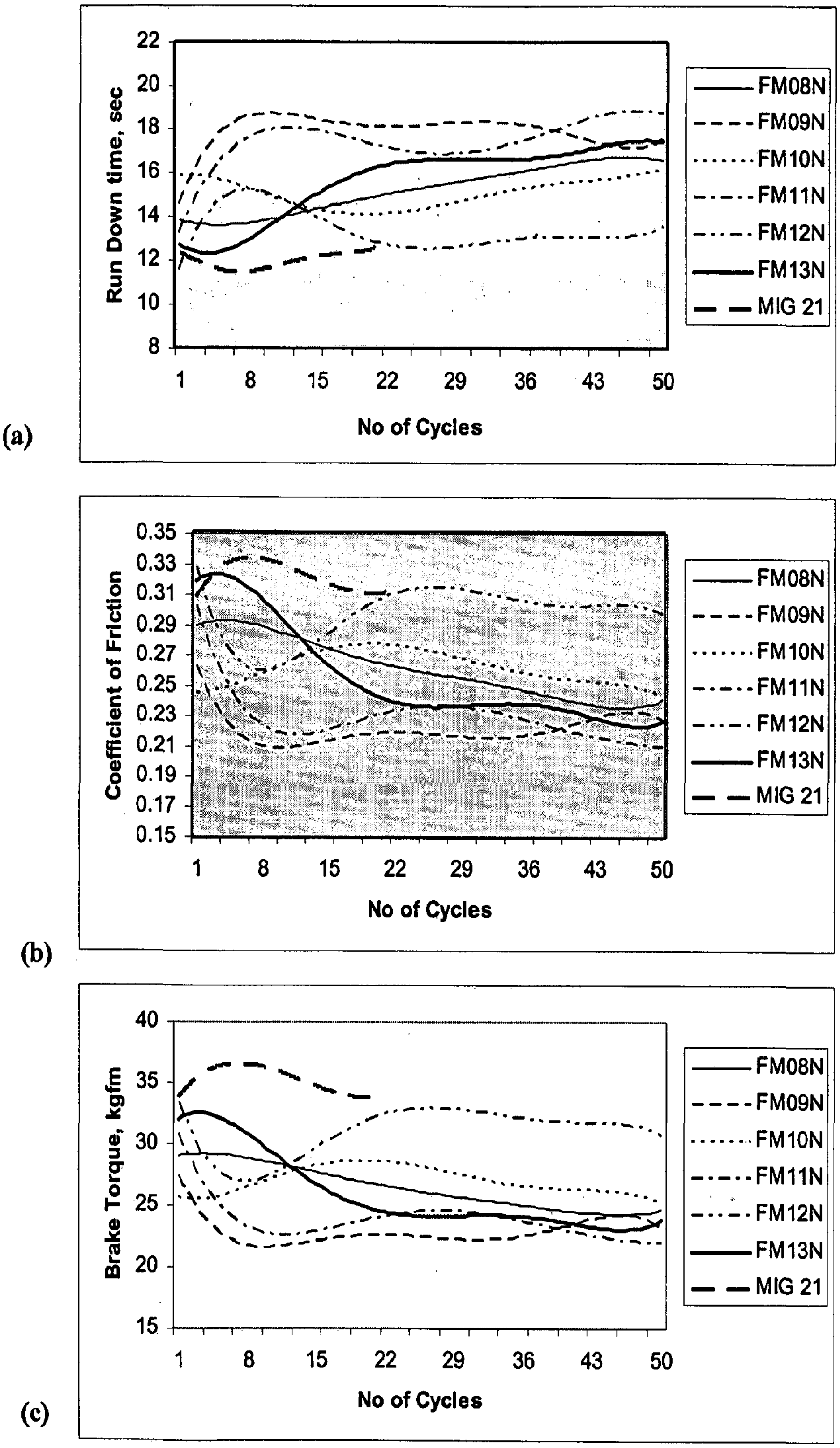
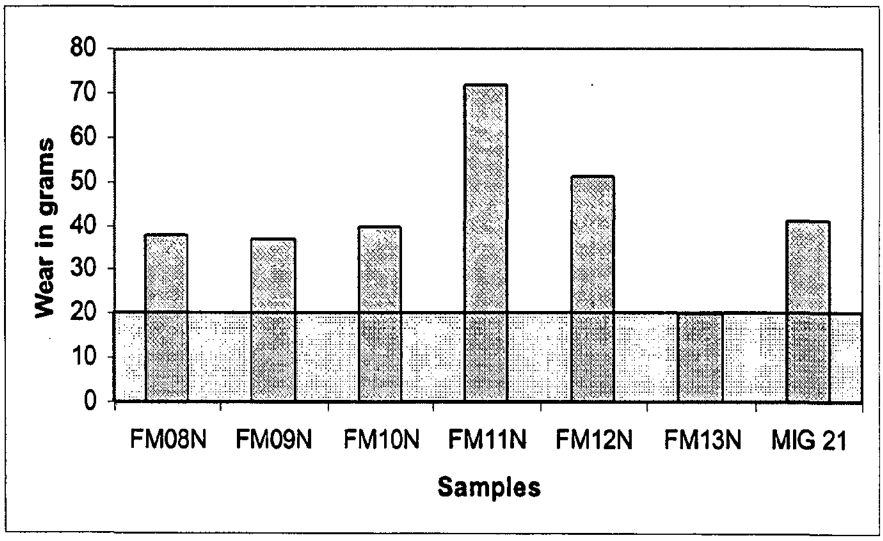
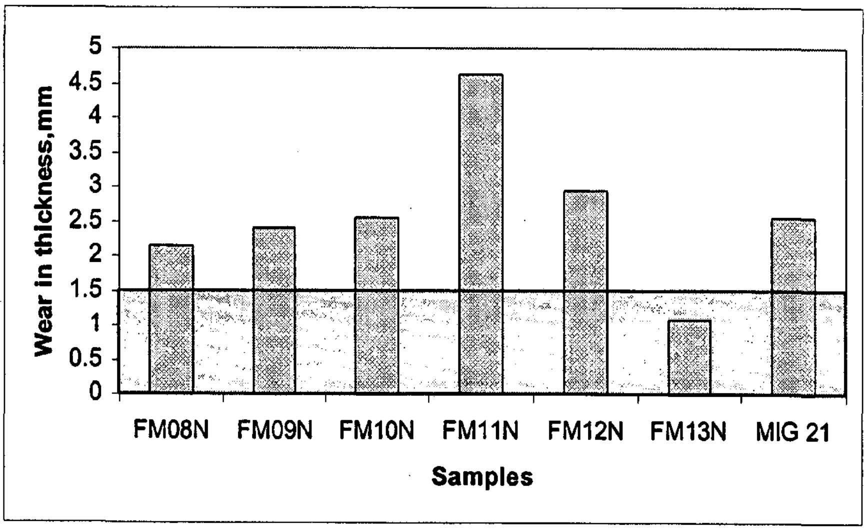


Fig. 5.7 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to MIG 27 aircraft stator application.

Fig. 5.8 represents wear data for 50 cycles of the test. According to this FM13N is within the permissible range whereas FM11N and FM12N are showing very high wear. As mentioned in previous section, this wear data could improve by annealing instead of normalizing such that all the samples would come within permissible limits of wear.



(a)



(b)

Fig. 5.8 Variations in wear data (a) in grams, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to MIG 27 aircraft stator application.

It is noteworthy to mention, that MIG 27 stator application is very specialized high energy condition for which chemistry of sintered pads is very complex and costly. In comparison to this, chemistry developed in the present investigation is much simpler and offer wide variety of choices to suit this challenging application.

It may further be stated test input and output parameters corresponding to MIG 27 stator and rotor application differ very marginally, they are likely to clear such an application as well. It can be therefore be inferred that the formulations developed in the present investigation along with processing would suit both these critical applications.

5.3.3. Role of Density and Annealing

The test described in the previous section corresponds to chemistry development in the present investigation. The data obtained in previous section made it very clear, that apart from chemistry, density and heat treatment also have prominent role to play. It was therefore decided in subsequent development to involve annealing cycle as the final heat treatment. It was observed during the trials that annealing temperature of 710°C with 5 hrs. duration would be the most suitable for sound brake pad processing. The density levels were altered by exercising number of repressings. Our technique of manufacturing permits us to control density parameter and therefore, it has been possible to produce these results which are not available in the literature. The results are described for different energy ranges of applications as given in Table 5.3.4

Table 5.6 Role of Density

Chemistry Nomenclature (as per table 4.1)	Energy levels	Density levels (in gm/cc) obtained			
		D1	D2	D3	D4
FM14A	Low	5.40	5.62	5.78	-
	Medium	5.28	5.46	5.70	5.85
	High	5.28	5.46	5.85	-
FM15A	Low	5.22	5.29	-	-
	Medium	5.23	5.42	-	-
FM16A	Low	5.72	-	-	-
	Medium	5.29	5.88	-	-

5.3.3.1 Density corresponding to AN 32 Rotor application

Fig 5.9 describes the test output parameters for AN 32 aircraft rotor application corresponding to three density levels of FM14A. According to these figures entire range of density from starting 5.4 to 5.78gm/cc qualify for the application.

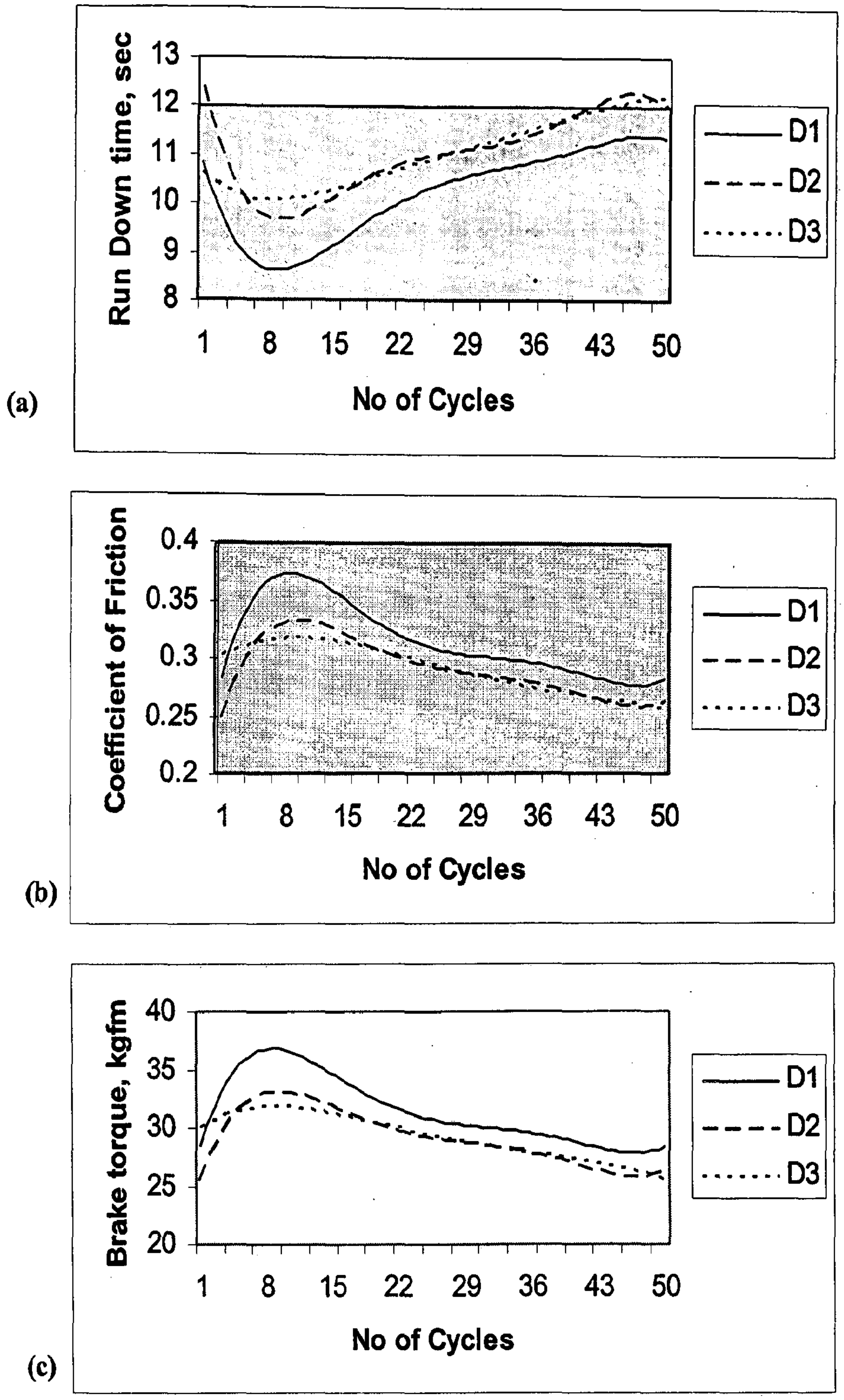
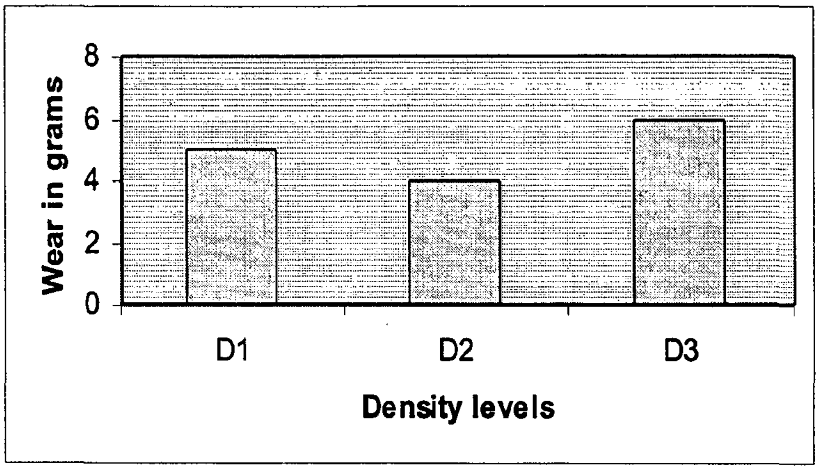


Fig. 5.9 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to AN 32 aircraft rotor application and chemistry of FM14A at different density levels as referred in Table 5.6.

Fig.5.10 represents wear data where again the entire density range is within the stipulated range of wear.

(a)



(b)

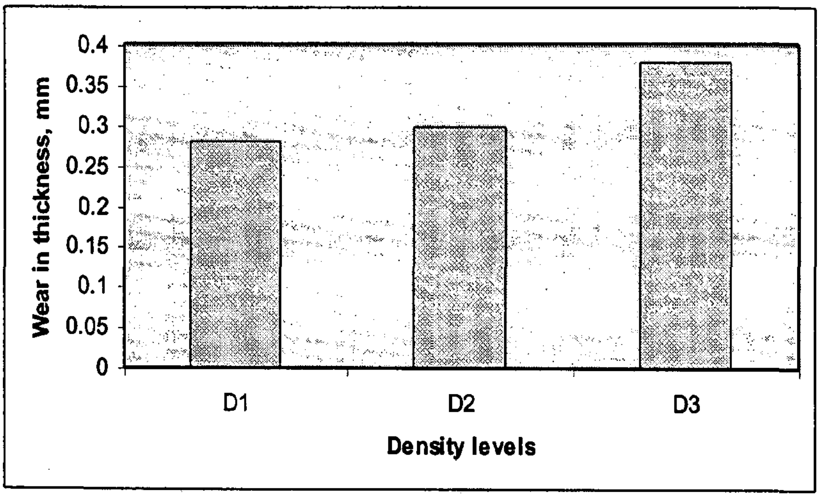


Fig. 5.10 Variation of wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to AN32 aircraft rotor application and chemistry of FM14A at different density levels as referred in Table 5.6.

Fig.5.11corresponds to FM15A for two density levels 5.22 and 5.29 gm/cc (which are much lower in comparison to 5.4 and 5.78) while RD time and COF appear to be reasonably O kay, the wear has gone much beyond the permissible range as shown in fig. 5.12. FM14A and FM15A are not different in chemistry but because of the significance difference in their density levels, the performance of FM15A has detoriated.

(a)

(b)

(c)

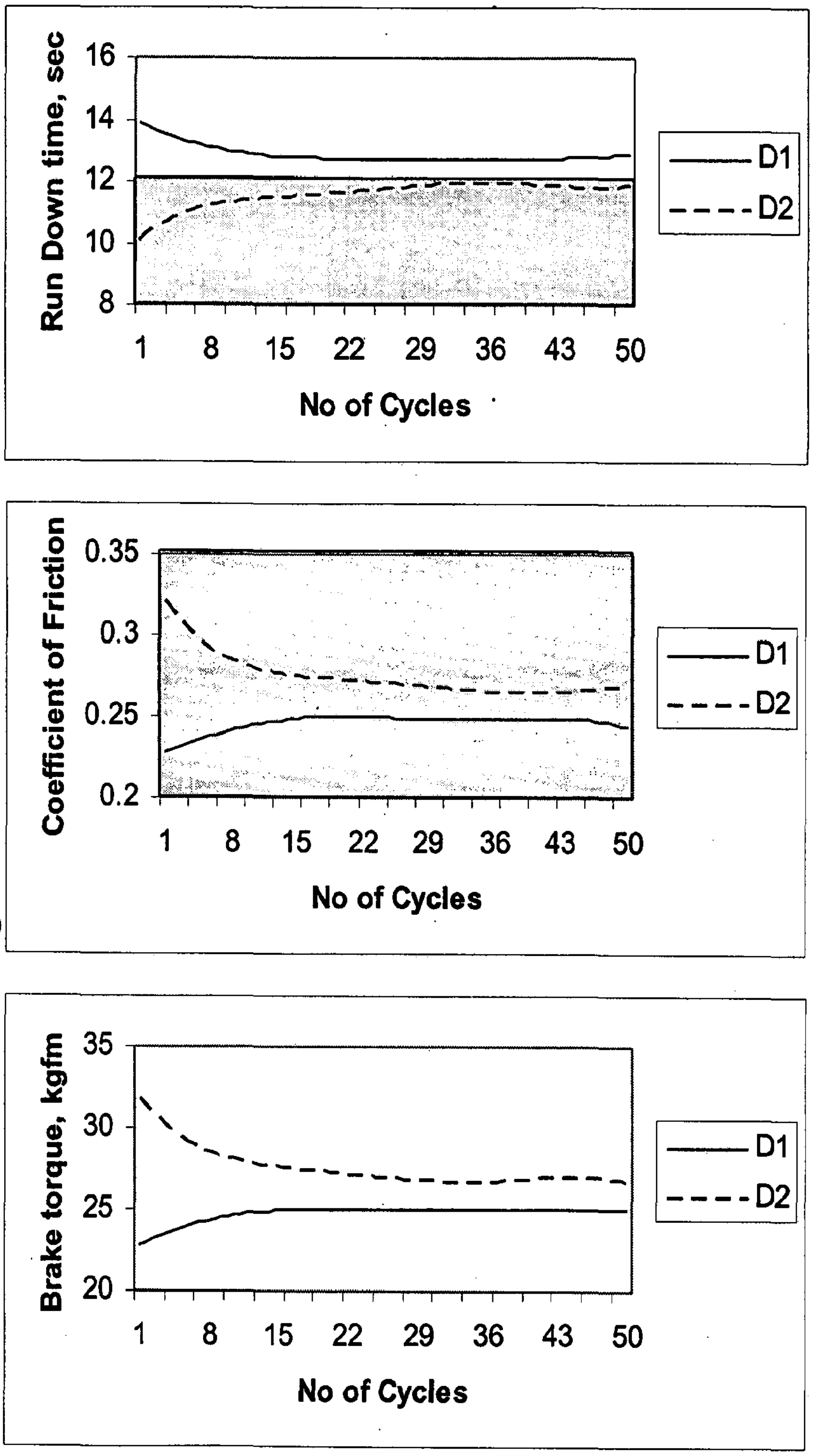
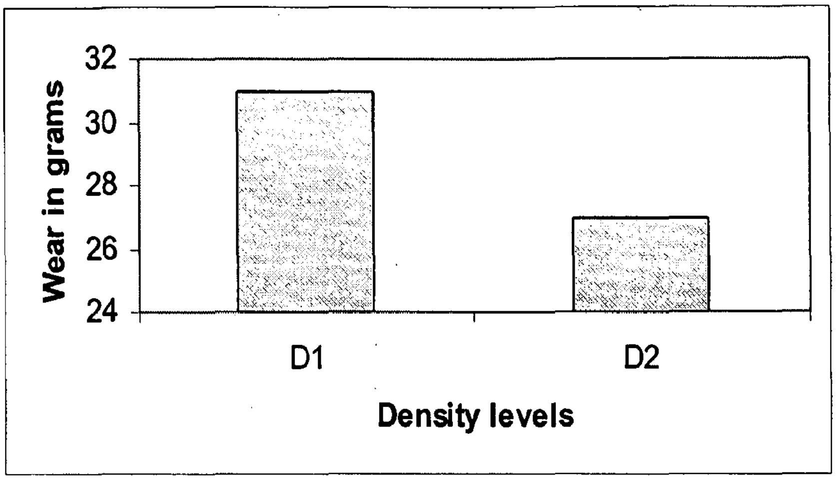


Fig. 5.11 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to AN 32 aircraft rotor application and chemistry of FM15A at different density levels as referred in Table 5.6.

(a)



(b)

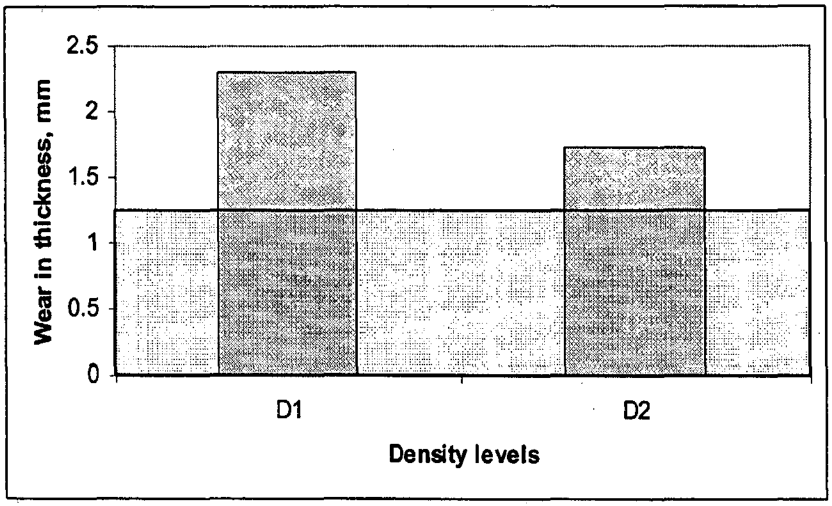


Fig.5.12 Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to AN32 aircraft rotor application and chemistry of FM15A at different density levels as referred in Table in 5.6.

Fig 5.13 corresponds to FM16A with only one density level 5.72. In this case, while it qualifies for this application, the wear data is higher by about 60% from permissible range as shown in figure 5.14 (a). However, wear from thickness point of view is close to be interpreted as qualifying.

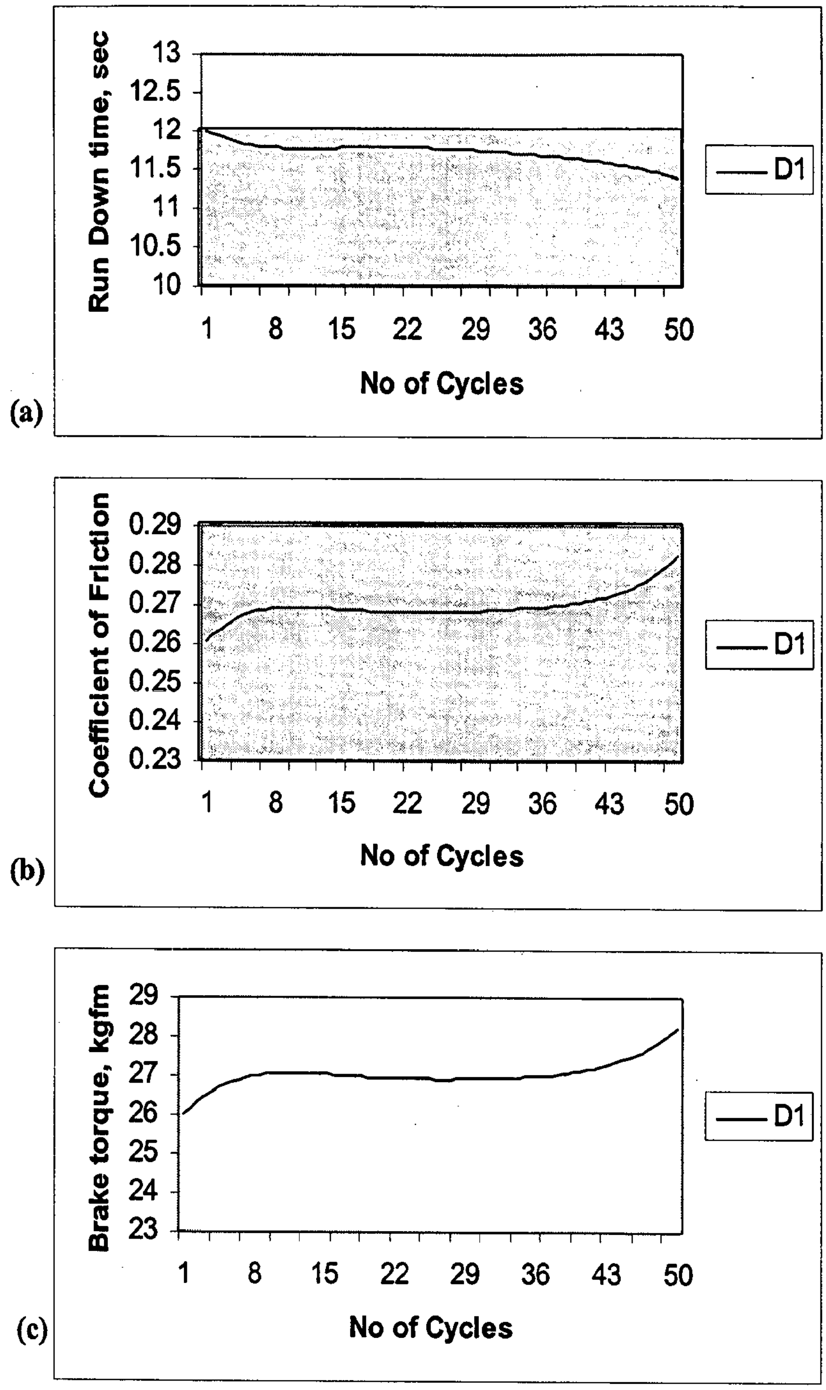
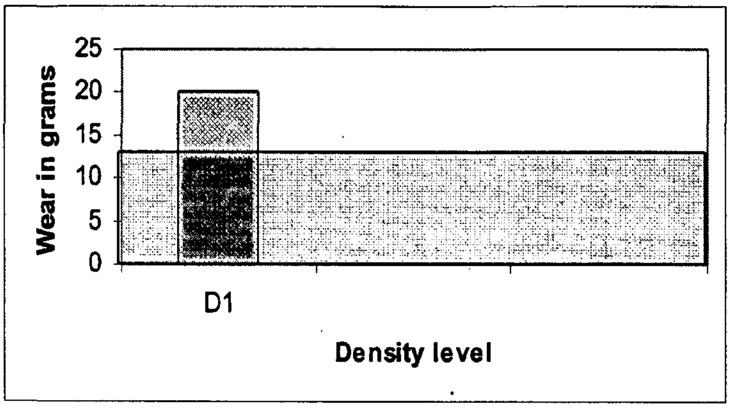


Fig. 5.13 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to AN 32 aircraft rotor application and chemistry of FM16A at different density levels as referred in Table 5.6.

(a)



(b)

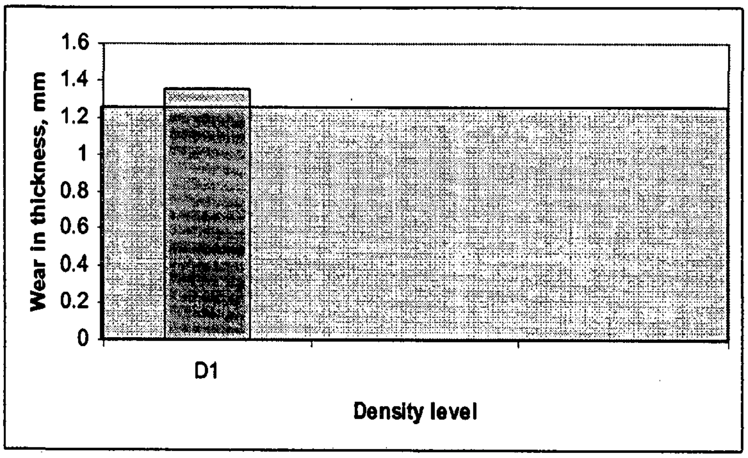


Fig. 5.14.Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to AN32 aircraft rotor application and chemistry of FM16A at different density levels as referred in Table in 5.6.

Based on the results described above, it can be concluded that higher density greater than 5.4 gm/cc of brake pad friction element is desirable for low energy application such as AN 32. But contents of the lubrication (such as Ba SO_4, Sb_2S_3, Sn, and graphite) should not exceed 13%. Because FM16A inspite of higher density, had total lubricants of the order of 14.5% and it has marginally qualified at high density level.

5.3.3.2 Density corresponding to MIG-27 stator application

Fig.5.15 represents four density levels starting from 5.28 to 5.85 gm/cc corresponding to FM14A chemistry. The entire range of density studied in the present investigation qualified for MIG 27 stator application. For the sake of comparison, data corresponding to MIG 21 sintered specimen has also been shown. Fig.5.16 shows the wear data for these density levels, and here also the different density levels qualify for the application. MIG 21 sample however does not qualify, and shows excessive wear for obvious reasons.

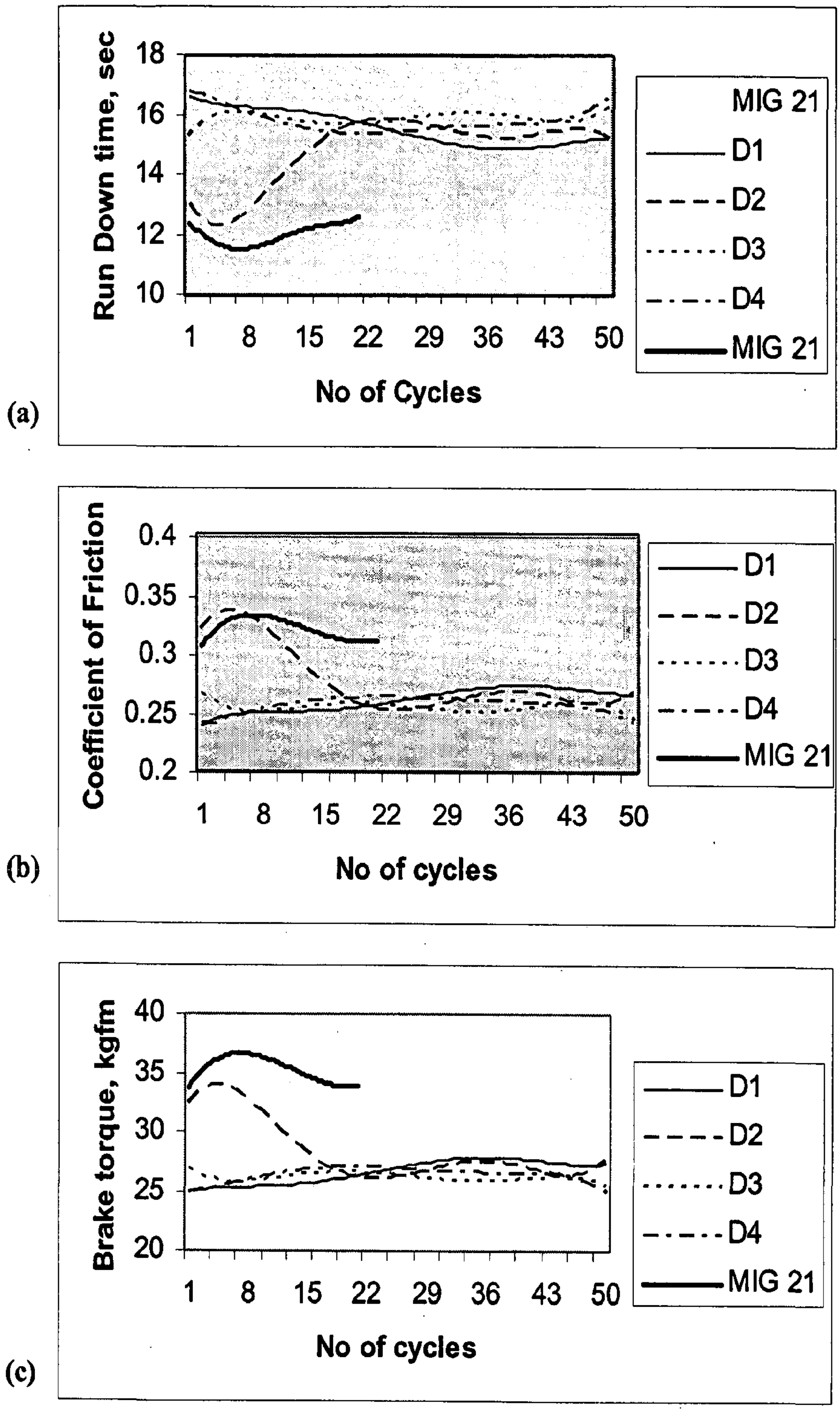
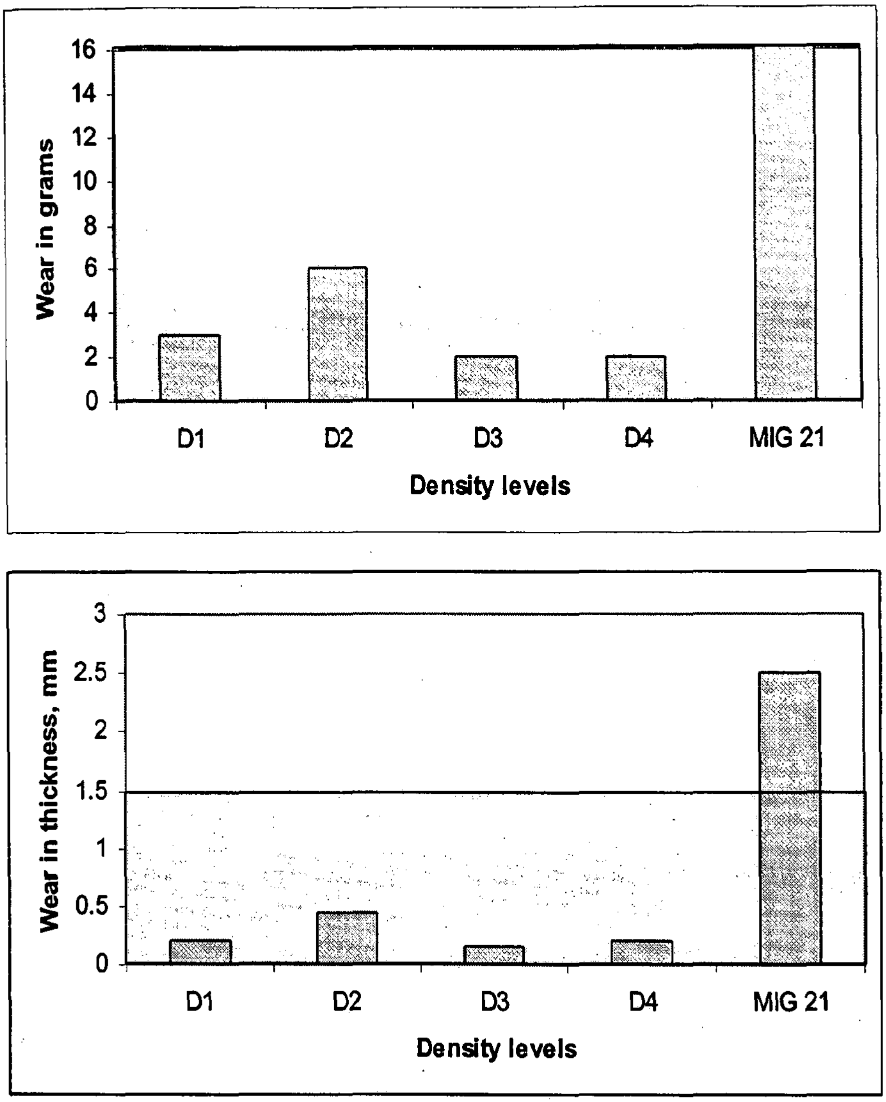


Fig. 5.15 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM14A at different density levels as referred in Table 5.6.

(a)



(b)

Fig. 5.16. Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM14A at different density levels as referred in Table in 5.6. (*Computed wear data for MIG 21 sample for 50 cycles comes out to be 41 gms)

Fig.5.17 represents the effect of density (ranging from 5.23to 5.42gm/cc) corresponding to FM15A chemistry. According to this figure both density levels qualify for the application, however the wear data for corresponding to FM15A is much higher and does not qualify for this application as shown in Fig. 5.18

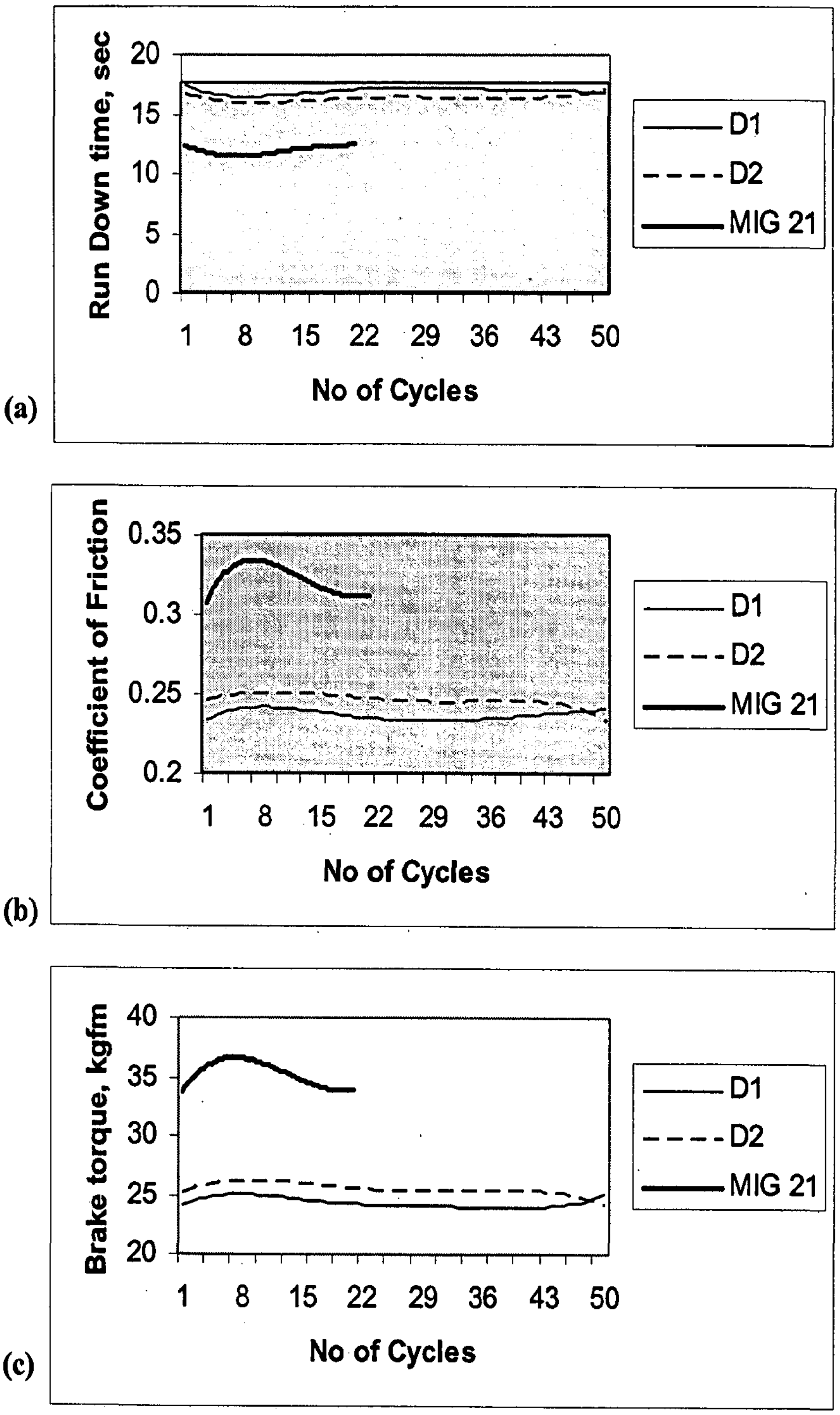
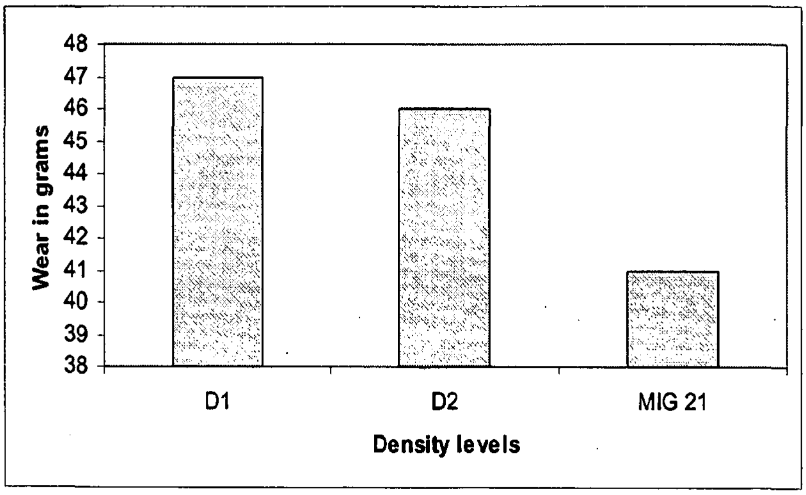
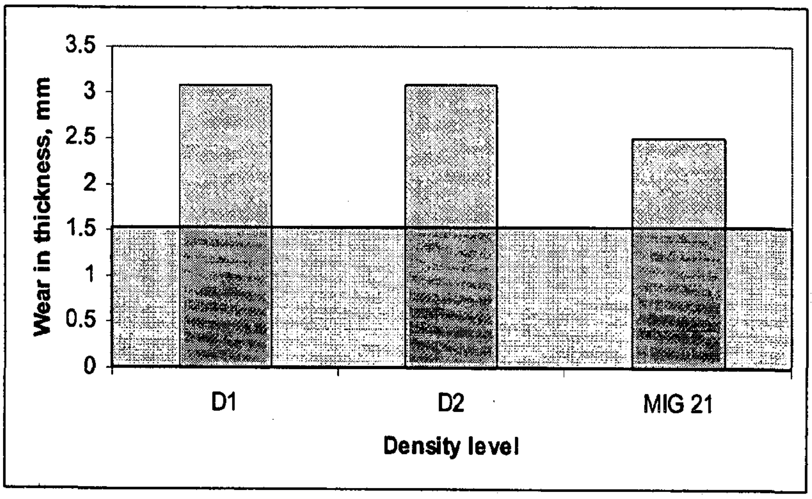


Fig. 5.17 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM15A at different density levels as referred in Table 5.6.



(a)

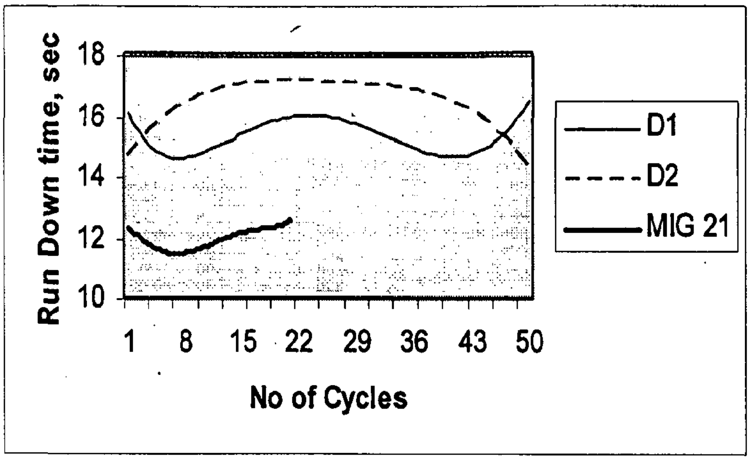


(b)

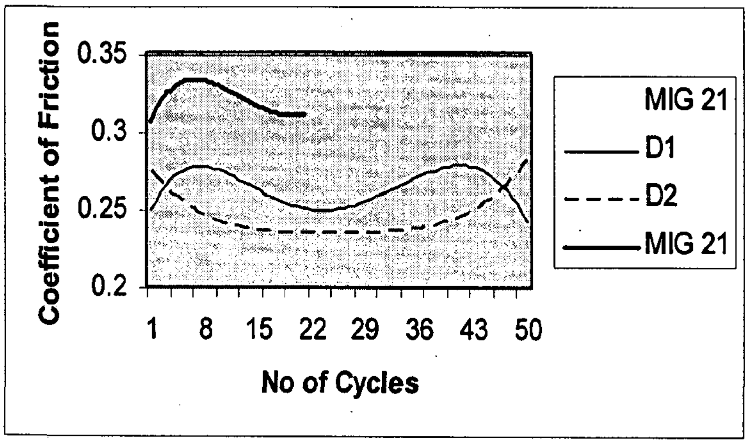
Fig. 5.18. Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM15A at different density levels as referred in Table in 5.6.

Fig.5.19 describes the performance of FM16A with density values varying from 5.29 to 5.88gm/cc. According to this fig. both the density levels qualify for application however, wear data corresponding to 5.88gm/cc marginally exceeds the prescribed limits as shown in fig. 5.20 and may be accepted as qualified.

(a)



(b)



(c)

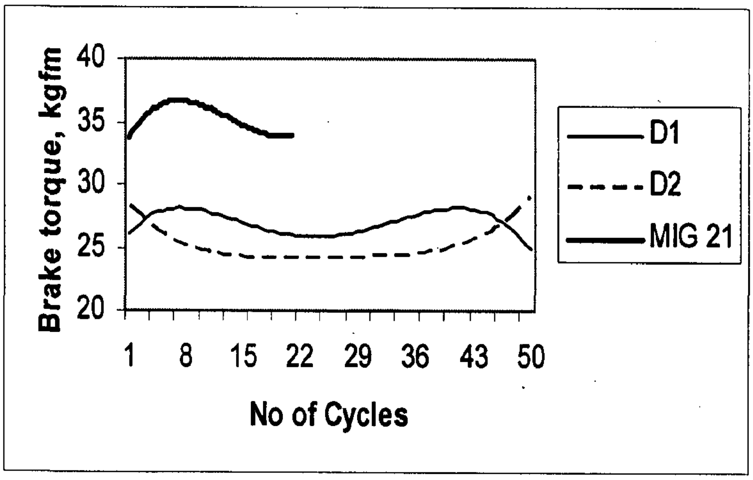
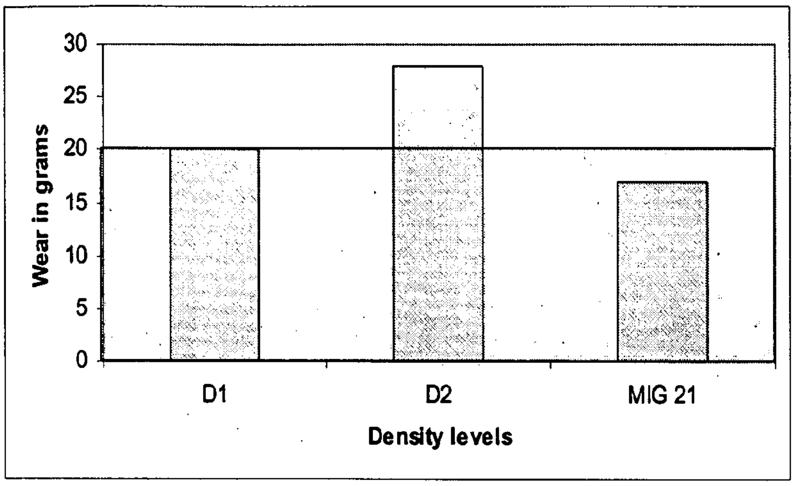


Fig. 5.19 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM16A at different density levels as referred in Table 5.6.

(a)



(b)

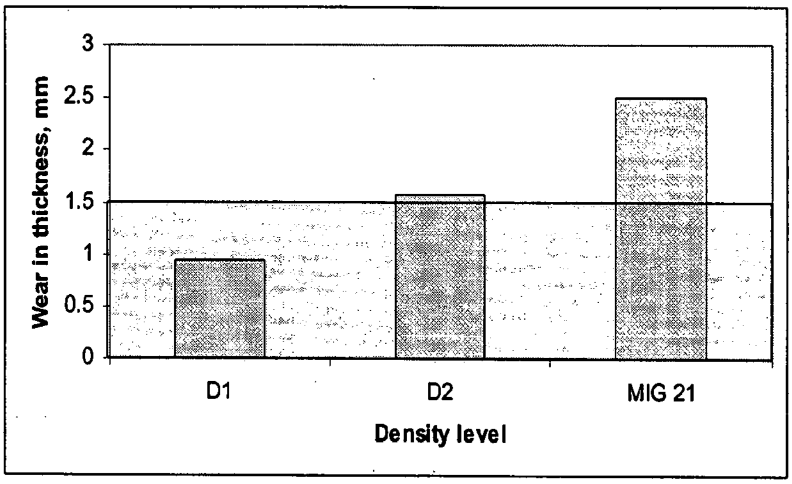


Fig.5.20. Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to MIG 27 aircraft stator application and chemistry of FM16A at different density levels as referred in Table in 5.6.

It may be therefore inferred that density for such a range of application is significant parameter and lower density is desirable for improved wear performance. Furthermore, quality of lubricants such as Sb_2S_3 would be more suited in comparison $BaSO_4$ and BN.

5.3.3.3 Density corresponding to MIG 27 rotor application

Fig 5.21 represents the role of density varying from 5.28 to 5.85gm/cc for FM14A chemistry. According to this fig. the entire range qualifies for the application. Fig.5.22 shows the wear data where again the entire density range qualify for the application however, lower density ranges (5.28, 5.46) are comparatively more suitable for such applications.

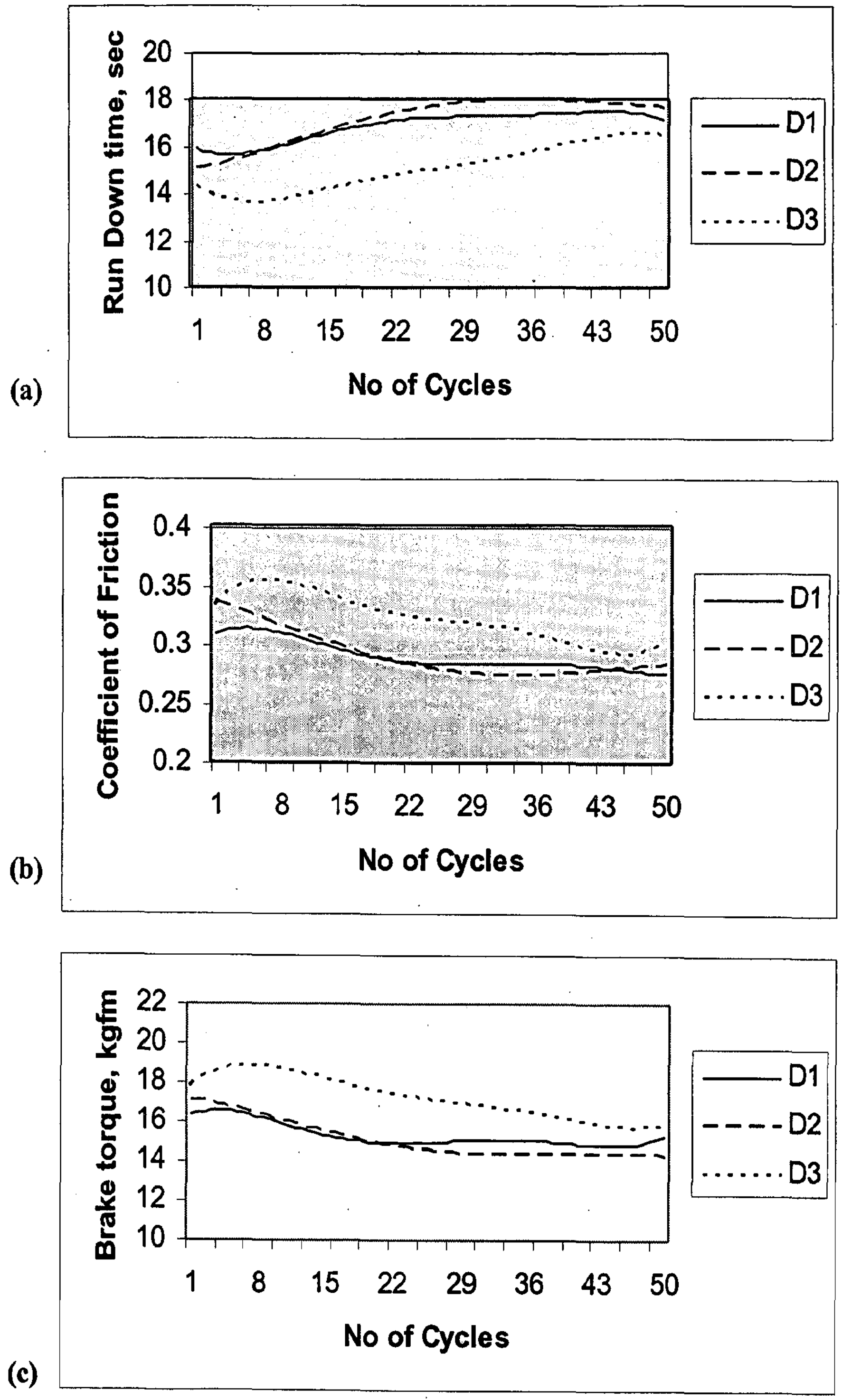
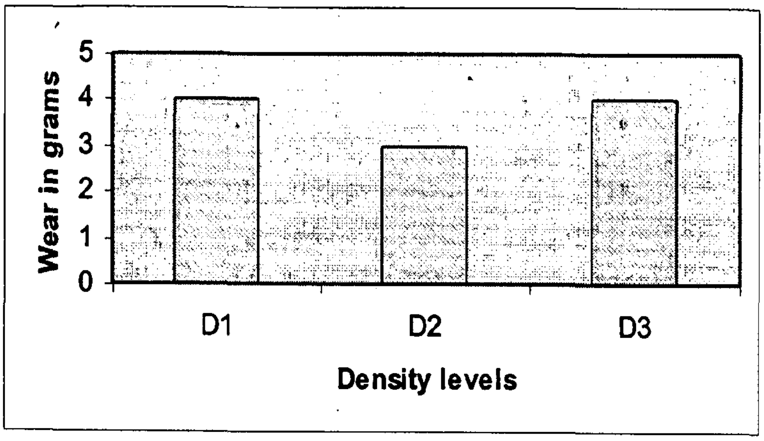


Fig. 5.21 Variations in (a) Run down time, (b) Coefficient of friction, and (c) Brake torque test parameters corresponding to MIG 27 aircraft rotor application and chemistry of FM14A at different density levels as referred in Table 5.6.

(a)



(b)

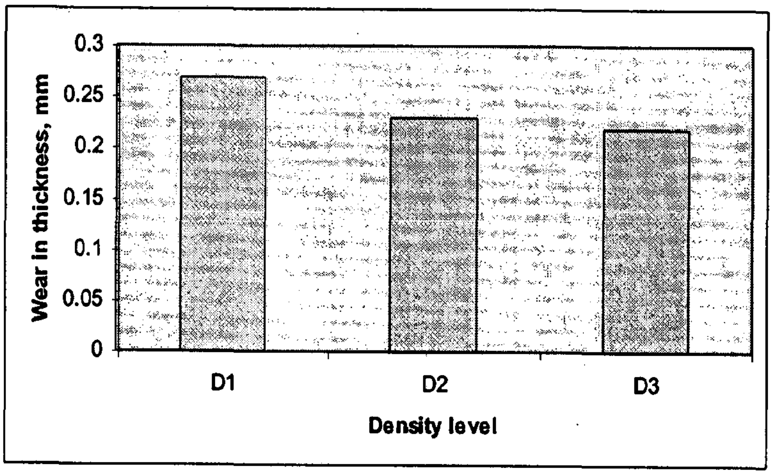


Fig. 5.22. Variation in wear data (a) in gram, and (b) in thickness for 50 numbers of cycles for test parameters corresponding to MIG 27 aircraft rotor application and chemistry of FM14A at different density levels as referred in Table in 5.6.

5.3.4 Summary of Dynamometer Test Results

All the results pertaining to sub-scale dynamometers mentioned above are summarized in Table No 5.7 for a cursory look and quick comparisons.

As a final conclusion, it may be inferred that for relatively lower energy applications; one should aim for high density ranges preferably >5.5gm/cc whereas for high energy applications such as MIG 27 rotor, intermediate density ranges of the order of 5.45gm/cc would be suitable, of course, with suitable choice of lubricants.

Furthermore, it is established form the present investigation that apart from chemistry, annealing treatment and density adjustments are equally important for different energy ranges of application.

Table 5.7 Summery of Sub-scale dynamometer test results

a) Test parameters for AN32 rotor applications as per table 5.3.2

Sample	50 Cys.	RD Revl.	RD time, Sec	COF	Mean Torque, kgfm	Peak Torque, kgfm	Mean Drag, kgf	Peak Drag, kgf	Wear			
									Thick.,mm		Wt., gm	
									Pad1	Pad2	Pad1	Pad2
FM08N	Max	106	12.7	0.33	33	86	182	476	0.86	1.43	16	20
	Min	75	9.0	0.23	24	39	131	218				
	Avg	84	10.1	0.30	30	51	165	286				
FM09N	Max	135	16.2	0.37	35	66	192	366	1.3	1.62	21	26
	Min	72	8.6	0.19	19	17	106	94				
	Avg	123	14.8	0.21	21	43	117	241				
FM10N	Max	127	15.3	0.36	34	72	192	398	1.27	1.36	18	21
	Min	72	8.7	0.20	20	49	112	274				
	Avg	83	10.0	0.31	30	61	169	341				
FM11N	Max	115	13.8	0.34	34	82	188	454	2.40	2.35	38	37
	Min	74	8.8	0.22	22	44	124	244				
	Avg	101	12.1	0.25	25	52	141	288				
FM12N	Max	103	12.3	0.35	35	81	196	447	1.88	2.29	29	32
	Min	70	8.4	0.25	25	50	137	275				
	Avg	78	9.3	0.32	32	57	178	315				
FM13N	Max	96	11.5	0.38	36	69	201	385	0.8	0.61	13	9
	Min	63	7.6	0.26	25	40	141	223				
	Avg	80	9.7	0.32	31	52	173	291				
FM14AA1	Max	105	12.6	0.35	34	73	190	403	0.40	0.21	5	3
	Min	78	9.4	0.25	25	50	140	275				
	Avg	92	11.0	0.29	29	60	161	331				
FM14AC3	Max	105	12.6	0.33	33	77	183	428	0.47	0.29	8	4
	Min	81	9.7	0.25	25	50	141	280				
	Avg	92	11.0	0.29	29	58	162	323				
FM14AB1	Max	98	11.8	0.38	38	71	209	394	0.38	0.19	6	4
	Min	71	8.5	0.27	27	53	151	296				
	Avg	85	10.2	0.32	31	61	175	339				
FM15AB1	Max	116	13.9	0.25	25	48	141	267	2.12	2.49	31	31
	Min	104	12.5	0.23	23	36	128	201				
	Avg	107	12.9	0.25	25	41	138	229				
FM15AB3	Max	101	12.1	0.32	32	56	179	314	1.73	1.74	27	27
	Min	83	9.9	0.26	26	37	146	207				
	Avg	96	11.6	0.27	28	44	153	242				
FM16AB1	Max	105	12.6	0.28	28	62	156	343	1.42	1.29	21	20
	Min	92	11.0	0.25	25	42	141	234				
	Avg	98	11.7	0.27	27	47	150	263				

b)Test parameters for MIG 27 stator applications as per table 5.3.2

Sample	50 Cys.	RD revl.	RD time, sec.	COF	Mean Torque, kgfm	Peak Torque, kgfm	Mean Drag, kgf	Peak Drag. kgf	Wear			
									Thick.,mm		Wt., gm	
									Pad1	Pad2	Pad1	Pad2
FM08N	Max	184	17	0.31	31	64	170	354	2.26	2.01	41	35
	Min	139	12.8	0.23	24	36	133	197				
	Avg	165	15.2	0.26	26	45	147	252				
FM09N	Max	209	19.3	0.27	28	58	154	322	1.85	2.92	28	46
	Min	156	14.4	0.20	21	34	117	190				
	Avg	194	17.9	0.22	23	42	127	234				
FM10N	Max	178	16.5	0.28	29	63	161	352	2.49	2.62	39	41
	Min	150	13.9	0.24	25	47	136	258				
	Avg	163	15.0	0.26	27	54	150	299				
FM11N	Max	214	19.8	0.31	31	58	173	322	4.83	4.44	79	64
	Min	141	13.0	0.20	21	40	117	223				
	Avg	189	17.4	0.23	24	46	132	258				
FM12N	Max	169	15.6	0.32	33	68	183	377	3	2.91	57	45
	Min	129	11.9	0.25	26	49	146	274				
	Avg	145	13.3	0.30	31	59	172	325				
FM13N	Max	197	18.2	0.34	34	61	187	340	1.26	0.94	23	17
	Min	128	11.9	0.22	22	35	124	196				
	Avg	170	15.7	0.26	26	41	144	230				
FM14AA1	Max	187	17.3	0.27	28	61	154	341	0.18	0.23	2	2
	Min	162	15.0	0.23	24	41	134	229				
	Avg	171	15.8	0.26	26	49	146	275				
FM14AC3	Max	179	16.5	0.27	28	63	154	349	0.14	0.16	2	2
	Min	162	14.9	0.24	25	41	139	227				
	Avg	172	15.8	0.26	26	49	145	270				
FM14AB1	Max	180	16.7	0.38	38	69	209	385	0.54	0.34	7	5
	Min	120	11	0.24	25	43	139	242				
	Avg	160	14.8	0.28	28	53	157	292				
FM14AB1	Max	183	16.9	0.29	29	59	161	328	0.25	0.15	3	2
	Min	154	14.2	0.24	25	44	136	242				
	Avg	168	15.5	0.26	27	50	148	277				
FM15AB1	Max	191	17.6	0.25	25	53	141	294	3.06	3.09	46	47
	Min	177	16.4	0.23	24	12	131	202				
	Avg	180	16.7	0.24	24	42	136	231				
FM15AB3	Max	185	17.1	0.25	26	50	146	279	2.87	3.3	48	44
	Min	171	15.8	0.23	24	40	135	220				
	Avg	176	16.3	0.25	25	44	141	244				
FM16AB1	Max	189	17.5	0.29	30	60	165	336	1.9	1.27	31	24
	Min	151	14.0	0.23	24	38	132	211				
	Avg	179	16.5	0.25	25	49	140	271				
FM16AB3	Max	180	16.6	0.29	29	70	163	390	1.52	0.36	27	12
	Min	153	14.1	0.24	25	44	138	244				
	Avg	166	15.4	0.26	27	52	150	288				

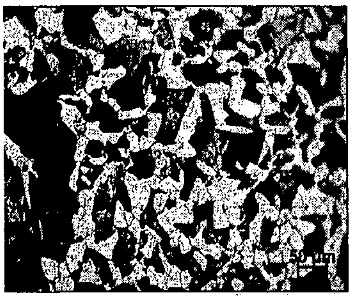
c) Test parameters for MIG 27 rotor applications as per table 5.3.2

Sample	50 Cys.	RD Revl.	RD time, sec.	COF	Mean Torque, kgfm	Peak Torque, kgfm	Mean Drag, kgf	Peak Drag. kgf	Wear			
									Thickness mm		Weight, gm	
									Pad1	Pad2	Pad1	Pad2
FM14AA1	Max	223	18.5	0.34	17	38	95	213	0.30	0.16	3	3
	Min	181	15	0.27	14	27	78	150				
	Avg	207	17.2	0.29	15	31	84	172				
FM14AC3	Max	203	16.8	0.37	20	64	108	356	0.22	0.23	4	3
	Min	160	13.2	0.29	15	32	86	180				
	Avg	181	15	0.32	17	39	96	217				
FM14AB1	Max	216	17.9	0.33	17	78	94	431	0.24	0.31	3	4
	Min	183	15.1	0.28	14	26	80	144				
	Avg	205	16.9	0.29	15	36	85	197				

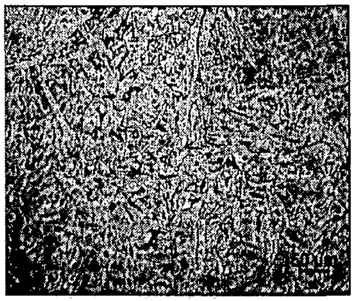
5.4. Metallographic examination

On the basis of detailed metallographic examination carried out, we have observed that the microstructures of friction layer as well as backing plate are finer and more homogeneous in case of forged samples in comparison to sintered pad represented by MIG 21 sample.

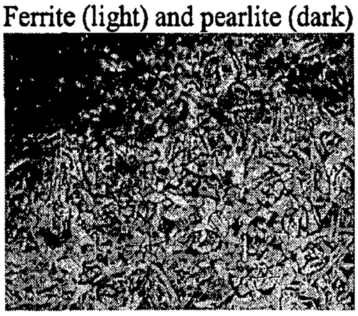
To illustrate this, three random forged samples were taken and compared with that of MIG 21. Fig. 5.23 consist of backing plate microstructures. It may be seen that backing plate of MIG 21 sample consists of ferrite-pearlite coarse structure with roughly 50% of pearlite in it. In contrast to this backing plate in forged samples is essentially a low carbon steel but with very fine ferrite grains, and, in one case it is Widmanstattan ferrite. This is because of high speed forging employed during processing providing fast cooled fine grained structure which in turn yields high strength backing plate without resorting to higher carbon steel. We are also likely to get the better toughness of backing plate due to fine ferrite grain structure which may help better engagement of brakes in actual applications.



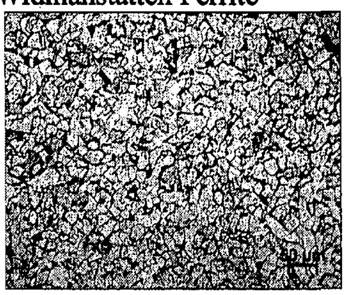
Mig 21 backing plate
Ferrite (light) and pearlite (dark)



FM13N-backing plate
Widmanstatten Ferrite



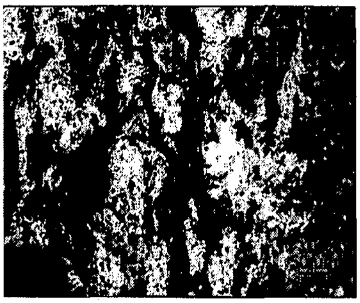
FM09N- backing plate



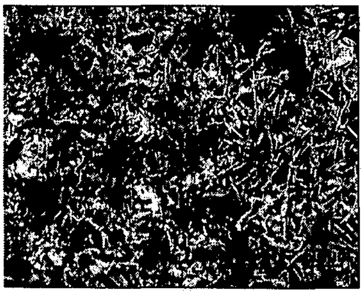
FM14AA1- backing plate

Fig.5.23 Microstructure of Backing plates of Sintered and Hot powder forged Friction pads.

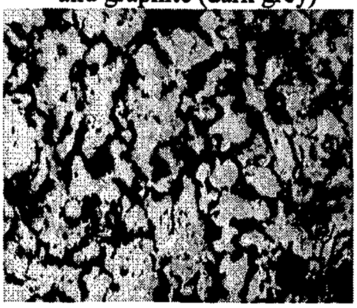
Fig.5.24 consist of microstructures of different friction materials. It may be noted that distribution of graphite in MIG 21 sample is very coarse and blocky whereas in forged samples it is much finer and better distributed. Apart from this, graphite in MIG 21 sample appears to be oriented perpendicular to the direction of pressing whereas forged samples do not have such orientation. Dull grey particles of SiC (to be confirmed after EDAX analysis) are also clearly visible in MIG 21 sample and these particles are very coarse (more than 100 microns). The distribution of other constituents in forged samples is also uniform. But variety of structures are developed depending upon the chemistry and subsequent treatments given to the forged samples. This is clear from the three microstructure shown the figure 5.4.2. Actual characterization of other phases and their distributions will follow in the section of EDAX analysis.



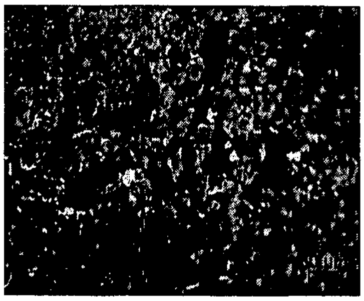
Mig 21- Friction Material
Coarse pearlite with uniform distribution of SiC particles (dull grey) and graphite (dark grey)



FM13N- Friction Material
ferrite with graphite flakes thin elongated (black) grains.



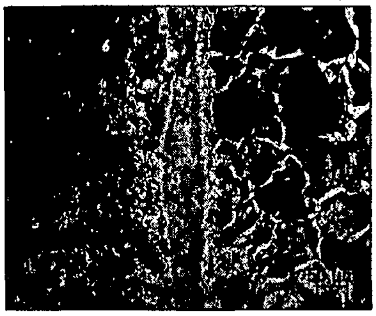
FM09N- Friction Material



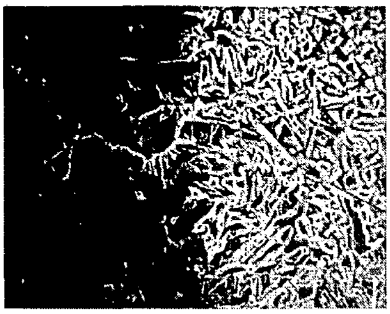
FM14AA1- Friction Material

Fig.5.24 Microstructure of Friction Materials Sintered and Hot powder forged Friction pads.

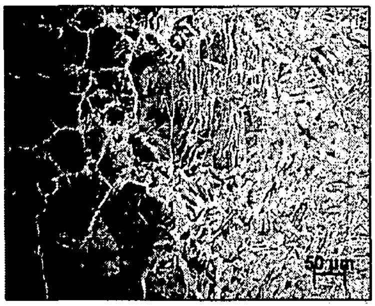
Fig.5.25 contains microstructure of intermediate location having backing plate on one side and friction material on another side. It may be seen that in case if MIG-21 sample there is distinct layer at the interface of about 60 microns thick separating backing plate and friction material. This layer is essentially electroplated Ni layer over the backing plate prior to sintering (this will be conformed by EDAX analysis). This layer appears to hinder diffusion carbon from friction element to backing plate and it is likely to weaken the joint strength which was indicated in bend test results. Due to the presence of this layer carbon appears to be segregated adjacent to the friction element side (Due to blockage of diffusion process by this layer) leading to coarse pearlite structure surrounded by ferrite network. In contrast to this, the interface layer in forged brake elements is completely absent. In fact, there is no such plating performed during the present investigation. The only plating done in the present investigation is of copper which has fully diffused towards friction element side during processing. In absence of any interface layer, carbon can easily diffuse towards the backing plate side leading to development of fully pearlitic structure in the adjacent backing plate. Depending upon the subsequent treatments performed on the forged samples, variety of fine microstructures are observed starting from bainitic, martensitic and fine ferritic (necklace type decoration) in the friction element adjacent to backing plate. All the microstructures of forged samples at the interface indicate strong bonding between backing plate and friction element because of enhanced diffusion of carbon from friction element side to backing plate side and absence of any layered structure at the interface. No attempt has been made to study the response of subsequent treatment on strength of joint in the present in the investigation. However, looking into the variety of microstructures developed in the present investigation, it will be worthwhile to further investigate the details of strength verses heat treatments in such composite samples so treatments that one can develop optimum joint strength for efficient braking applications. It is all the more important since sintered materials suffer from this limitation very seriously.



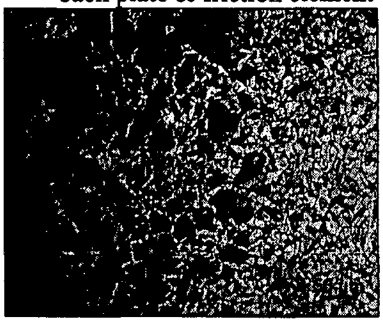
Mig 21 - Friction material & Back plate
Ni (~100μm) layer at interface



FM09N-Friction material & Back Plate
Coherent interface between
back plate & friction element



FM13N- Friction material & Back plate



FM14AA1-Friction material & Back plate

Fig.5.25 Microstructure of Friction Material with backing plate of Sintered and Hot powder forged Friction pads.

5.5 EDAX analysis of selected samples

Fig. 5.26 (a) represents the EDAX microstructure corresponding to sintered MIG 21 sample at a magnification of 100X. The first picture is the microstructure of the region which has been analyzed for distribution of different elements. In subsequent pictures distribution of following elements are shown. This is clear from the pictures that carbon is visible in the form of flakes, and coarse copper particulates are separately visible. Distribution of oxygen and silicon is highly heterogeneous, and coarse. Fig. 5.26 (b) shows combination of elements such as silicon and oxygen, silicon and carbon, magnesium and oxygen in the form of overlaps. It may be inferred from these that SiC particles appear to have oxidized at the surface and hence overlapping of SiC and SiO_2 appear identical. Our observation from the previous section is confirmed that SiC particles are +100μ and they are heterogeneously distributed. Similar features are available in Fig.5.27 and 5.28 at different locations of MIG 21 sintered sample.

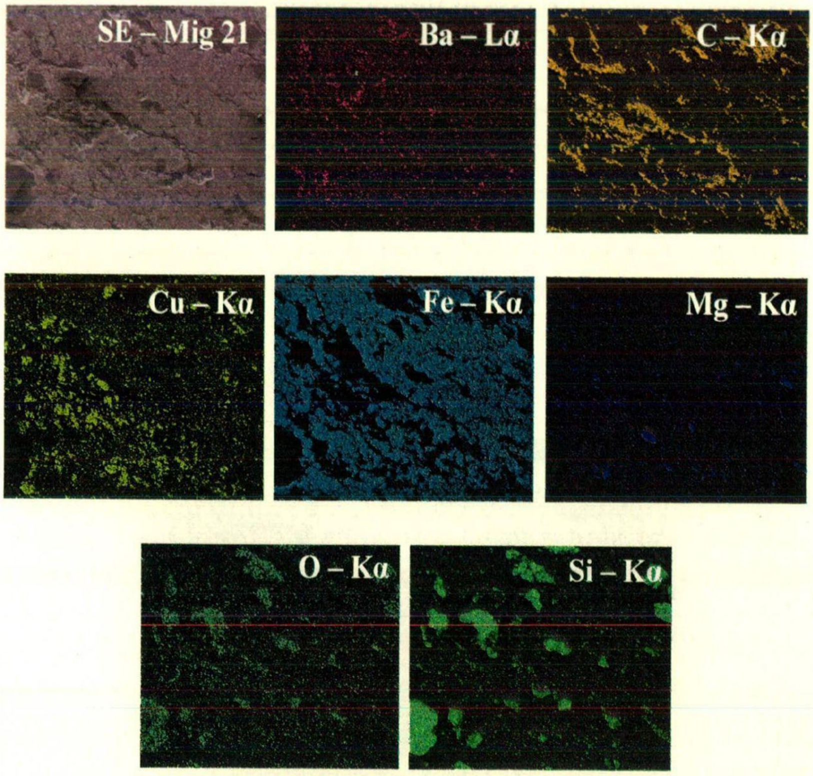


Fig. 5.26 (a) X-Ray mapping at 100X showing particle distribution of Mig 21 Sintered Friction Material

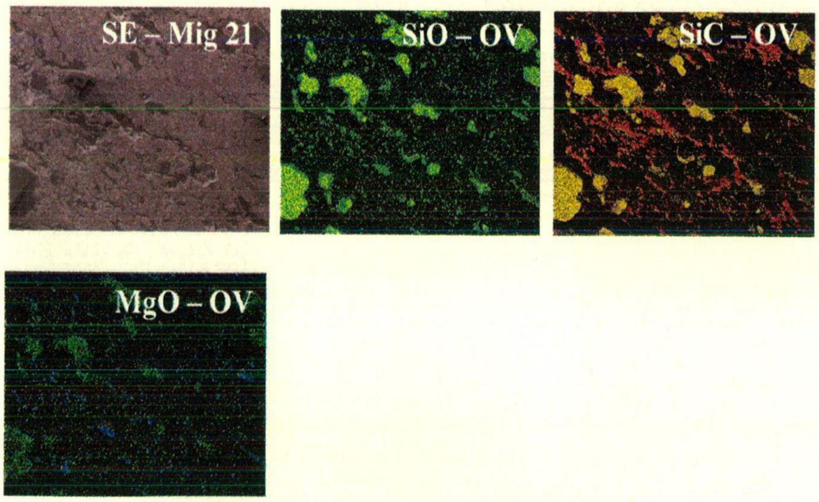


Fig. 5.26 (b) X-Ray mapping at 100X showing different constituents of Mig 21 Sintered Friction Material

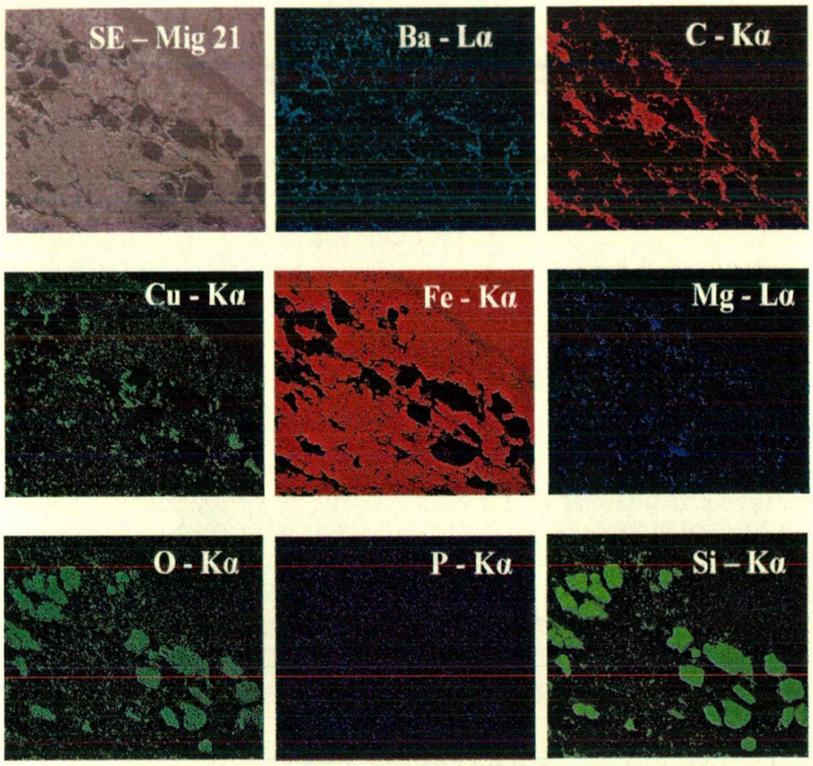


Fig. 5. 27 (a) X-Ray mapping at 100X showing particle distribution of Mig 21 Sintered Brake pad (interface layer)

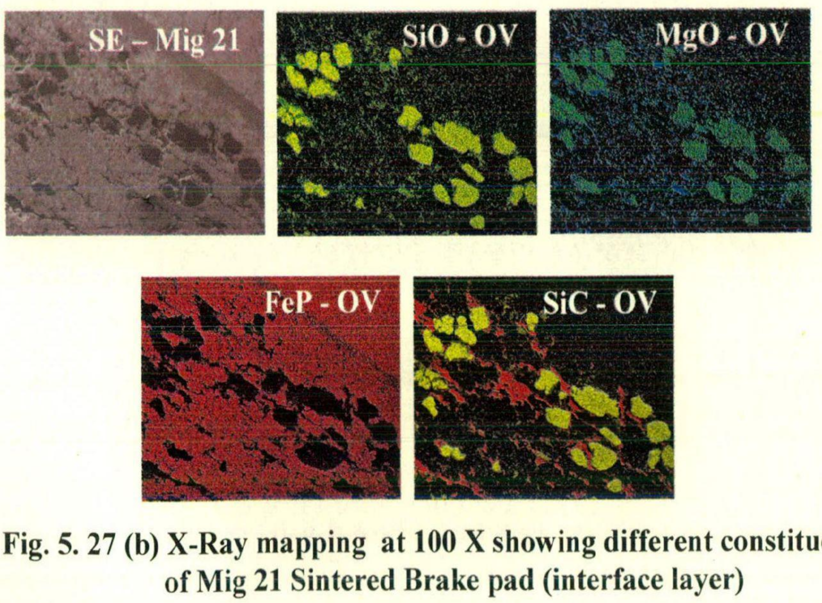


Fig. 5. 27 (b) X-Ray mapping at 100 X showing different constituents of Mig 21 Sintered Brake pad (interface layer)

Fracture Specimen

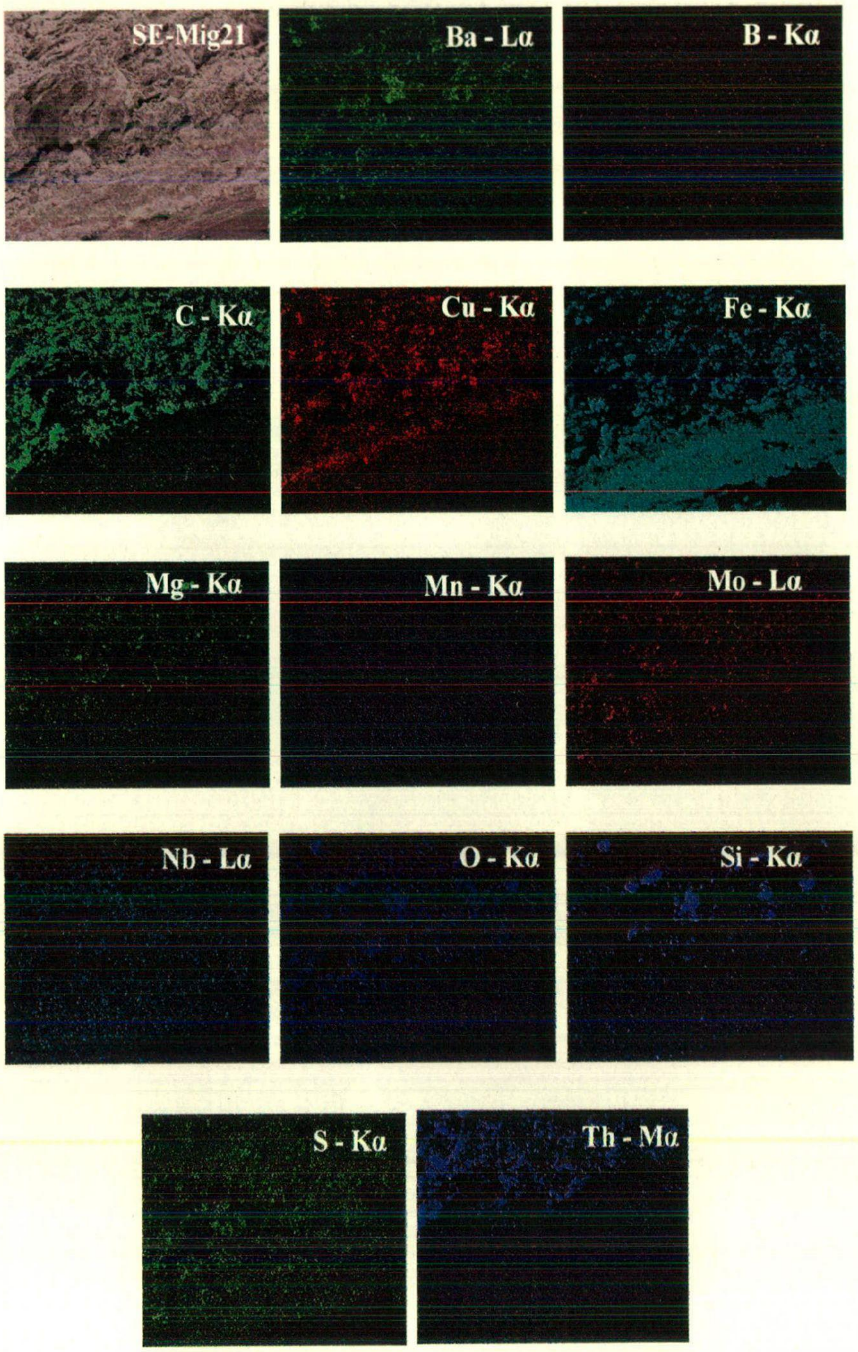


Fig. 5.28 (a) X-Ray Mapping at 100X showing particles distribution of Fractured Mig 21 Sintered brake pad material

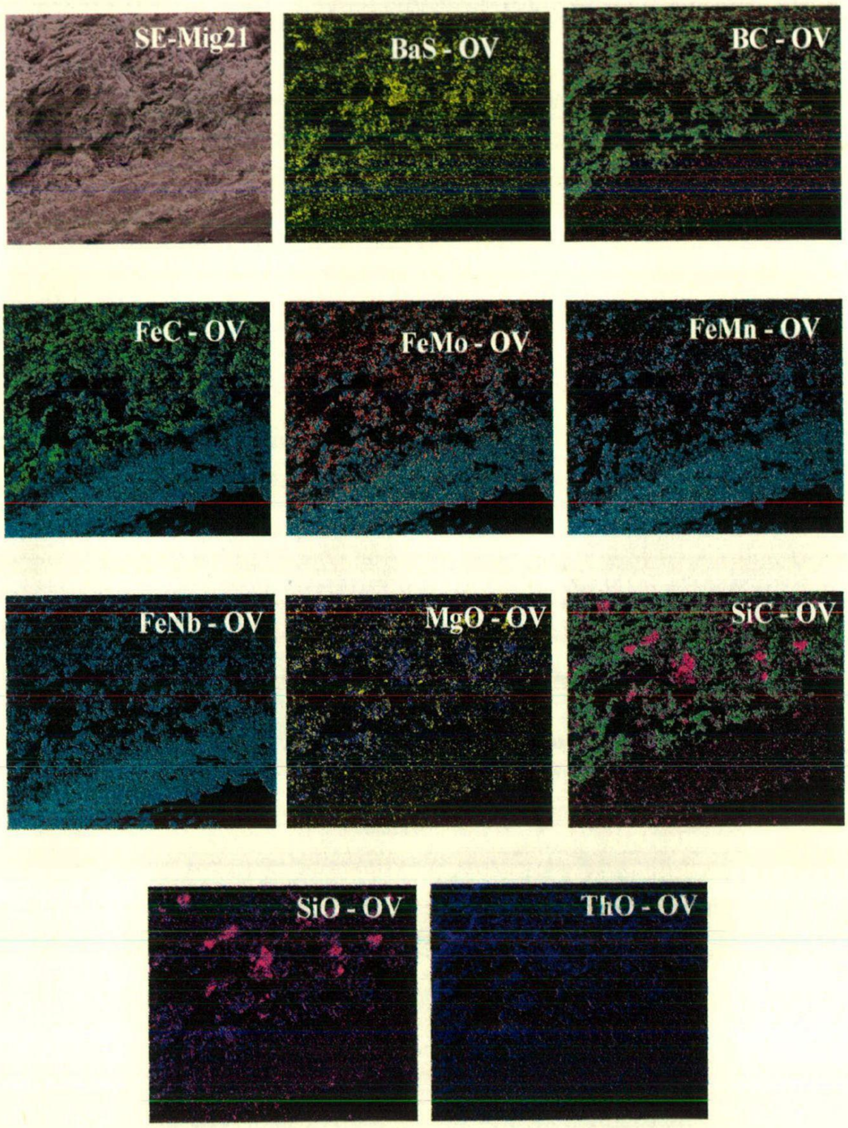


Fig. 5.28 (b) X-Ray Mapping at 100X showing different constituents of Fractured Mig 21 Sintered brake pad material

Fig. 5.29 is the structure at the interface of friction material and backing plate in case of MIG 21. Interface layer of about 60μ is clearly visible which is confirmed by this analysis as of nickel. This layer obstructs the diffusion of elements like carbon and copper from friction layer to backing plate. It is also a source of weakness (being pure nickel) which is responsible for inadequate coherency between friction layer and backing plate.

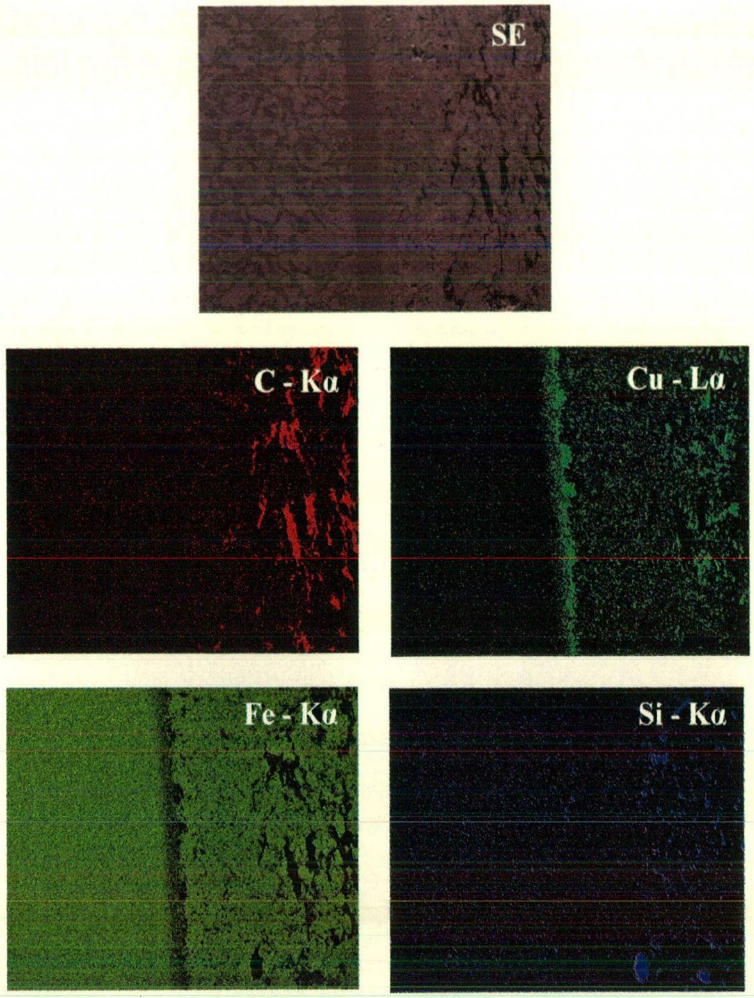


Fig. 5.29 (a) X-ray mapping of MIG 21 sintered brake pad at interface layer (backing plate and friction material) at 100X

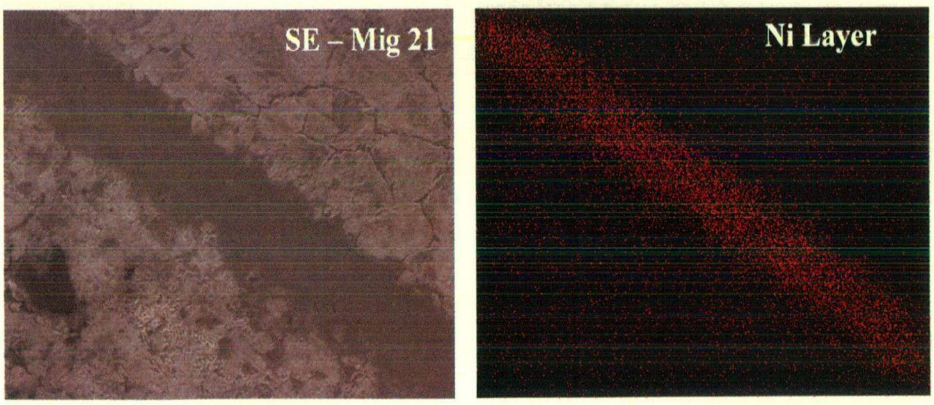


Fig. 5.29 (b) Ni layer at the interface between friction material and backing plate in Mig 21 Sintered Brake pad, 200X

Figs.5.30-5.33 shows the distribution different elements in sample No FM09N, FM13N and, FM14A. It is clear from these pictures the constituents present in the samples are uniformly distributed. There appears to be no segregation of constituents in the structure. Accordingly, the performance of these samples in actual service conditions is expected to be more consistent in comparison to sintered samples.

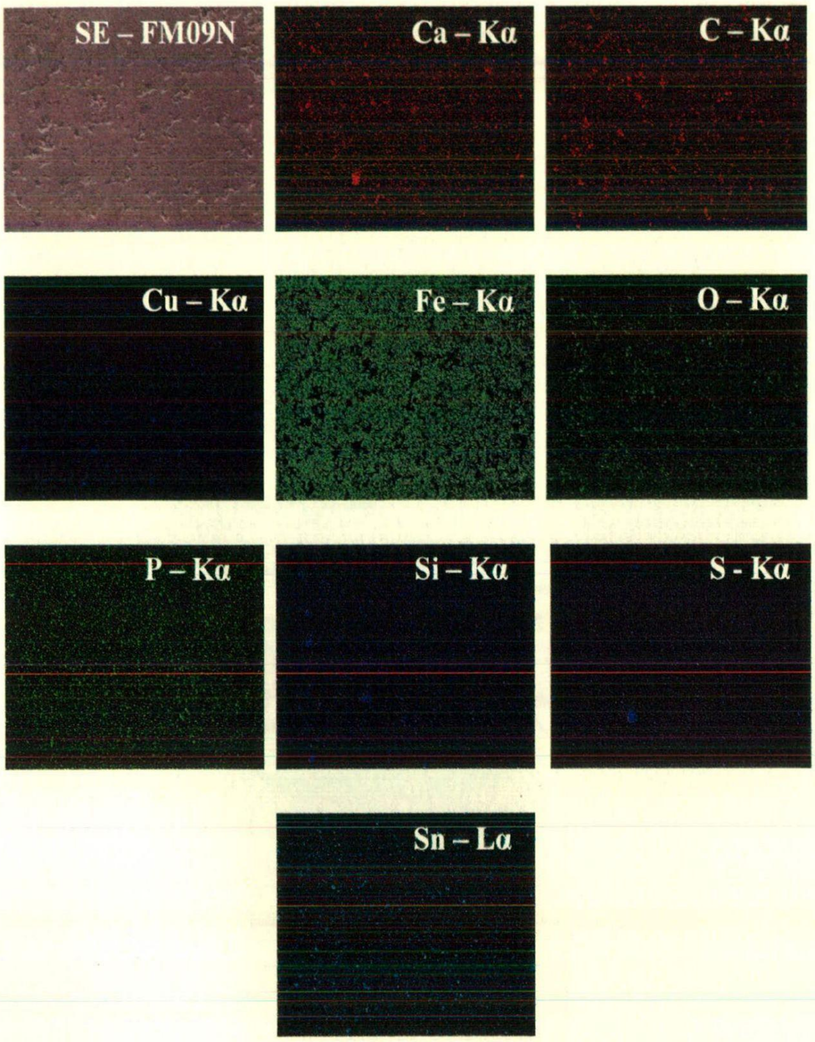


Fig. 5.30 (a) X-Ray mapping at 100X showing particle distribution of FM09N Friction Material

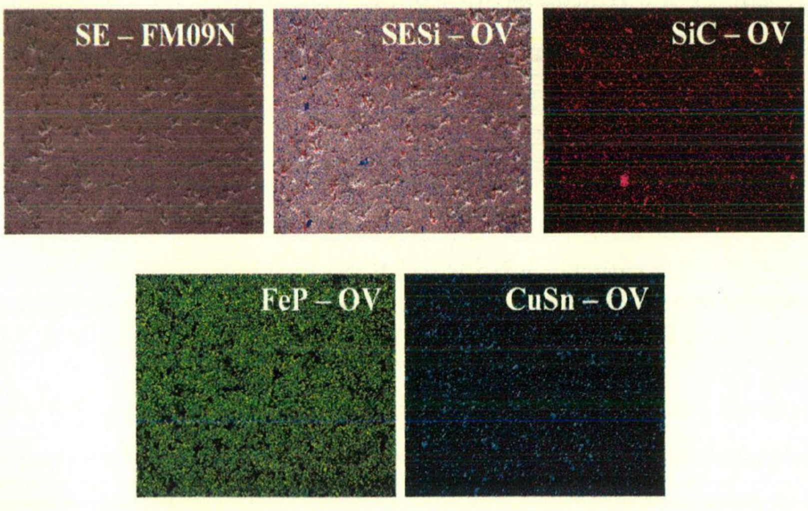


Fig. 5.30 (b) X-Ray mapping at 100X showing different constituents of FM09N Friction Material

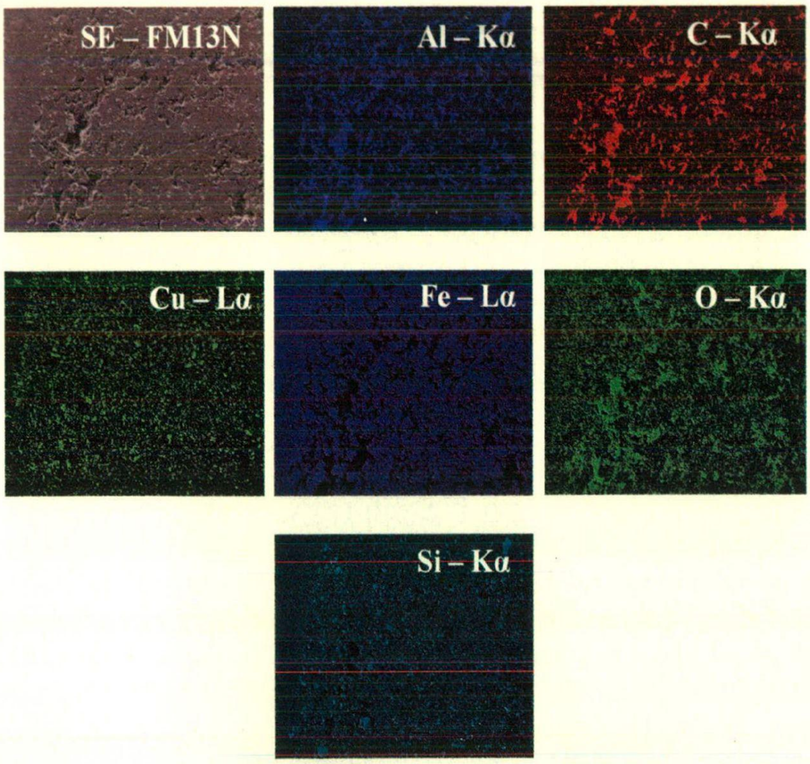


Fig. 5.31 X-Ray mapping at 100X showing particle distribution of FM13N Friction Material

Fractured specimen

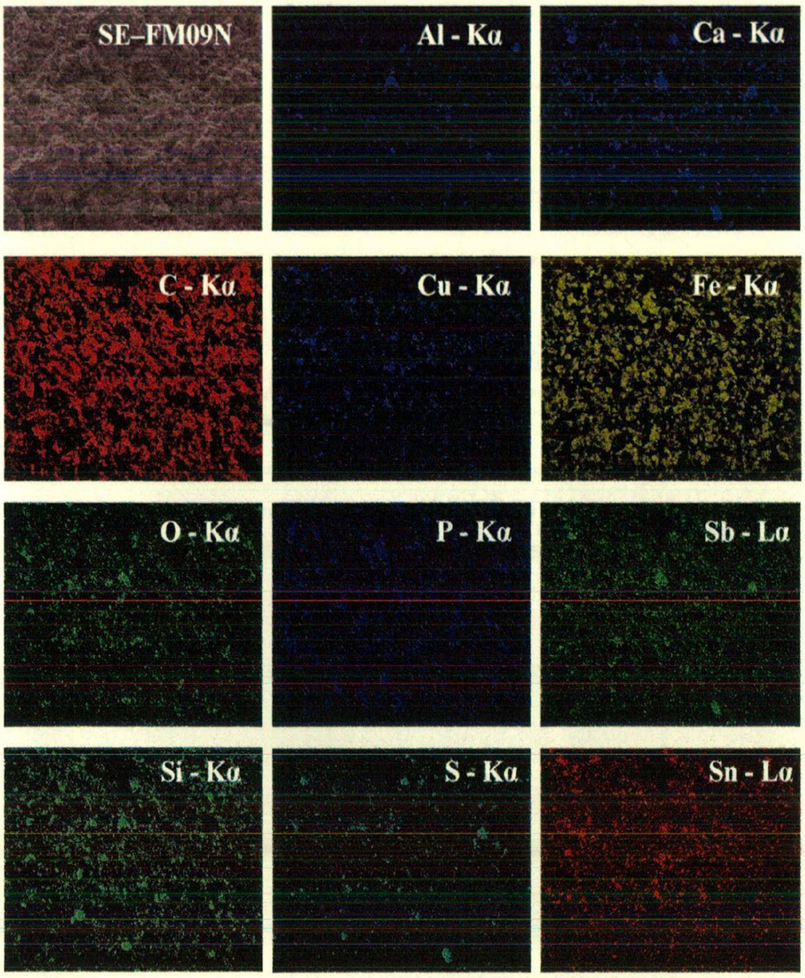


Fig. 5.32 (a) X-Ray Mapping of Fractured FM09N Hot Powder Forged friction material at 100X

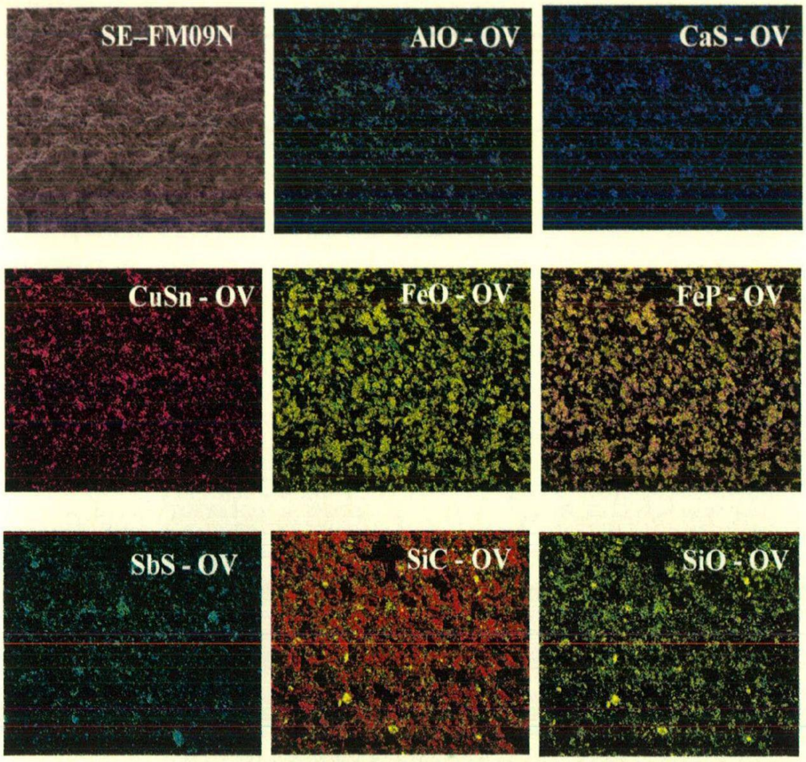


Fig. 5.32 (b) X-Ray Mapping of Fractured FM09N Hot Powder Forged Friction Material at 100X

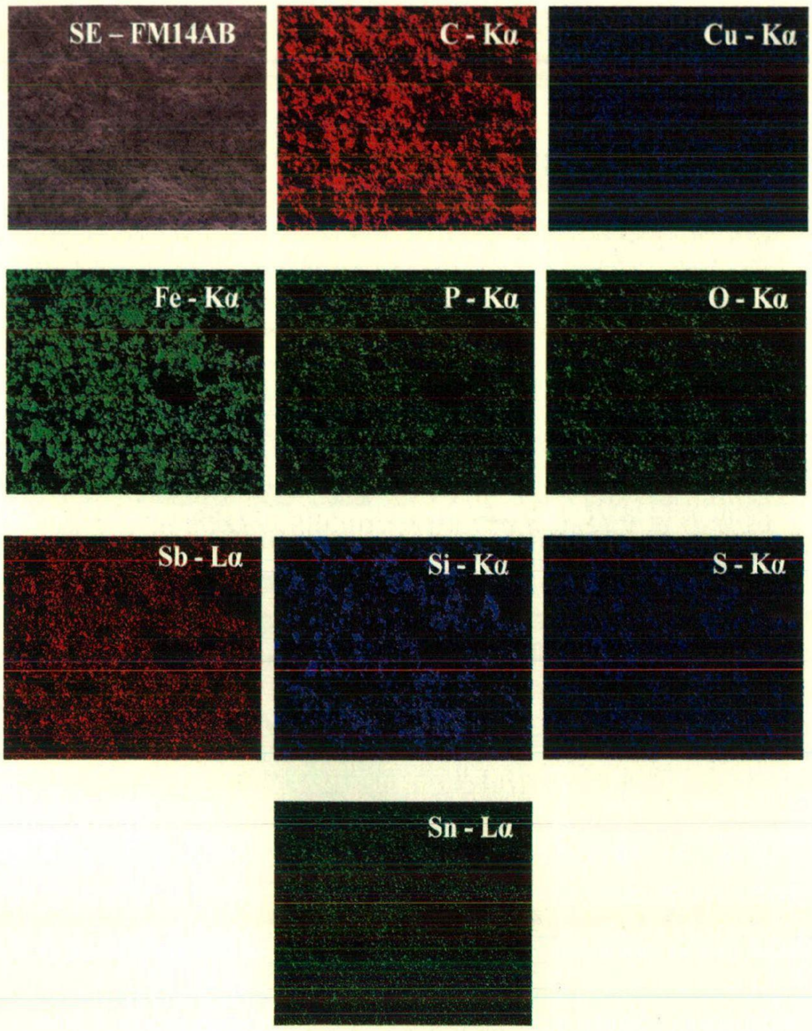


Fig. 5.33 X- Ray mapping of different constituents of FM14AA1 Friction Material at 100X

5.6 Bend Test

Bend test was carried out on few random samples by employing three pin support as described in Fig.5.34. Table 5.8 provides the results of the test. This table also contains the results of sintered brake pad employed in MIG 21. It may be noted that thickness of friction material is varying from 3mm to 4.7mm. Thickness of backing plate varies from 1.5 to 2.8mm however, there is no significant change in the load reading obtained prior to separation of friction layer. Similarly the angle of bend till the cracking of friction layer is nearly independent of friction layer thickness and backing plate thickness which is close to 15^o-16^o only. This angle is significantly higher than the angle obtained in sample corresponding to MIG 21 brake pad (12^o).

It may therefore be inferred that the bending behavior of forged brake pad samples is significantly superior to sintered sample for equivalent applications. It may also be mentioned that the separation of backing plate with friction element is not observed after bending in case of our forged samples where as for sintered sample there is clear cut separation along the interface. This establishes that joining between backing plate and friction element is superior owing to hot forging technique in comparison to pressure sintering technique employed in MIG 21 pads. This will be further confirmed by ultrasonic testing and metallographic examination described in subsequent sections.

Table 5.8: Bend Test Results

Test Parameters: Strain rate- 1mm/sec Span length- 50mm; Diameter of roll- 25mm; Initial dimensions of the specimens: length-57.5mm; width; 16.5mm

Specifications of friction material				Load sustained in bending, KN	Angle of bend till the friction layer cracks (in degrees)
Specimen notation	Thickness, in mm				
	Friction Material	Backing Plate	Total		
FM08N	4.7	2.4	7.1	0.603	15
FM09N	3.4	2.8	6.1	0.714	16
FM10N	3.8	2.7	6.5	0.831	15
FM14AC3	3.3	2.7	6.0	0.692	15
MIG 21	3.0	1.5	4.5	0.652	12

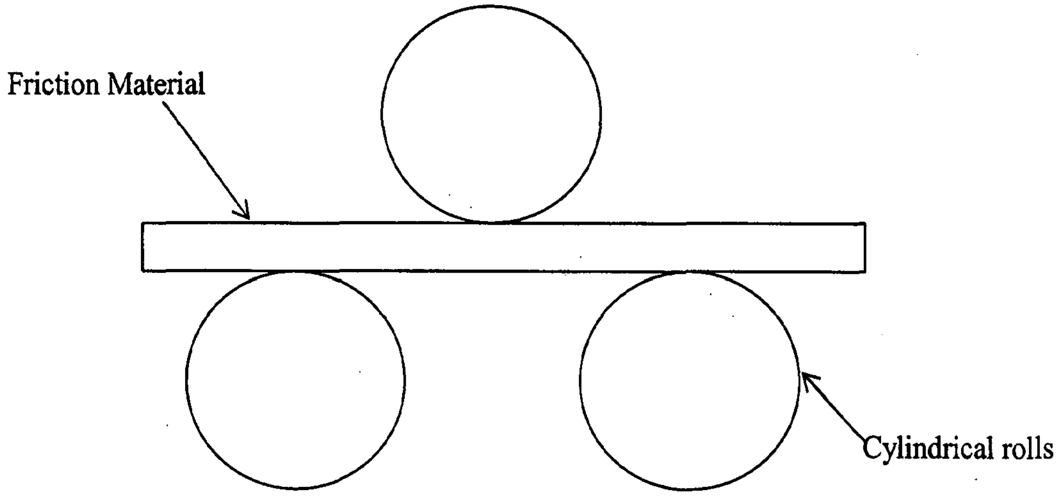


Fig. 5.34. Three Point Bend Test

5.7. Ultrasonic Flaw Detection test

In order to investigate the soundness of the interface between friction material and backing plate, sintered sample of MIG 21 and forged samples of present investigation were taken. They were subjected to ultrasonic flaw detection tests employing dual probe system of M/S Krauntker, Germany' model USM 35. The probe was placed over the backing plate side whose thickness was in the range of 3mm. Fig. 5.35 to5.38 represents the echo pattern obtained from the MIG 21 sample at four different locations, randomly chosen. It is clear from these figures that significant peaks showing the interface are observed at a depth ranging from 1.33 to 2.00mm whereas in sample FM14A the first significant peak is observed at a depth, ranging from 6.2 to 6.58mm (this corresponds to overall thickness of the sample itself) as shown in fig. 5.39 to 5.41.

It is therefore, obvious, that MIG 21 sample contains a defect layer possibly at the interface between backing plate and friction element which is giving echo whereas no echo is observed in our samples from the interface. Repeated tests on our other samples also confirm this finding.

It can therefore be concluded that forged brake pads developed in the present investigation possess sound, defect free interface between backing plate and friction layer unlike sintered pads.

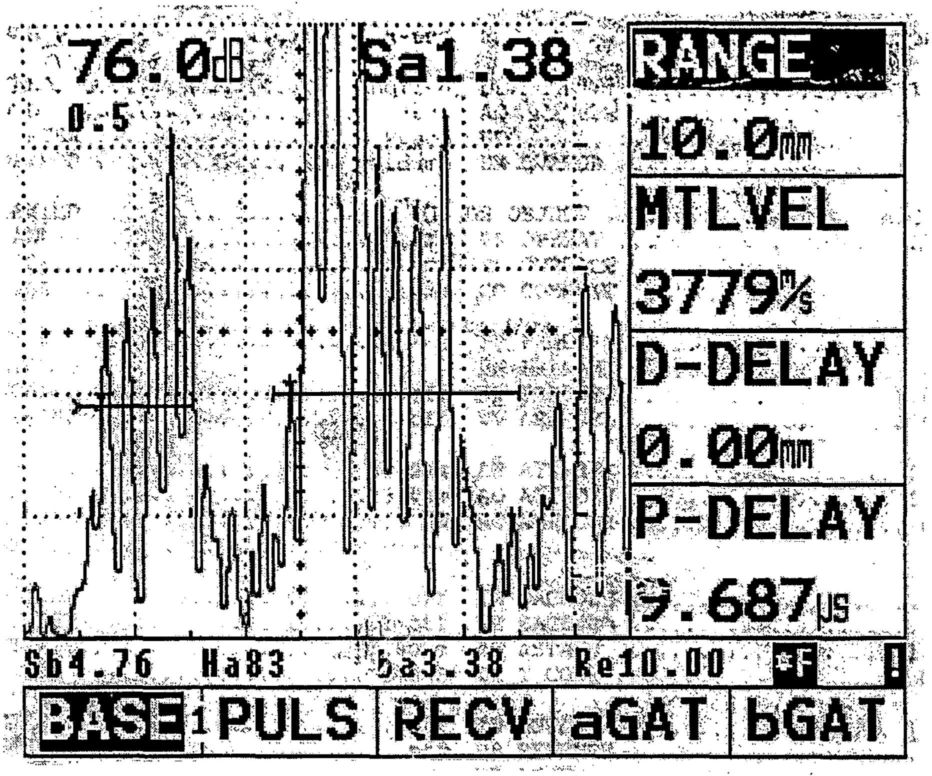


Fig. 5.35 Ultrasonic echo pattern for MIG 21 Sintered brake pad

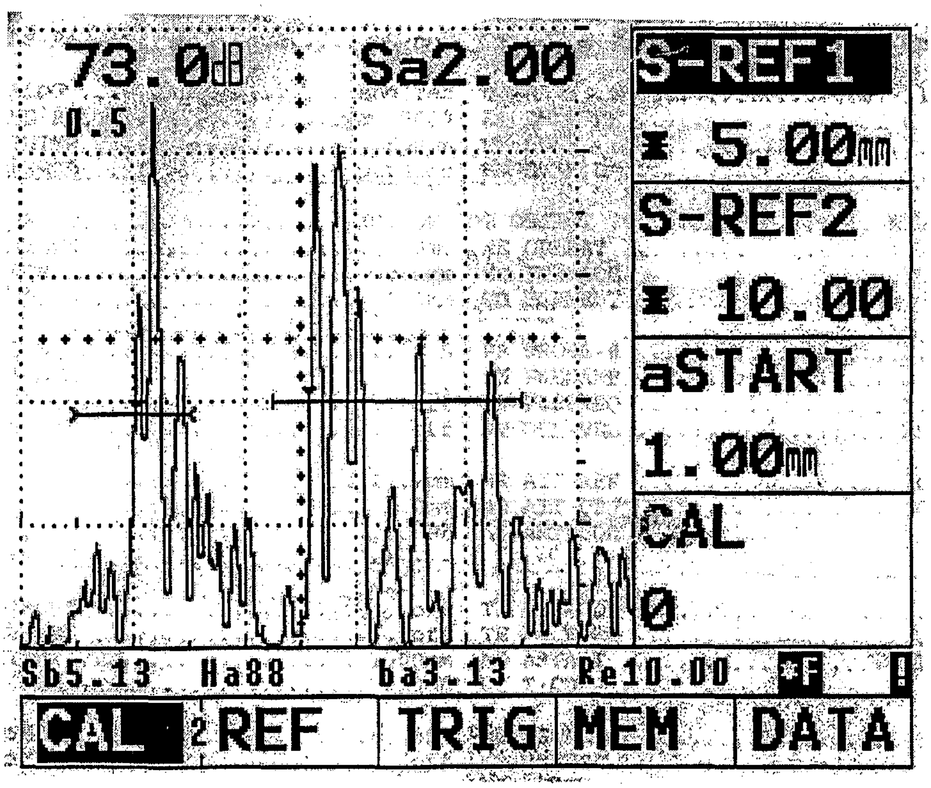


Fig. 5.36 Ultrasonic echo pattern for MIG 21 Sintered brake pad

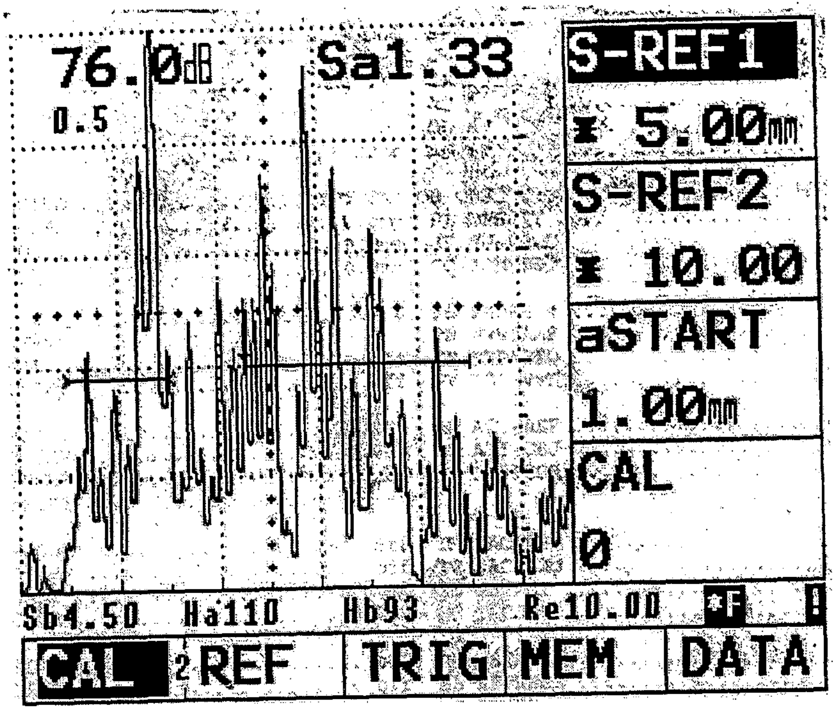


Fig. 5.37 Ultrasonic echo pattern for MIG 21 Sintered brake pad

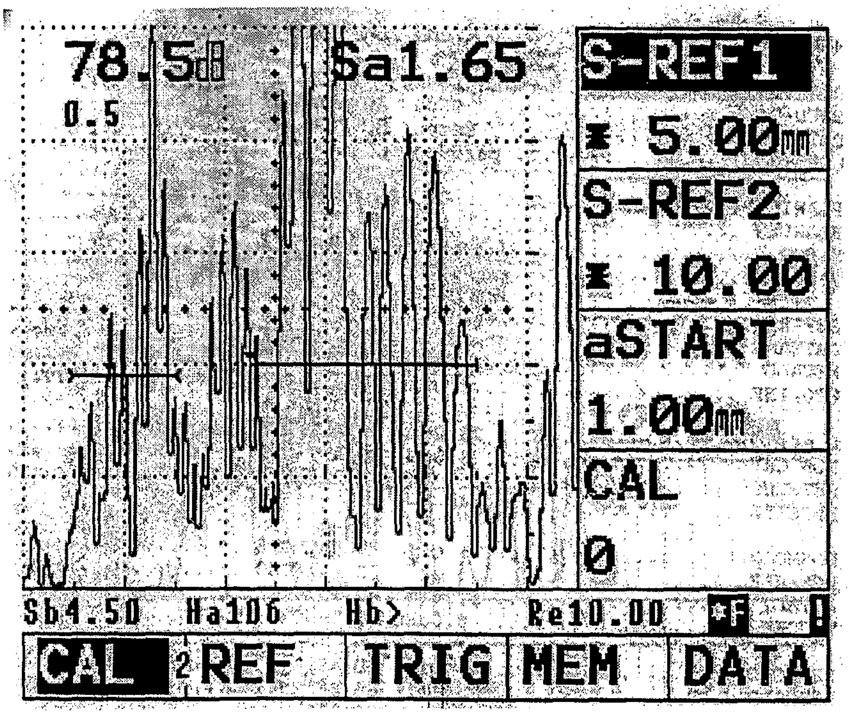


Fig. 5.38 Ultrasonic echo pattern for MIG 21 Sintered brake pad

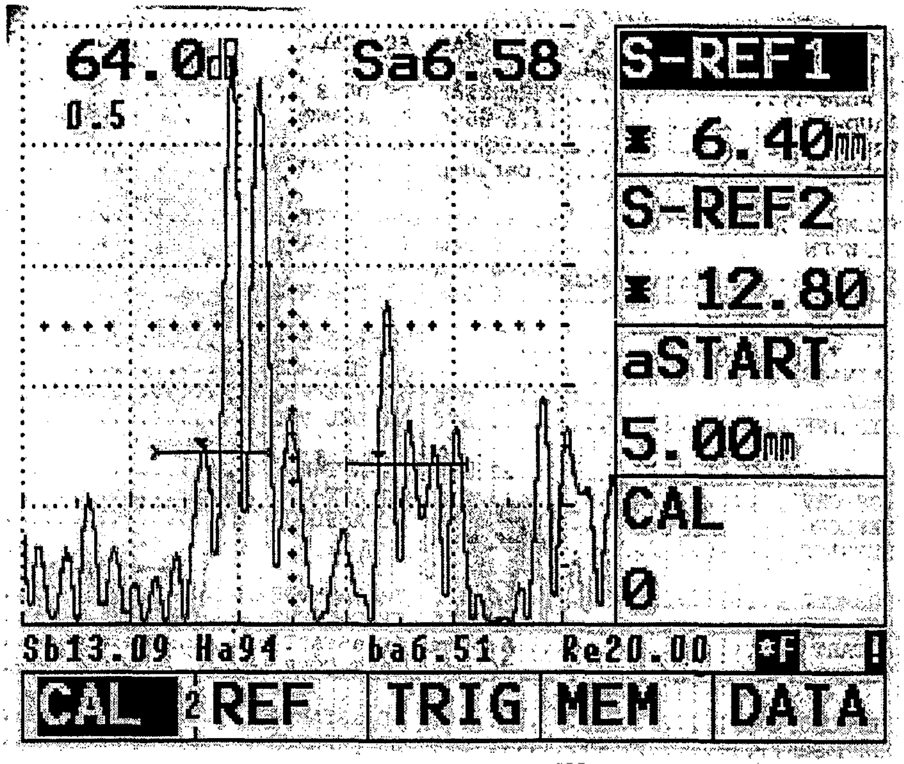


Fig. 5.39 Ultrasonic echo pattern FM14AA1 Hot powder forged brake pad

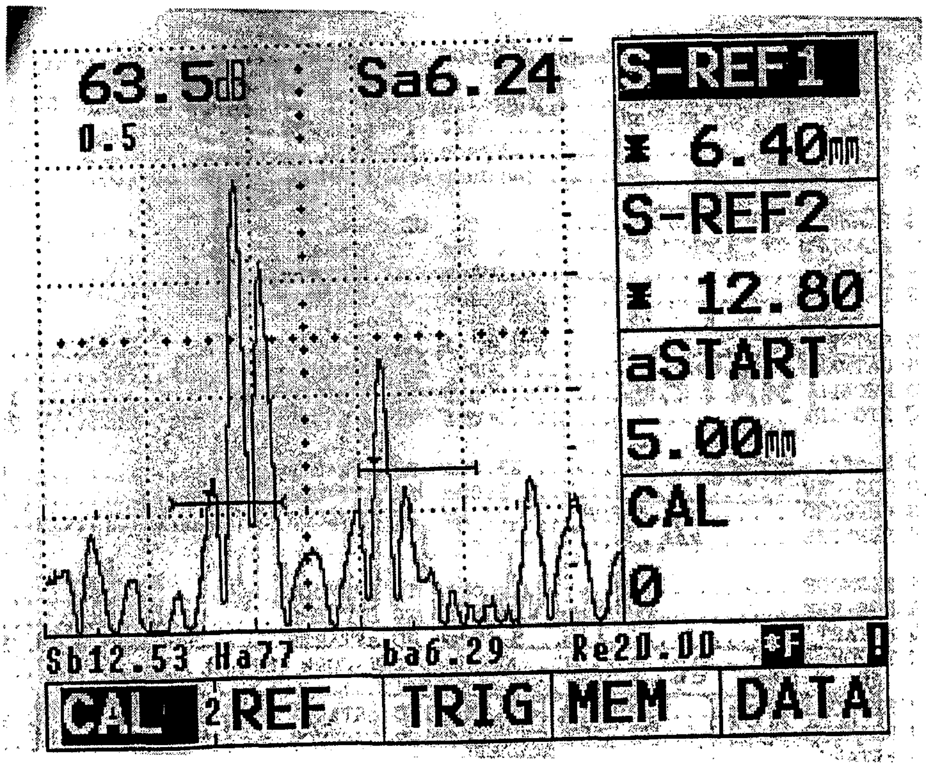


Fig. 5.40 Ultrasonic echo pattern FM14AA1 Hot powder forged brake pad

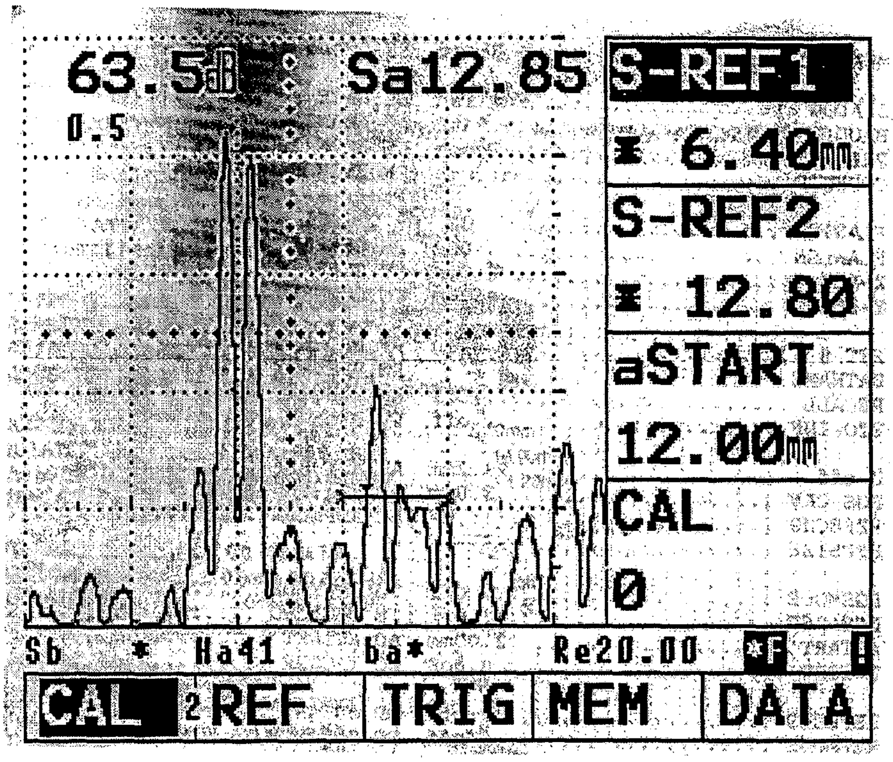


Fig. 5.41 Ultrasonic echo pattern FM14AA1 Hot powder forged brake pad

5.8 Correlations between the Pin-on-disc tests and Sub-scale dynamometer tests

No strict correlations are possible between these two types of tests for the simple reason that the test conditions are entirely different. However, Pin-on-disc test is a good test to assess the performance of chemistry formulations.

Qualitatively, specific wear data as obtained in Fig. 5.1 is similar to the wear data as shown in Table 5.5 corresponding to aircraft applications. Relatively a pattern of wear is available and individual samples can be compared under both the conditions. Similarly, barring few exceptions, the COF shown in Fig. 5.3 (corresponding to Pin-on-disc) also has similarity with respect to Table 5.5.

It can be therefore be concluded that Pin-on-disc tests must be performed as a preliminary testing and once the data obtained are in appropriate range, such samples can be subjected to sub scale dynamometer for further testing. To this extent, this correlation can be helpful for further work in developing brake pads for heavy-duty applications.

Chapter 6

CONCLUSIONS AND SUGGESTIONS

6.1 CONCLUSTIONS

The present investigation has been primarily meant to develop alternative technology for the manufacture of heavy duty brake pads and test the quality of these pads so developed for the purpose of possible applications in actual military based aircrafts. This primary objective has been successfully met and it can be reasonably concluded that this investigation has given rise to development of brake pads by a new alternative technology for the first time in the world.

The detailed significant achievements have been listed as follows in the chronological order in accordance with objectives setout in section 3.4 of Chapter 3.

1. Hot powder forging for the manufacturing of friction materials overcoming the limitation of sintering process has been successfully developed.
2. New set of iron based friction materials have been prepared with simpler chemistry and superior application with regard to aircrafts such as AN 32, and MIG 27.
3. Brake pads with sound joint between backing plate and friction element has been possible by the forging technology.
4. Any shape and sizes of brake pads is possible to produce for variety of vehicles.
5. The technology completely eliminates the problems of joining between backing plate and friction element on account of simultaneous application of pressure and temperature.
6. It has been observed that with simpler chemistry of friction layer, but changing density level during processing, superior performance in heavy duty range is possible. For relatively low energy applications such as AN 32 aircraft high density of friction layer such as greater than 5.45gm/cc is adequate. For heavy – moderate duty applications such as MIG 27 aircraft, density in the range 5.28 to 5.8gm/cc, but preferably 5.6gm/cc would be suitable.

7. Although no effort has been made to economize on the raw material quality but because of the inherent potential of the present technology of cleaning the powders during processing, it is expected that quality of the final product would not affect, if inferior quality raw materials are employed in the present technology.
8. It has been possible to reduce costly ceramic content by incorporating phosphorous as an alloying element and thereby affecting simplicity in the chemistry of brake elements.
9. By judicious use of copper in brake elements heat transfer capabilities of these have been improved and thereby life of brake elements could be extended by way of improved wear resistance.
10. No problem of brake fading has occurred in brake pads developed in the present investigation.
11. Detailed characterization of brake pads developed in the present investigation and their comparison with sintered counterpart has led to possible substitution in actual application.
12. Overall performance of the product made by forging technology has led to significant improvement in quality comparison to existing sintering technology.
13. It has been possible to eliminate the failure rate of brake pads due to breakage and warpage of the product. This is mainly because of the simplified chemistry with overall greater weightage of metallic constituents.
14. The forging technology as developed in the present investigation is free from the use of sophisticated and custom built equipments.
15. The forging technology is expected to be cost effective on account of features described in point number 14 above. However, no effort has been made in the present investigation to quantify the economy.
16. The present investigation has developed a suitable co-relation between pin-on-disc tests and sub scale dynamometer tests which is likely to help further investigation towards developing new friction materials.

6.2 SUGGESTIONS FOR THE FUTURE WORK

The present investigation has primarily focused on development of technology and product, and provides a viable alternative to existing sintering technology. Some of the points that emerged during investigation need to be further investigated in detail. These are as follows.

1. To employ iron powder of inferior quality with relatively higher oxygen content and coarse particle size such as mill scale obtained from Hot rolling mills and optimize processing parameters for such a raw material.
2. To investigate in detail the role of phosphorous in brake pads
3. To investigate in detail the performance of sulphur based compounds as lubricants with respect to coefficient of friction and wear resistance obtained.
4. To fine tune the chemistry employing phosphorous and sulphur based lubricants in combinations for variety of brake applications and investigate if hard abrasive particle employed in such pads can be altogether eliminated.
5. To extend the application of forged brake pads for other aircrafts as well as vehicles with an intent of substitution of resin bonded brake pads.
6. Monitoring the noise levels of brake pads by varying chemistry.
7. To carryout detailed economic analysis of brake pad manufacturing with specific applications.

RESESEARCH PAPERS PRESENTED/PUBLISHED

1. Lenin Singaravelu D., Chandra K., Misra P.S., "Friction and Wear Characteristics of Fe-based Friction Pads for Heavy Duty Brake Applications", paper presented in the ASMP 2006 – Asian Symposium on Materials and Processing 2006 organised by Japan Society of Mechanical Engineers, Japan held at Sofitel Central Plaza Bangkok, Thailand from November 9-10, 2006.
2. Lenin Singaravelu D., Chandra K., Misra P.S., "Wear Characteristics of Iron based Friction Materials for brake applications", presented and published in the Proceedings of the International Symposium for Research Scholars on Metallurgy and Materials Engineering (ISRS 2006) organized by Indian Institute of Technology Chennai, from December 20-23, 2006.
3. Lenin Singaravelu D, Chandra, K., Mishra P.S., 'A Comparative Study of Wear characteristics for sintered and hot powder forged friction materials', presented in PM-07 International conference on Powder Metallurgy and Particulate Materials organized by Powder Metallurgical Association of India, Noida, Feb. 09-11, 2007.
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PATENT FILED

The complete specification for Patent on **'Iron based Cermet Friction Materials / Composites / Brake Elements with Builtin Backing Plates'** has been filed on Nov. 6, 2007; the provisional specifications were filed on Nov.7, 2006 (Patent application No.2421/DEL/2006).

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1 **The brake bible,** url:http://www.carbibles.com/brake_bible.html
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Ref. No.	Patent No.	Dated (yyyy-mm-dd)	Title of Patent	Inventers
USP01	7094473	2006-08-22	Wear resistant sintered contact material, wear resistant sintered composite contact component and method of producing the same	Takemori Takayama, Kazuo Okamura Yoshikiyo Tanaka, Tetsuo Ohnishi
USP02	6439353	2002-08-27	Aircraft wheel brake with exchangeable brake segments	Gerd Roloff, Tilman Haug
USP03	6143051	2000-11-07	Friction material, method of preparing same and friction lining	Ole Kraemer, Niels Bramso, Erik Simonsen, noel De Leon, Knud Strande Rolf Tornberg, Claes Kuylenstierna
USP04	6110268	2000-07-29	Sintered brake lining and method for its manufacture	Gerhard Gross, Bobingen; Tilmann Haug, Uhldingen-Muhlhofen
USP05	4576872	1986-03-18	Friction element and method of manufacture thereof	Melvyn Ward, Redditch
USP06	4415363	1983-11-15	Sintered iron base friction material	Keith E. Sanftleben, Waler R. Tarr,
USP07	4391641	1983-06-05	Sintered powder metal friction material	Herbert W. Lloyd, Monsey N.Y.
USP08	4350530	1982-09-21	Sintered alloy for friction materials	Nobuo Kamioka, Kasukabe
USP09	4311524	1982-01-19	Sintered iron-based friction material	Valery A. Genkin ulitsa Gaya, Alexandr A Dmitrovich, bulvar Lunacharakogo, Efim I Fishbein Ulitsa Brilevskaya
USP10	4280935	1981-06-28	Friction material comprising an iron powder having a carbon content of from 0.5-1 percent	Osao Ogiwara, Hanyu
USP11	4278153	1981-06-14	Brake friction material with reinforcement material	Doulatabad A. Venkatu Stow
USP12	3341931	1967-09-19	Brake shoes	Herbert L. Libbin, New Shrewsbury, and Roswell S. Frichette, jr., Ramsey, N.I., and Howard B. Huntress, Suffern.
IP01	Patent application No.2420/DEL/2006	2006-11-07	A Process for Manufacturing Cermet Friction Materials / Composites/ Brake Elements with Builtin Backing Plates	Dr. P.S. Misra Dr. K Chandra
IP02	Patent application No.2421/DEL/2006	2006-11-07	Iron based/ Cermet Friction Materials/Composites/Brake Elements with Builtin Backing Plates	Dr. P.S. Misra Dr. K Chandra
IP03	198715/ 2002	Year 2002	Preparation of novel ceramic friction composites	HAL, Bangalore.

USP-United State Patent

JP -Japanese Patent

IP -Indian Patent

Annexure
Sub scale dynamometer test results
(Page A1 to A62)

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM08N

Date	7/24/2006	
Time	2:13:39 PM	
Project Name	IIT Roorkee	
Part No	C11C12	
Batch Number	C11C12	
Brake Speed	1000	RPM
Brake Pressure	17.15	kg/sq.cm
Brake Force	150	kgf
File Name	Testing brake padsss_7_24_2006_2_13_39 PM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	106	12.7	0.33	33	86	182	476	0	0
Min	17330	75	9	0.23	24	0	131	0	0	0
Avg	17330	84	10.1	0.3	30	51	165	286	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	10.05	9.19	0.86	2488	2472	16
2	10.03	8.6	1.43	2492	2472	20

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : [signature] 2/8/06.

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/24/2006	
Time	2:13:39 PM	
Project Name	IIT Roorkee	
Part No	C11C12	
Batch Number	C11C12	
Brake Speed	1000	RPM
Brake Pressure	17.15	kg/sq.cm
Brake Force	150	Kgf
File Name	Testing brake padsss_7_24_2006_2_13_39 PM	

Brake pad material -FM08N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	90	10.8	0.27	27	0	153	0	0	0
2	17330	92	11.0	0.27	27	0	151	0	0	0
3	17330	106	12.7	0.23	24	57	131	314	0	0
4	17330	93	11.1	0.27	27	56	150	309	0	0
5	17330	89	10.6	0.28	28	60	155	335	0	0
6	17330	91	10.9	0.28	27	55	153	307	0	0
7	17330	90	10.8	0.28	28	86	153	476	0	0
8	17330	81	9.7	0.31	30	70	169	389	0	0
9	17330	80	9.6	0.31	31	78	173	435	0	0
10	17330	77	9.3	0.32	32	66	178	367	0	0
11	17330	76	9.2	0.33	32	59	180	329	0	0
12	17330	78	9.3	0.32	32	61	178	340	0	0
13	17330	75	9.0	0.33	33	57	182	315	0	0
14	17330	85	10.2	0.29	29	48	161	269	0	0
15	17330	77	9.2	0.33	32	54	179	302	0	0
16	17330	77	9.2	0.33	33	54	181	301	0	0
17	17330	77	9.2	0.32	31	53	174	293	0	0
18	17330	76	9.1	0.33	32	53	180	296	0	0
19	17330	80	9.5	0.32	31	50	173	280	0	0
20	17330	77	9.3	0.32	32	53	177	296	0	0
21	17330	79	9.4	0.32	32	54	175	298	0	0
22	17330	80	9.6	0.31	31	52	172	288	0	0
23	17330	80	9.6	0.32	31	57	173	316	0	0
24	17330	79	9.5	0.32	31	54	174	301	0	0
25	17330	81	9.7	0.31	31	52	171	288	0	0
26	17330	80	9.6	0.32	31	52	173	288	0	0
27	17330	82	9.9	0.31	30	52	168	287	0	0
28	17330	81	9.7	0.30	30	48	167	265	0	0
29	17330	79	9.5	0.31	30	55	169	307	0	0
30	17330	82	9.9	0.31	30	51	169	285	0	0
31	17330	84	10.1	0.30	30	49	166	273	0	0
32	17330	86	10.3	0.30	29	52	162	290	0	0
33	17330	84	10.1	0.30	30	54	165	299	0	0
34	17330	85	10.1	0.30	30	50	165	278	0	0
35	17330	82	9.9	0.30	30	47	166	261	0	0
36	17330	85	10.1	0.30	30	50	164	280	0	0
37	17330	85	10.2	0.30	29	60	164	333	0	0
38	17330	85	10.2	0.30	30	50	164	280	0	0
39	17330	85	10.2	0.30	29	64	163	357	0	0
40	17330	87	10.4	0.29	29	46	161	254	0	0
41	17330	86	10.3	0.30	29	47	163	262	0	0
42	17330	86	10.3	0.29	29	50	161	279	0	0
43	17330	86	10.3	0.29	29	49	160	271	0	0
44	17330	88	10.5	0.29	29	44	159	246	0	0
45	17330	87	10.4	0.29	29	46	161	256	0	0
46	17330	89	10.7	0.29	28	48	158	265	0	0
47	17330	88	10.5	0.29	29	41	161	227	0	0
48	17330	91	10.9	0.28	28	49	154	273	0	0
49	17330	90	10.8	0.28	28	39	156	218	0	0
50	17330	89	10.7	0.29	28	41	158	226	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/31/2006	
Time	6:51:21 PM	
Project Name	IIT ROORKEE	
Part No	C11C12 HIGH	
Batch Number	C11C12 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.79	kg/sq.cm
Brake Force	150	kgf
File Name	C11C12 HIGH_7_31_2006_6_51_21 PM	

Brake pad material -FM08N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	184	17	0.31	31	64	170	354	0	0
Min	29158	139	12.8	0.23	24	36	133	197	0	0
Avg	29158	165	15.2	0.26	26	45	147	252	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	9.15	6.89	2.26	2471	2430	41
2	8.79	6.78	2.01	2468	2433	35

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : [signature] 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/31/2006	
Time	6:51:21 PM	
Project Name	IIT ROORKEE	
Part No	C11C12 HIGH	
Batch Number	C11C12 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.79	kg/sq.cm
Brake Force	150	Kgf
File Name	C11C12 HIGH_7_31_2006_6_51_21 PM	

Brake pad material -FM08N

Sl NO.	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-T (Deg
1	29158	157	14.5	0.28	28	60	154	334	0	0
2	29158	145	13.3	0.30	30	64	165	354	0	0
3	29158	144	13.3	0.30	30	61	166	336	0	0
4	29158	149	13.8	0.28	28	54	158	298	0	0
5	29158	139	12.8	0.31	31	61	170	338	0	0
6	29158	156	14.4	0.28	28	52	154	290	0	0
7	29158	149	13.7	0.29	29	57	161	316	0	0
8	29158	148	13.6	0.29	29	49	162	271	0	0
9	29158	148	13.7	0.29	29	52	160	287	0	0
10	29158	152	14.0	0.28	28	51	157	281	0	0
11	29158	151	13.9	0.29	29	49	160	272	0	0
12	29158	155	14.3	0.28	28	56	155	312	0	0
13	29158	153	14.1	0.28	28	46	156	256	0	0
14	29158	158	14.6	0.27	27	41	151	226	0	0
15	29158	156	14.4	0.27	28	49	154	272	0	0
16	29158	158	14.6	0.27	28	44	153	244	0	0
17	29158	158	14.6	0.27	27	43	152	240	0	0
18	29158	158	14.5	0.27	27	43	152	238	0	0
19	29158	156	14.4	0.27	28	40	154	224	0	0
20	29158	159	14.6	0.27	27	45	152	249	0	0
21	29158	166	15.3	0.26	26	48	146	265	0	0
22	29158	163	15.0	0.26	27	54	148	301	0	0
23	29158	161	14.9	0.27	27	47	150	262	0	0
24	29158	164	15.2	0.26	26	40	147	225	0	0
25	29158	162	14.9	0.26	26	40	146	224	0	0
26	29158	169	15.6	0.26	26	42	144	233	0	0
27	29158	167	15.4	0.26	26	47	146	258	0	0
28	29158	170	15.7	0.25	26	48	143	269	0	0
29	29158	168	15.5	0.25	26	38	144	213	0	0
30	29158	167	15.4	0.26	26	42	146	235	0	0
31	29158	173	16.0	0.25	25	40	141	221	0	0
32	29158	171	15.8	0.25	26	46	142	256	0	0
33	29158	171	15.8	0.25	26	46	142	254	0	0
34	29158	173	15.9	0.25	25	40	141	221	0	0
35	29158	174	16.1	0.25	25	41	140	225	0	[illegible]
36	29158	175	16.1	0.25	25	37	140	208	0	[illegible]
37	29158	176	16.3	0.24	25	41	137	227	0	[illegible]
38	29158	175	16.1	0.24	25	47	139	260	0	[illegible]
39	29158	180	16.6	0.24	24	40	135	220	0	[illegible]
40	29158	180	16.7	0.24	24	39	136	214	0	
41	29158	179	16.5	0.24	24	46	136	253	0	
42	29158	178	16.5	0.24	25	39	138	218	0	
43	29158	178	16.5	0.24	25	37	137	204	0	
44	29158	183	16.9	0.23	24	36	133	202	0	
45	29153	179	16.6	0.24	24	41	136	227	0	
46	29153	177	16.4	0.24	25	40	139	220	0	
47	29158	178	16.4	0.24	25	37	138	207	0	
48	29158	184	17.0	0.23	24	36	134	197	0	
49	29158	181	16.7	0.24	25	36	136	200	0	
50	29158	180	16.7	0.24	24	40	136	224	0	

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/25/2006	
Time	3:39:40 PM	
Project Name	IIT Roorkee	
Part No	C21C22	
Batch Number	C21C22	
Brake Speed	1000	RPM
Brake Pressure	17.39	kg/sq.cm
Brake Force	150	kgf
File Name	C21C22_7_25_2006_3_39_40 PM	

Brake pad material -FM09N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	135	16.2	0.37	35	66	192	366	0	0
Min	17330	72	8.6	0.19	19	17	106	94	0	0
Avg	17330	123	14.8	0.21	21	43	117	241	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	9.95	8.65	1.3	2473	2452	21
2	10	8.38	1.62	2467	2441	26

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : [signature] 2/8/06.

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/26/2006	
Time	3:39:40 PM	
Project Name	IIT Roorkee	
Part No	C21C22	
Batch Number	C21C22	
Brake Speed	1000	RPM
Brake Pressure	17.39	kg/sq.cm
Brake Force	160	Kgf
File Name	C21C22_7_26_2006_3_39_40 PM	

Brake pad material -FM09N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	72	8.6	0.36	35	58	192	320	0	0
2	17330	72	8.6	0.37	34	57	191	317	0	0
3	17330	86	10.4	0.30	29	56	160	309	0	0
4	17330	90	10.8	0.28	27	55	152	306	0	0
5	17330	99	11.9	0.25	25	54	137	301	0	0
6	17330	105	12.6	0.24	24	51	131	284	0	0
7	17330	110	13.2	0.23	23	66	127	366	0	0
8	17330	115	13.8	0.22	22	46	123	254	0	0
9	17330	118	14.1	0.22	22	48	120	266	0	0
10	17330	121	14.5	0.21	21	62	117	345	0	0
11	17330	123	14.7	0.21	21	47	116	262	0	0
12	17330	124	14.8	0.21	21	47	115	258	0	0
13	17330	125	15.0	0.20	20	43	114	240	0	0
14	17330	126	15.1	0.20	20	61	111	337	0	0
15	17330	130	15.6	0.20	20	63	110	348	0	0
16	17330	130	15.6	0.20	20	42	109	235	0	0
17	17330	130	15.6	0.20	20	45	110	248	0	0
18	17330	132	15.9	0.19	19	39	107	218	0	0
19	17330	129	15.5	0.19	20	40	109	224	0	0
20	17330	132	15.9	0.19	19	39	108	218	0	0
21	17330	130	15.6	0.20	20	17	109	94	0	0
22	17330	133	15.9	0.19	19	42	107	235	0	0
23	17330	133	16.0	0.19	19	50	107	277	0	0
24	17330	131	15.7	0.20	20	41	109	230	0	0
25	17330	132	15.8	0.19	20	41	108	230	0	0
26	17330	130	15.6	0.20	20	41	110	230	0	0
27	17330	128	15.4	0.20	20	36	110	199	0	0
28	17330	130	15.6	0.20	20	36	110	198	0	0
29	17330	127	15.3	0.20	20	37	111	206	0	0
30	17330	135	16.2	0.19	19	54	106	303	0	0
31	17330	134	16.0	0.19	19	38	107	208	0	0
32	17330	127	15.2	0.20	20	38	110	209	0	0
33	17330	132	15.8	0.19	19	37	107	203	0	0
34	17330	132	15.9	0.19	19	40	108	221	0	0
35	17330	131	15.8	0.19	20	38	109	211	0	0
36	17330	131	15.7	0.19	20	38	108	212	0	0
37	17330	133	15.9	0.19	19	37	108	205	0	0
38	17330	129	15.5	0.20	20	38	110	212	0	0
39	17330	130	15.5	0.20	20	40	110	222	0	0
40	17330	129	15.4	0.20	20	37	111	203	0	0
41	17330	127	15.2	0.20	20	39	112	217	0	0
42	17330	127	15.2	0.20	20	38	111	214	0	0
43	17330	131	15.7	0.20	20	37	110	206	0	0
44	17330	129	15.4	0.20	20	38	111	210	0	0
45	17330	128	15.4	0.20	20	41	110	226	0	0
46	17330	129	15.5	0.20	20	35	111	194	0	0
47	17330	129	15.4	0.20	20	38	111	213	0	0
48	17330	124	14.8	0.20	20	37	113	204	0	0
49	17330	127	15.3	0.20	20	37	113	204	0	0
50	17330	125	15.0	0.20	21	36	115	200	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/31/2006	
Time	5:33:38 PM	
Project Name	IIT ROORKEE	
Part No	C21C22 HIGH	
Batch Number	C21C22 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.93	kg/sq.cm
Brake Force	150	kgf
File Name	C21C22 HIGH_7_31_2006_5_33_38 PM	

Brake pad material -FM09N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	209	19.3	0.27	28	58	154	322	0	0
Min	29158	156	14.4	0.2	21	34	117	190	0	0
Avg	29158	194	17.9	0.22	23	42	127	234	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	8.59	6.74	1.85	2451	2423	28
2	8.25	5.33	2.92	2439	2393	46

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : [signature] 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/31/2006	
Time	5:33:38 PM	
Project Name	IIT ROORKEE	
Part No	C21C22 HIGH	
Batch Number	C21C22 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.93	kg/sq.cm
Brake Force	150	Kgf
File Name	C21C22 HIGH_7_31_2006_5_33_38 PM	

Brake pad material -FM09N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	156	14.4	0.27	28	51	154	284	0	0
2	29158	166	15.4	0.25	26	48	145	267	0	0
3	29158	182	16.8	0.23	24	45	133	248	0	0
4	29158	190	17.6	0.22	23	44	128	245	0	0
5	29158	192	17.8	0.22	23	41	126	225	0	0
6	29158	199	18.3	0.21	22	45	123	249	0	0
7	29158	199	18.4	0.21	22	45	123	253	0	0
8	29158	198	18.2	0.22	22	43	124	237	0	0
9	29158	209	19.3	0.20	21	43	117	238	0	0
10	29158	198	18.3	0.21	22	41	123	227	0	0
11	29158	196	18.1	0.22	23	40	125	220	0	0
12	29158	199	18.4	0.21	22	43	122	237	0	0
13	29158	202	18.7	0.21	22	39	121	217	0	0
14	29158	200	18.5	0.21	22	37	122	207	0	0
15	29158	207	19.1	0.21	21	34	119	190	0	0
16	29158	197	18.1	0.22	22	38	125	208	0	0
17	29158	200	18.4	0.21	22	37	122	205	0	0
18	29158	192	17.8	0.22	22	50	125	278	0	0
19	29158	195	18.0	0.22	23	38	126	209	0	0
20	29158	195	18.0	0.22	23	38	126	212	0	0
21	29158	196	18.1	0.22	23	45	125	251	0	0
22	29158	198	18.3	0.21	22	39	123	217	0	0
23	29158	197	18.1	0.22	23	38	125	210	0	0
24	29158	198	18.3	0.22	22	40	124	220	0	0
25	29158	195	18.0	0.22	23	39	126	215	0	0
26	29158	199	18.4	0.21	22	40	124	221	0	0
27	29158	187	17.3	0.22	23	44	129	246	0	0
28	29158	194	17.9	0.22	23	45	125	248	0	0
29	29158	206	19.1	0.21	21	39	119	215	0	0
30	29158	202	18.6	0.21	22	44	122	244	0	0
31	29158	198	18.3	0.22	22	40	124	224	0	0
32	29158	194	17.9	0.22	23	41	127	226	0	0
33	29158	199	18.4	0.21	22	43	124	240	0	0
34	29158	199	18.4	0.21	22	40	124	222	0	0
35	29158	202	18.6	0.21	22	39	123	215	0	0
36	29158	196	18.1	0.22	22	39	125	214	0	0
37	29158	198	18.3	0.22	22	42	125	233	0	0
38	29158	187	17.3	0.23	24	41	131	229	0	0
39	29158	193	17.8	0.22	23	42	128	233	0	0
40	29158	189	17.4	0.23	24	42	131	233	0	0
41	29158	189	17.4	0.23	24	46	131	255	0	0
42	29158	187	17.3	0.23	24	44	132	243	0	0
43	29158	196	18.1	0.22	23	41	128	226	0	0
44	29158	185	17.1	0.23	24	43	134	238	0	0
45	29158	186	17.2	0.23	24	58	133	322	0	0
46	29158	185	17.1	0.23	24	55	134	303	0	0
47	29158	188	17.4	0.23	24	42	131	231	0	0
48	29158	188	17.3	0.23	24	42	132	231	0	0
49	29158	194	17.9	0.22	23	42	129	231	0	0
50	29158	182	16.8	0.24	24	40	136	224	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/25/2006	
Time	5:18:01 PM	
Project Name	IIT Roorkee	
Part No	C31C32	
Batch Number	C31C32	
Brake Speed	1000	RPM
Brake Pressure	16.8	kg/sq.cm
Brake Force	150	kgf
File Name	C31C32_7_25_2006_5_18_01 PM	

Brake pad material -FM09N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	127	15.3	0.36	34	72	192	398	0	0
Min	17330	72	8.7	0.2	20	49	112	274	0	0
Avg	17330	83	10	0.31	30	61	169	341	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	9.86	8.59	1.27	2460	2442	18
2	9.98	8.62	1.36	2468	2447	21

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/25/2006
Time	5:18:01 PM
Project Name	IIT Roorkee
Part No	C31C32
Batch Number	C31C32
Brake Speed	1000 RPM
Brake Pressure	16.8 kg/sq.cm
Brake Force	150 Kgf
File Name	C31C32_7_25_2006_5_18_01 PM

Brake pad material –FM10N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	127	15.3	0.20	20	50	112	279	0	0
2	17330	108	13.0	0.24	24	49	132	274	0	0
3	17330	104	12.5	0.25	24	52	135	288	0	0
4	17330	103	12.3	0.25	25	54	138	299	0	0
5	17330	99	11.9	0.26	25	55	142	305	0	0
6	17330	97	11.6	0.27	26	52	145	290	0	0
7	17330	97	11.6	0.26	26	57	144	317	0	0
8	17330	93	11.2	0.28	27	54	150	300	0	0
9	17330	92	11.1	0.28	27	54	151	302	0	0
10	17330	90	10.8	0.28	27	64	152	355	0	0
11	17330	90	10.8	0.29	28	61	156	336	0	0
12	17330	91	11.0	0.28	27	61	152	340	0	0
13	17330	86	10.3	0.29	28	60	157	335	0	0
14	17330	90	10.8	0.29	28	61	155	340	0	0
15	17330	86	10.3	0.30	29	58	161	324	0	0
16	17330	91	10.9	0.28	28	62	153	346	0	0
17	17330	88	10.5	0.29	28	60	158	332	0	0
18	17330	82	9.9	0.31	30	63	165	348	0	0
19	17330	82	9.8	0.31	30	58	169	324	0	0
20	17330	81	9.7	0.32	31	59	171	327	0	0
21	17330	76	9.1	0.34	33	59	181	326	0	0
22	17330	79	9.5	0.32	31	60	174	336	0	0
23	17330	81	9.7	0.31	30	68	169	380	0	0
24	17330	77	9.2	0.34	32	60	180	333	0	0
25	17330	80	9.5	0.33	31	68	174	376	0	0
26	17330	79	9.4	0.33	31	64	174	353	0	0
27	17330	75	9.0	0.34	33	65	183	361	0	0
28	17330	77	9.2	0.34	32	65	180	359	0	0
29	17330	78	9.3	0.34	32	66	180	369	0	0
30	17330	76	9.1	0.34	33	70	183	392	0	0
31	17330	76	9.1	0.34	33	64	182	358	0	0
32	17330	75	9.0	0.34	33	71	182	394	0	0
33	17330	75	8.9	0.35	34	61	186	341	0	0
34	17330	76	9.2	0.34	33	61	181	340	0	0
35	17330	79	9.4	0.33	32	62	179	343	0	0
36	17330	77	9.2	0.34	33	62	182	342	0	0
37	17330	76	9.1	0.34	33	67	183	370	0	0
38	17330	76	9.1	0.34	33	63	184	351	0	0
39	17330	76	9.1	0.34	33	61	183	340	0	0
40	17330	76	9.2	0.34	33	66	184	366	0	0
41	17330	72	8.7	0.36	34	72	192	398	0	0
42	17330	74	8.9	0.35	34	67	186	374	0	0
43	17330	77	9.2	0.34	33	65	183	361	0	0
44	17330	75	9.0	0.35	33	62	186	343	0	0
45	17330	74	8.8	0.36	34	60	191	334	0	0
46	17330	75	8.9	0.34	33	66	184	368	0	0
47	17330	79	9.4	0.33	32	64	180	356	0	0
48	17330	74	8.9	0.35	34	61	190	337	0	0
49	17330	77	9.3	0.34	33	63	183	352	0	0
50	17330	77	9.3	0.34	33	64	181	356	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM10N

Date	7/31/2006	
Time	4:20:56 PM	
Project Name	IIT ROORKEE	
Part No	C31C32 HIGH	
Batch Number	C31C32 HIGH	
Brake Speed	1300	RPM
Brake Pressure	18.02	kg/sq.cm
Brake Force	150	kgf
File Name	C31C32 HIGH_7_31_2006_4_20_56 PM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	178	16.5	0.28	29	63	161	352	0	0
Min	29158	150	13.9	0.24	25	47	136	258	0	0
Avg	29158	163	15	0.26	27	54	150	299	0	0

WEAR REPORT

PAD	THICKNESS In mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	8.37	5.88	2.49	2441	2402	39
2	8.6	5.98	2.62	2446	2405	41

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work.

PRODUCTION/DEVELOPMENT : [signature] 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT.

Date	7/31/2006	
Time	4:20:56 PM	
Project Name	IIT ROORKEE	
Part No	C31C32 HIGH	
Batch Number	C31C32 HIGH	
Brake Speed	1300	RPM
Brake Pressure	18.02	kg/sq.cm
Brake Force	150	Kgf
File Name	C31C32 HIGH_7_31_2006_4_20_56 PM	

Brake pad material –FM10N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	167	15.4	0.25	26	49	145	271	0	0
2	29158	169	15.6	0.25	26	53	144	296	0	0
3	29158	177	16.3	0.24	25	47	136	258	0	0
4	29158	175	16.2	0.24	25	48	139	267	0	0
5	29158	170	15.7	0.25	26	47	143	259	0	0
6	29158	172	15.9	0.25	25	48	141	267	0	0
7	29158	162	15.0	0.26	27	48	148	269	0	0
8	29158	166	15.3	0.26	26	51	147	282	0	0
9	29158	165	15.2	0.26	27	50	148	279	0	0
10	29158	161	14.9	0.26	27	56	148	312	0	0
11	29158	159	14.7	0.27	27	48	153	265	0	0
12	29158	154	14.3	0.27	28	52	157	289	0	0
13	29158	158	14.5	0.27	28	53	154	297	0	0
14	29158	153	14.1	0.27	28	53	155	293	0	0
15	29158	154	14.3	0.28	28	51	157	286	0	0
16	29158	153	14.1	0.28	29	54	159	301	0	0
17	29158	154	14.2	0.28	29	63	159	352	0	0
18	29158	152	14.0	0.28	29	59	160	330	0	0
19	29158	150	13.9	0.28	29	59	159	330	0	0
20	29158	155	14.3	0.27	28	60	157	331	0	0
21	29158	151	13.9	0.28	29	57	161	318	0	0
22	29158	156	14.4	0.27	28	55	156	307	0	0
23	29158	155	14.3	0.27	28	58	157	320	0	0
24	29158	151	14.0	0.28	29	59	161	331	0	0
25	29158	158	14.6	0.27	28	55	155	308	0	0
26	29158	160	14.8	0.27	27	51	153	285	0	0
27	29158	162	14.9	0.27	27	58	152	324	0	0
28	29158	161	14.9	0.26	27	54	151	301	0	0
29	29158	153	14.2	0.27	28	58	154	322	0	0
30	29158	158	14.6	0.27	28	53	155	293	0	0
31	29158	158	14.6	0.27	28	56	155	313	0	0
32	29158	165	15.2	0.26	27	55	149	305	0	0
33	29158	159	14.7	0.27	28	54	154	303	0	0
34	29158	162	14.9	0.26	27	60	152	334	0	0
35	29158	164	15.1	0.26	26	53	147	294	0	0
36	29158	161	14.9	0.26	27	60	153	334	0	0
37	29158	168	15.5	0.25	26	54	146	298	0	0
38	29158	164	15.1	0.26	27	56	150	309	0	0
39	29158	168	15.5	0.26	27	53	147	292	0	0
40	29158	169	15.6	0.25	26	50	147	275	0	0
41	29158	163	15.0	0.26	27	58	150	323	0	0
42	29158	173	16.0	0.25	26	50	143	280	0	0
43	29158	173	16.0	0.24	25	55	142	307	0	0
44	29158	174	16.0	0.25	26	54	142	302	0	0
45	29158	171	15.8	0.25	26	53	145	295	0	0
46	29158	174	16.0	0.25	26	50	143	279	0	0
47	29158	173	16.0	0.25	26	50	144	276	0	0
48	29158	169	15.6	0.25	26	53	146	296	0	0
49	29158	168	15.5	0.25	26	52	147	291	0	0
50	29158	178	16.5	0.24	25	51	139	281	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM11N

Date	7/26/2006	
Time	10:34:41 AM	
Project Name	IIT Roorkee	
Part No	C41C42	
Batch Number	C41C42	
Brake Speed	1000	RPM
Brake Pressure	17.68	kg/sq.cm
Brake Force	150	kgf
File Name	C41C42_7_26_2006_10_34_41 AM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	115	13.8	0.34	34	82	188	454	0	0
Min	17330	74	8.8	0.22	22	44	124	244	0	0
Avg	17330	101	12.1	0.25	25	52	141	288	0	0

WEAR REPORT

PAD No	THICKNESS in mm			WEIGHT IN grams		
	Initial	Final	Wear	Initial	Final	Wear
1	9.95		9.95	2473		2473
2	9.94		9.94	2466		2466

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT :

2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/26/2006	
Time	10:34:41 AM	
Project Name	IIT Roorkee	
Part No	C41C42	
Batch Number	C41C42	
Brake Speed	1000	RPM
Brake Pressure	17.68	kg/sq.cm
Brake Force	150	Kgf
File Name	C41C42_7_26_2006_10_34_41 AM	

Brake pad material –FM11N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	86	10.3	0.29	29	64	164	356	0	0
2	17330	84	10.1	0.29	29	60	162	331	0	0
3	17330	82	9.8	0.31	30	69	168	382	0	0
4	17330	78	9.4	0.32	32	82	176	454	0	0
5	17330	74	8.8	0.34	34	70	188	388	0	0
6	17330	80	9.5	0.30	30	65	169	363	0	0
7	17330	83	9.9	0.30	30	60	166	332	0	0
8	17330	85	10.1	0.30	29	77	164	425	0	0
9	17330	89	10.7	0.28	28	54	155	300	0	0
10	17330	97	11.6	0.26	26	50	143	276	0	0
11	17330	104	12.5	0.24	24	46	135	258	0	0
12	17330	104	12.5	0.24	24	52	135	286	0	0
13	17330	104	12.5	0.24	24	48	134	267	0	0
14	17330	104	12.4	0.25	25	50	137	280	0	0
15	17330	110	13.2	0.23	23	47	129	260	0	0
16	17330	108	12.9	0.23	24	45	131	251	0	0
17	17330	106	12.7	0.23	24	48	132	266	0	0
18	17330	109	13.0	0.23	23	47	130	258	0	0
19	17330	112	13.4	0.23	23	44	127	246	0	0
20	17330	111	13.3	0.23	23	47	129	259	0	0
21	17330	115	13.8	0.22	22	56	124	309	0	0
22	17330	109	13.1	0.23	23	44	130	246	0	0
23	17330	108	13.0	0.24	24	52	131	287	0	0
24	17330	107	12.9	0.24	24	51	133	283	0	0
25	17330	106	12.7	0.24	24	44	134	247	0	0
26	17330	103	12.3	0.24	24	52	136	289	0	0
27	17330	105	12.6	0.24	24	48	136	265	0	0
28	17330	107	12.9	0.24	24	49	133	270	0	0
29	17330	107	12.9	0.24	24	46	133	257	0	0
30	17330	105	12.6	0.24	24	46	135	256	0	0
31	17330	106	12.7	0.24	24	47	135	262	0	0
32	17330	103	12.4	0.24	25	49	139	271	0	0
33	17330	108	12.9	0.24	24	48	132	266	0	0
34	17330	102	12.3	0.25	25	49	140	274	0	0
35	17330	109	13.1	0.23	24	45	132	249	0	0
36	17330	107	12.9	0.24	24	56	133	310	0	0
37	17330	107	12.9	0.24	24	45	134	251	0	0
38	17330	103	12.3	0.24	25	47	138	264	0	0
39	17330	107	12.8	0.24	24	44	135	244	0	0
40	17330	103	12.4	0.25	25	47	139	259	0	0
41	17330	106	12.7	0.24	24	52	136	290	0	0
42	17330	103	12.3	0.25	25	44	139	244	0	0
43	17330	100	12.0	0.26	26	72	144	400	0	0
44	17330	98	11.8	0.26	26	54	145	299	0	0
45	17330	107	12.8	0.24	24	45	135	248	0	0
46	17330	105	12.6	0.24	25	48	138	267	0	0
47	17330	101	12.1	0.25	25	48	142	268	0	0
48	17330	98	11.8	0.25	26	47	143	259	0	0
49	17330	104	12.4	0.25	25	46	140	257	0	0
50	17330	99	11.9	0.26	26	48	146	269	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/31/2006
Time	9:45:54 PM
Project Name	IIT ROORKEE
Part No	C41C42 HIGH
Batch Number	C41C42 HIGH
Brake Speed	1300 RPM
Brake Pressure	18.07 kg/sq.cm
Brake Force	150 kgf
File Name	C41C42 HIGH_7_31_2006_9_45_54 PM

Brake pad material –FM11N

	Kinetic Energy	RD rev.	RD time	Coefficient	Mean Torque	Peak Torque	Mean Drag	Peak Drag	Pad1-Temp	Pad2-Temp
	(kgfm)		(sec)	of friction	(kgfm)	(kgfm)	(kgf)	(kgf)	(DegC)	(DegC)
Max	29158	214	19.8	0.31	31	58	173	322	0	0
Min	29158	141	13	0.2	21	40	117	223	0	0
Avg	29158	189	17.4	0.23	24	46	132	258	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.51	2.68	4.83	2435	2356	79
2	7.28	2.84	4.44	2426	2362	64

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT :

2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date 7/31/2006
Time 9:45:54 PM
Project Name IIT ROORKEE
Part No C41C42 HIGH
Batch Number C41C42 HIGH
Brake Speed 1300 RPM
Brake Pressure 18.07 kg/sq.cm
Brake Force 150 Kgf
File Name C41C42 HIGH_7_31_2006_9_45_54 PM

Brake pad material –FM11N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	145	13.3	0.30	31	58	170	322	0	0
2	29158	141	13.0	0.31	31	50	173	276	0	0
3	29158	165	15.2	0.26	27	55	148	304	0	0
4	29158	179	16.5	0.24	25	50	137	276	0	0
5	29158	189	17.4	0.23	24	46	131	255	0	0
6	29158	188	17.4	0.23	24	46	131	254	0	0
7	29158	195	18.0	0.22	23	51	127	285	0	0
8	29158	190	17.5	0.22	23	57	130	318	0	0
9	29158	192	17.7	0.22	23	44	129	247	0	0
10	29158	192	17.8	0.22	23	41	129	229	0	0
11	29158	190	17.5	0.22	23	49	130	270	0	0
12	29158	189	17.5	0.22	23	44	129	242	0	0
13	29158	190	17.5	0.23	23	42	130	236	0	0
14	29158	191	17.6	0.23	24	47	131	262	0	0
15	29158	190	17.5	0.23	24	41	131	228	0	0
16	29158	190	17.6	0.23	23	41	130	226	0	0
17	29158	187	17.2	0.23	24	40	134	223	0	0
18	29158	191	17.7	0.22	23	40	130	225	0	0
19	29158	193	17.8	0.22	23	43	129	237	0	0
20	29158	188	17.1	0.23	24	44	134	247	0	0
21	29158	189	17.4	0.23	24	44	132	242	0	0
22	29158	194	17.9	0.22	23	43	129	241	0	0
23	29158	183	16.9	0.24	24	43	136	239	0	0
24	29158	187	17.2	0.23	24	45	133	249	0	0
25	29158	191	17.6	0.23	24	43	131	240	0	0
26	29158	188	17.4	0.23	24	47	133	262	0	0
27	29158	185	17.1	0.23	24	49	134	274	0	0
28	29158	181	16.7	0.24	25	49	137	273	0	0
29	29158	184	17.0	0.23	24	42	135	233	0	0
30	29158	178	16.5	0.24	25	47	140	260	0	0
31	29158	182	16.8	0.24	25	48	137	264	0	0
32	29158	187	17.2	0.23	24	47	134	261	0	0
33	29158	190	17.5	0.23	24	43	132	239	0	0
34	29158	189	17.4	0.23	24	43	132	239	0	0
35	29158	179	16.5	0.24	25	45	137	251	0	0
36	29158	184	17.0	0.23	24	48	135	269	0	0
37	29158	185	17.1	0.23	24	46	133	257	0	0
38	29158	193	17.8	0.22	23	49	130	271	0	0
39	29158	185	17.1	0.23	24	55	134	305	0	0
40	29158	199	18.3	0.22	23	52	126	291	0	0
41	29158	195	18.0	0.22	23	46	128	254	0	0
42	29158	204	18.8	0.21	22	48	122	267	0	0
43	29158	197	18.2	0.22	23	49	127	270	0	0
44	29158	208	19.2	0.21	22	47	120	261	0	0
45	29158	199	18.4	0.22	23	44	126	246	0	0
46	29158	214	19.8	0.20	21	48	117	253	0	0
47	29158	211	19.5	0.20	21	40	118	224	0	0
48	29158	201	18.5	0.21	22	47	123	263	0	0
49	29158	202	18.6	0.21	22	47	124	259	0	0
50	29158	198	18.2	0.22	23	48	126	268	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/26/2006	
Time	12:34:02 PM	
Project Name	IIT Roorkee	
Part No	C51C52	
Batch Number	C51C52	
Brake Speed	1000	RPM
Brake Pressure	17.2	kg/sq.cm
Brake Force	150	kgf
File Name	C51C52_7_26_2006_12_34_02 PM	

Brake pad material –FM12N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	7330	103	12.3	0.35	35	81	196	447	0	0
Min	7330	70	8.4	0.25	25	50	137	275	0	0
Avg	7330	78	9.3	0.32	32	57	178	315	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	9.99	8.11	1.88	2465	2436	29
2	9.97	7.68	2.29	2461	2429	32

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : [signature]

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/26/2006	
Time	12:34:02 PM	
Project Name	IIT Roorkee	
Part No	C51C52	
Batch Number	C51C52	
Brake Speed	1000	RPM
Brake Pressure	17.2	kg/sq.cm
Brake Force	150	Kgf
File Name	C51C52_7_26_2006_12_34_02 PM	

Brake pad material –FM12N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	103	12.3	0.25	25	50	137	275	0	0
2	17330	91	10.9	0.28	28	53	154	294	0	0
3	17330	88	10.6	0.28	28	57	157	316	0	0
4	17330	87	10.4	0.29	29	53	160	296	0	0
5	17330	84	10.1	0.29	29	58	160	323	0	0
6	17330	85	10.2	0.29	29	60	161	334	0	0
7	17330	85	10.2	0.29	29	53	162	296	0	0
8	17330	87	10.4	0.29	29	55	161	303	0	0
9	17330	85	10.2	0.30	30	54	164	301	0	0
10	17330	84	10.1	0.30	30	55	164	305	0	0
11	17330	83	10.0	0.30	30	56	166	309	0	0
12	17330	83	10.0	0.30	30	56	166	311	0	0
13	17330	84	10.1	0.30	30	55	164	305	0	0
14	17330	81	9.7	0.31	31	50	170	279	0	0
15	17330	79	9.5	0.31	31	53	173	295	0	0
16	17330	78	9.4	0.32	31	53	174	296	0	0
17	17330	81	9.7	0.31	31	50	170	279	0	0
18	17330	81	9.8	0.31	30	56	169	312	0	0
19	17330	80	9.6	0.31	31	52	172	289	0	0
20	17330	80	9.6	0.31	31	51	173	285	0	0
21	17330	77	9.3	0.32	32	51	176	282	0	0
22	17330	74	8.8	0.33	33	54	181	299	0	0
23	17330	76	9.1	0.33	32	53	180	293	0	0
24	17330	73	8.8	0.33	33	55	182	308	0	0
25	17330	77	9.2	0.33	32	57	179	317	0	0
26	17330	75	8.9	0.33	33	55	183	307	0	0
27	17330	71	8.5	0.34	34	81	187	447	0	0
28	17330	72	8.7	0.34	33	56	185	309	0	0
29	17330	75	8.9	0.33	33	57	185	318	0	0
30	17330	73	8.8	0.33	33	61	184	338	0	0
31	17330	75	9.0	0.32	32	57	180	317	0	0
32	17330	75	9.0	0.33	33	56	185	312	0	0
33	17330	72	8.6	0.34	34	59	190	328	0	0
34	17330	73	8.6	0.34	34	53	187	294	0	0
35	17330	74	8.9	0.33	33	61	185	339	0	0
36	17330	74	8.9	0.34	34	58	188	323	0	0
37	17330	72	8.7	0.35	34	59	191	330	0	0
38	17330	72	8.7	0.34	34	57	191	316	0	0
39	17330	70	8.4	0.35	35	60	194	336	0	0
40	17330	71	8.5	0.35	35	57	194	318	0	0
41	17330	71	8.5	0.35	35	58	196	324	0	0
42	17330	74	8.9	0.34	34	58	188	323	0	0
43	17330	71	8.6	0.35	35	66	194	365	0	0
44	17330	72	8.6	0.35	35	57	193	316	0	0
45	17330	72	8.6	0.35	35	58	194	320	0	0
46	17330	71	8.5	0.35	35	67	193	370	0	0
47	17330	71	8.6	0.35	35	67	196	370	0	0
48	17330	74	8.9	0.34	34	59	189	325	0	0
49	17330	73	8.7	0.34	34	56	191	310	0	0
50	17330	74	8.8	0.34	34	55	190	306	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date 8/1/2006
Time 9:29:04 AM
Project Name IIT ROORKEE
Part No C51C52 HIGH
Batch Number C51C52 HIGH
Brake Speed 1300 RPM
Brake Pressure 18.05 kg/sq.cm
Brake Force 150 kgf
File Name C51C52 HIGH_8_1_2006_9_29_04 AM

Brake pad material –FM12N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	169	15.6	0.32	33	68	183	377	0	0
Min	29158	129	11.9	0.25	26	49	146	274	0	0
Avg	29158	145	13.3	0.3	31	59	172	325	0	0

WEAR REPORT

PAD	THICKNESS In mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	8.07	5.07	3	2436	2391	45
2	7.66	4.75	2.91	2428	2371	57

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT :

2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	8/1/2006	
Time	9:29:04 AM	
Project Name	IIT ROORKEE	
Part No	C61C62 HIGH	
Batch Number	C61C62 HIGH	
Brake Speed	1300	RPM
Brake Pressure	18.05	kg/sq.cm
Brake Force	150	Kgf
File Name	C61C62 HIGH_8_1_2006_9_29_04 AM	

Brake pad material –FM12N

SI NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	129	11.9	0.32	32	59	179	329	0	0
2	29158	133	12.3	0.32	33	53	182	293	0	0
3	29158	142	13.1	0.30	31	61	171	338	0	0
4	29158	155	14.3	0.27	28	57	157	319	0	0
5	29158	162	14.9	0.26	27	52	152	289	0	0
6	29158	165	15.2	0.26	27	50	150	275	0	0
7	29158	164	15.2	0.26	27	51	150	284	0	0
8	29158	166	15.3	0.26	27	57	148	317	0	0
9	29158	169	15.6	0.25	26	52	146	287	0	0
10	29158	160	14.8	0.27	28	53	154	297	0	0
11	29158	162	14.9	0.27	28	53	153	296	0	0
12	29158	161	14.8	0.26	27	49	152	274	0	0
13	29158	150	13.9	0.29	30	56	165	309	0	0
14	29158	151	14.0	0.28	29	56	163	311	0	0
15	29158	149	13.7	0.29	30	55	166	307	0	0
16	29158	149	13.7	0.29	30	55	166	307	0	0
17	29158	145	13.4	0.29	31	61	170	340	0	0
18	29158	142	13.1	0.30	31	59	174	326	0	0
19	29158	145	13.4	0.30	31	60	171	331	0	0
20	29158	138	12.8	0.31	32	58	180	321	0	0
21	29158	137	12.7	0.31	33	59	181	329	0	0
22	29158	138	12.8	0.31	32	60	179	333	0	0
23	29158	141	13.0	0.31	32	60	176	332	0	0
24	29158	137	12.6	0.31	33	62	182	347	0	0
25	29158	137	12.6	0.31	33	64	182	356	0	0
26	29158	137	12.6	0.32	33	60	183	334	0	0
27	29158	135	12.4	0.31	33	63	183	350	0	0
28	29158	140	12.9	0.31	32	62	179	343	0	0
29	29158	137	12.7	0.31	32	61	180	336	0	0
30	29158	138	12.7	0.31	33	60	181	334	0	0
31	29158	137	12.6	0.31	33	64	181	358	0	0
32	29158	137	12.7	0.32	33	63	182	349	0	0
33	29158	138	12.7	0.31	33	62	182	345	0	0
34	29158	136	12.6	0.32	33	62	183	347	0	0
35	29158	141	13.0	0.30	32	68	176	377	0	0
36	29158	140	12.9	0.31	32	61	178	336	0	0
37	29158	142	13.1	0.30	32	56	176	314	0	0
38	29158	137	12.6	0.30	32	63	176	350	0	0
39	29158	144	13.3	0.30	31	54	173	301	0	0
40	29158	143	13.2	0.30	31	61	174	341	0	0
41	29158	142	13.1	0.30	32	61	175	341	0	0
42	29158	140	12.9	0.31	32	64	178	357	0	0
43	29158	142	13.1	0.30	32	61	175	341	0	0
44	29158	140	12.9	0.31	32	59	178	327	0	0
45	29158	142	13.1	0.30	32	61	176	340	0	0
46	29158	142	13.1	0.30	32	61	176	339	0	0
47	29158	144	13.3	0.30	31	56	174	313	0	0
48	29158	145	13.4	0.30	31	56	172	309	0	0
49	29158	145	13.4	0.30	31	59	173	326	0	0
50	29158	143	13.2	0.30	31	56	171	310	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/25/2006	
Time	2:08:47 PM	
Project Name	IIT Roorkee	
Part No	C61C62	
Batch Number	C61C62	
Brake Speed	1000	RPM
Brake Pressure	16.62	kg/sq.cm
Brake Force	150	kgf
File Name	C61C62_7_25_2006_2_08_47 PM	

Brake pad material –FM13N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	96	11.5	0.38	36	69	201	385	0	0
Min	17330	63	7.6	0.26	25	40	141	223	0	0
Avg	17330	80	9.7	0.32	31	52	173	291	0	0

WEAR REPORT

PAD No	THICKNESS in mm Initial	Final	Wear	WEIGHT IN grams Initial	Final	Wear
1	9.51	8.71	0.8	2474	2461	13
2	9.61	9	0.61	2479	2470	9

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT :

2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/25/2006	
Time	2:08:47 PM	
Project Name	IIT Roorkee	
Part No	C61C62	
Batch Number	C61C62	
Brake Speed	1000	RPM
Brake Pressure	18.62	kg/sq.cm
Brake Force	150	Kgf
File Name	C61C62_7_25_2006_2_08_47 PM	

Brake pad material –FM13N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	95	11.4	0.27	27	66	147	367	0	0
2	17330	88	10.6	0.30	29	65	159	359	0	0
3	17330	91	11.0	0.28	27	68	153	376	0	0
4	17330	96	11.5	0.26	25	64	141	355	0	0
5	17330	96	11.5	0.27	26	61	146	340	0	0
6	17330	96	11.5	0.27	26	62	147	344	0	0
7	17330	88	10.6	0.29	28	60	157	331	0	0
8	17330	82	9.8	0.32	30	61	169	340	0	0
9	17330	81	9.7	0.33	31	58	173	321	0	0
10	17330	80	9.5	0.33	32	64	176	355	0	0
11	17330	76	9.1	0.35	33	69	183	385	0	0
12	17330	82	9.8	0.33	31	54	172	301	0	0
13	17330	73	8.8	0.35	33	56	188	311	0	0
14	17330	73	8.7	0.36	34	57	190	318	0	0
15	17330	74	8.9	0.35	33	55	185	306	0	0
16	17330	68	8.2	0.37	35	58	197	323	0	0
17	17330	71	8.5	0.35	34	52	187	291	0	0
18	17330	63	7.6	0.38	36	54	201	302	0	0
19	17330	68	8.2	0.38	36	53	199	296	0	0
20	17330	72	8.7	0.36	34	56	190	312	0	0
21	17330	68	8.2	0.37	35	55	198	304	0	0
22	17330	71	8.5	0.37	35	52	196	286	0	0
23	17330	70	8.4	0.37	35	52	197	291	0	0
24	17330	70	8.4	0.37	35	49	195	270	0	0
25	17330	72	8.6	0.36	34	48	189	264	0	0
26	17330	74	8.8	0.35	34	52	187	291	0	0
27	17330	73	8.8	0.34	33	50	183	276	0	0
28	17330	74	8.9	0.34	32	48	180	269	0	0
29	17330	77	9.2	0.34	32	46	180	258	0	0
30	17330	79	9.5	0.32	31	49	174	275	0	0
31	17330	78	9.4	0.32	31	45	174	248	0	0
32	17330	81	9.8	0.31	30	54	166	301	0	0
33	17330	76	9.2	0.34	33	46	181	254	0	0
34	17330	81	9.7	0.32	31	45	172	251	0	0
35	17330	80	9.6	0.32	31	46	173	258	0	0
36	17330	84	10.1	0.31	30	50	165	279	0	0
37	17330	85	10.2	0.30	29	52	162	289	0	0
38	17330	84	10.1	0.30	29	53	162	294	0	0
39	17330	88	10.6	0.29	28	43	158	237	0	0
40	17330	83	10.0	0.31	30	47	167	260	0	0
41	17330	83	9.9	0.31	30	46	169	253	0	0
42	17330	84	10.1	0.30	29	42	161	231	0	0
43	17330	86	10.3	0.30	29	41	162	230	0	0
44	17330	84	10.1	0.31	30	44	166	244	0	0
45	17330	86	10.3	0.30	29	44	163	246	0	0
46	17330	86	10.4	0.30	29	40	162	223	0	0
47	17330	87	10.4	0.30	29	43	162	238	0	0
48	17330	87	10.4	0.29	29	43	160	240	0	0
49	17330	84	10.1	0.31	30	49	166	272	0	0
50	17330	92	11.0	0.29	28	51	153	283	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	7/31/2006	
Time	8:20:16 PM	
Project Name	IIT ROORKEE	
Part No	C61C62 HIGH	
Batch Number	C61C62 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.73	kg/sq.cm
Brake Force	160	kgf
File Name	C61C62 HIGH_7_31_2006_8_20_16 PM	

Brake pad material –FM13N

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	197	18.2	0.34	34	61	187	340	0	0
Min	29158	128	11.9	0.22	22	35	124	196	0	0
Avg	29158	170	15.7	0.26	26	41	144	230	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	8.79	7.53	1.26	2464	2441	23
2	9	8.06	0.94	2468	2451	17

Total Number of Cycles completed: 50

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT : 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/31/2006
Time	8:20:16 PM
Project Name	IIT ROORKEE
Part No	C61C62 HIGH
Batch Number	C61C62 HIGH
Brake Speed	1300 RPM
Brake Pressure	17.73 kg/sq.cm
Brake Force	150 Kgf
File Name	C61C62 HIGH_7_31_2006_8_20_16 PM

Brake pad material –FM13N

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	145	13.4	0.30	30	61	167	283	0	0
2	29158	129	11.9	0.34	34	61	187	340	0	0
3	29158	132	12.1	0.33	33	50	183	279	0	0
4	29158	134	12.3	0.32	33	61	181	282	0	0
5	29158	128	11.9	0.34	34	53	187	292	0	0
6	29158	143	13.2	0.30	30	54	168	298	0	0
7	29158	134	12.4	0.32	32	53	180	292	0	0
8	29158	146	13.5	0.29	30	46	165	258	0	0
9	29158	140	13.0	0.31	31	46	171	257	0	0
10	29158	149	13.7	0.29	29	44	163	243	0	0
11	29158	146	13.5	0.29	30	47	164	259	0	0
12	29158	153	14.1	0.28	28	45	157	251	0	0
13	29158	161	14.8	0.27	27	52	150	290	0	0
14	29158	167	15.4	0.26	26	39	145	215	0	0
15	29158	166	15.3	0.26	26	41	145	227	0	0
16	29158	163	15.0	0.26	27	42	149	234	0	0
17	29158	165	15.2	0.26	26	41	146	227	0	0
18	29158	169	15.6	0.25	26	41	143	230	0	0
19	29158	170	15.7	0.25	26	39	142	215	0	0
20	29158	172	15.9	0.25	25	40	141	222	0	0
21	29158	178	16.5	0.24	24	36	136	199	0	0
22	29158	176	16.3	0.24	25	36	137	199	0	0
23	29158	178	16.5	0.24	25	37	136	204	0	0
24	29158	182	16.8	0.23	24	36	133	199	0	0
25	29158	180	16.6	0.24	24	35	135	196	0	0
26	29158	178	16.4	0.24	25	35	136	197	0	0
27	29158	176	16.3	0.24	25	37	137	204	0	0
28	29158	181	16.7	0.23	24	38	132	213	0	0
29	29158	180	16.6	0.24	24	38	135	213	0	0
30	29158	183	16.9	0.23	24	42	133	235	0	0
31	29158	179	16.5	0.24	24	38	136	211	0	0
32	29158	180	16.6	0.24	24	39	134	218	0	0
33	29158	181	16.7	0.24	24	44	134	245	0	0
34	29158	183	16.9	0.23	24	37	133	208	0	0
35	29158	178	16.5	0.24	24	36	136	199	0	0
36	29158	180	16.6	0.24	24	42	135	232	0	0
37	29158	181	16.7	0.24	24	38	134	209	0	0
38	29158	188	17.3	0.23	23	43	130	239	0	0
39	29158	181	16.7	0.24	24	37	134	203	0	0
40	29158	178	16.5	0.23	24	38	134	210	0	0
41	29158	185	17.0	0.23	24	36	132	199	0	0
42	29158	186	17.2	0.23	23	37	130	206	0	0
43	29158	180	16.6	0.23	24	36	132	201	0	0
44	29158	179	16.6	0.24	24	39	136	215	0	0
45	29158	197	18.2	0.22	22	38	124	212	0	0
46	29158	181	16.7	0.23	24	36	132	199	0	0
47	29158	194	17.9	0.22	23	37	126	205	0	0
48	29158	192	17.7	0.22	23	37	127	207	0	0
49	29158	192	17.7	0.22	23	38	127	212	0	0
50	29158	186	17.1	0.23	24	36	131	203	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	1/30/2007	
Time	2:46:36 PM	
Project Name	IIT	
Part No	A3 A62 LOW	
Batch Number	A3 A62 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	150	kgf
File Name	A3 A62 LOW	_1_30_2007_2_46_36 PM

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	105	12.6	0.35	34	73	190	403	0	189
Min	17330	78	9.4	0.25	25	50	140	275	0	0
Avg	17330	92	11	0.29	29	60	161	331	0	46

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.34	5.94	0.4	2399	2394	5
2	6.48	6.27	0.21	2408	2405	3

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/30/2007	
Time	2:46:36 PM	
Project Name	IIT	
Part No	A3 A62 LOW	
Batch Number	A3 A62 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	150	Kgf
File Name	A3 A62 LOW	_1_30_2007_2_46_36 PM

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	105	12.6	0.25	25	60	140	334	0	0
2	17330	93	11.2	0.28	29	56	159	310	0	0
3	17330	94	11.3	0.28	28	57	157	319	0	58
4	17330	88	10.6	0.30	30	59	168	329	0	0
5	17330	86	10.3	0.31	31	57	172	315	0	88
6	17330	81	9.7	0.33	33	63	183	352	0	0
7	17330	81	9.7	0.33	33	61	183	340	0	0
8	17330	82	9.8	0.33	33	60	181	334	0	0
9	17330	79	9.5	0.33	33	61	181	338	0	0
10	17330	78	9.4	0.35	34	68	190	379	0	29
11	17330	81	9.8	0.33	33	70	182	390	0	0
12	17330	82	9.8	0.33	33	59	181	327	0	0
13	17330	86	10.3	0.31	31	66	173	368	0	0
14	17330	82	9.8	0.32	32	70	177	387	0	0
15	17330	87	10.4	0.31	31	73	170	403	0	0
16	17330	84	10.1	0.32	32	62	175	345	0	87
17	17330	92	11.0	0.29	29	61	162	340	0	85
18	17330	85	10.2	0.32	31	64	175	356	0	0
19	17330	84	10.1	0.32	32	60	176	334	0	87
20	17330	87	10.4	0.31	31	65	170	360	0	116
21	17330	87	10.4	0.31	31	61	171	336	0	44
22	17330	93	11.1	0.29	29	59	159	327	0	93
23	17330	93	11.1	0.28	28	64	157	354	0	93
24	17330	87	10.4	0.30	30	63	166	349	0	16
25	17330	97	11.6	0.27	27	56	152	309	0	169
26	17330	90	10.8	0.29	30	61	164	339	0	148
27	17330	92	11.0	0.29	29	59	161	326	0	95
28	17330	90	10.8	0.30	30	60	165	331	0	80
29	17330	93	11.2	0.28	29	55	159	308	0	0
30	17330	96	11.5	0.28	28	61	154	338	0	189
31	17330	92	11.0	0.29	29	61	161	340	0	0
32	17330	93	11.2	0.28	28	59	157	325	0	113
33	17330	92	11.0	0.29	29	57	161	316	0	159
34	17330	93	11.2	0.28	28	58	157	322	0	63
35	17330	93	11.1	0.28	28	55	157	303	0	174
36	17330	95	11.4	0.28	28	61	155	337	0	134
37	17330	94	11.3	0.28	28	58	154	322	0	0
38	17330	95	11.3	0.27	27	57	152	319	0	36
39	17330	105	12.6	0.25	25	56	141	311	0	140
40	17330	96	11.5	0.28	28	59	155	329	0	0
41	17330	101	12.1	0.26	26	59	145	330	0	0
42	17330	105	12.6	0.25	25	54	141	302	0	0
43	17330	98	11.8	0.27	27	50	149	277	0	0
44	17330	99	11.8	0.27	27	51	150	281	0	0
45	17330	102	12.2	0.26	26	67	145	370	0	0
46	17330	99	11.9	0.27	27	55	149	308	0	0
47	17330	102	12.2	0.26	26	58	145	320	0	0
48	17330	105	12.5	0.25	25	52	142	286	0	0
49	17330	101	12.1	0.26	26	50	146	275	0	0
50	17330	100	12.0	0.26	26	50	147	280	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	1/31/2007	
Time	2:52:15 PM	
Project Name	IIT	
Part No	A2 A51 LOW	
Batch Number	A2 A51 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	150	kgf
File Name	A2 A51 LOW	_1_31_2007_2_52_15 PM

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	105	12.6	0.33	33	77	183	428	0	0
Min	17330	81	9.7	0.25	25	50	141	280	0	0
Avg	17330	92	11	0.29	29	58	162	323	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.47	6	0.47	2405	2397	8
2	6.2	5.91	0.29	2404	2400	4

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

HAL

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/31/2007	
Time	2:52:16 PM	
Project Name	IIT	
Part No	A2 A61 LOW	
Batch Number	A2 A61 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	160	Kgf
File Name	A2 A61 LOW	_1_31_2007_2_52_16 PM

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	89	10.6	0.30	30	57	166	319	0	0
2	17330	84	10.0	0.32	32	51	177	281	0	0
3	17330	87	10.4	0.31	31	55	170	307	0	0
4	17330	89	10.6	0.29	29	56	162	312	0	0
5	17330	87	10.4	0.31	31	60	171	332	0	0
6	17330	84	10.0	0.32	32	56	177	312	0	0
7	17330	87	10.4	0.31	31	59	170	327	0	0
8	17330	83	10.0	0.32	32	56	178	309	0	0
9	17330	85	10.2	0.31	31	66	174	368	0	0
10	17330	83	10.0	0.32	32	55	178	306	0	0
11	17330	83	9.9	0.32	32	60	179	334	0	0
12	17330	81	9.7	0.33	33	57	183	314	0	0
13	17330	83	9.9	0.32	32	59	179	329	0	0
14	17330	84	10.1	0.32	32	57	176	319	0	0
15	17330	85	10.2	0.31	31	63	174	350	0	0
16	17330	90	10.7	0.30	30	59	165	329	0	0
17	17330	87	10.4	0.31	31	58	170	323	0	0
18	17330	87	10.4	0.31	31	56	169	314	0	0
19	17330	87	10.5	0.30	30	56	169	310	0	0
20	17330	87	10.5	0.31	31	57	170	318	0	0
21	17330	92	11.0	0.29	29	59	162	327	0	0
22	17330	87	10.4	0.31	31	54	170	298	0	0
23	17330	92	11.0	0.29	29	55	160	304	0	0
24	17330	92	11.0	0.29	29	71	161	393	0	0
25	17330	92	11.0	0.29	29	64	160	355	0	0
26	17330	91	10.9	0.29	29	60	163	332	0	0
27	17330	92	11.0	0.29	29	54	161	299	0	0
28	17330	91	10.9	0.29	29	58	160	325	0	0
29	17330	92	11.0	0.29	29	53	161	293	0	0
30	17330	90	10.8	0.29	29	55	163	303	0	0
31	17330	94	11.2	0.29	29	77	163	428	0	0
32	17330	95	11.4	0.27	28	57	153	314	0	0
33	17330	96	11.5	0.27	28	55	153	307	0	0
34	17330	100	12.0	0.26	27	60	148	332	0	0
35	17330	94	11.3	0.28	28	50	158	280	0	0
36	17330	96	11.5	0.28	28	55	154	307	0	0
37	17330	96	11.5	0.27	28	73	154	404	0	0
38	17330	93	11.1	0.28	29	66	159	366	0	0
39	17330	98	11.7	0.27	27	53	151	293	0	0
40	17330	96	11.6	0.27	28	52	153	287	0	0
41	17330	96	11.6	0.27	27	57	153	318	0	0
42	17330	102	12.2	0.26	26	65	145	359	0	0
43	17330	98	11.8	0.27	27	73	151	407	0	0
44	17330	100	12.0	0.26	27	58	148	322	0	0
45	17330	104	12.5	0.25	26	51	142	282	0	0
46	17330	100	12.0	0.26	26	53	147	292	0	0
47	17330	99	11.9	0.27	27	56	150	312	0	0
48	17330	105	12.6	0.25	25	54	141	298	0	0
49	17330	100	12.0	0.26	26	57	145	314	0	0
50	17330	100	12.0	0.26	26	56	144	310	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	1/31/2007		
Time	1:50:11 PM		
Project Name	IIT		
Part No	A22 A31 LOW		
Batch Number	A22 A31 LOW		
Brake Speed	1000	RPM	
Brake Pressure	17.34	kg/sq.cm	
Brake Force	150	kgf	
File Name	A22 A31 LOW	_1_31_2007_1_50_11 PM	

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	98	11.8	0.38	38	71	209	394	0	0
Min	17330	71	8.5	0.27	27	53	151	296	0	0
Avg	17330	85	10.2	0.32	31	61	175	339	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.23	6.85	0.38	2413	2407	6
2	6.2	6.01	0.19	2404	2400	4

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

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HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/31/2007	
Time	1:50:11 PM	
Project Name	IIT	
Part No	A22 A31 LOW	
Batch Number	A22 A31 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.34	kg/sq.cm
Brake Force	160	Kgf
File Name	A22 A31 LOW	_1_31_2007_1_50_11 PM

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	94	11.3	0.27	27	56	153	312	0	0
2	17330	87	10.5	0.30	30	59	169	328	0	0
3	17330	79	9.4	0.34	34	58	188	320	0	0
4	17330	73	8.7	0.36	36	60	198	333	0	0
5	17330	71	8.5	0.38	37	59	208	327	0	0
6	17330	74	8.9	0.36	36	61	200	338	0	0
7	17330	72	8.6	0.38	37	57	206	318	0	0
8	17330	73	8.8	0.36	36	60	197	333	0	0
9	17330	73	8.8	0.37	36	71	202	394	0	0
10	17330	77	9.2	0.35	35	66	193	367	0	0
11	17330	71	8.5	0.38	38	64	209	358	0	0
12	17330	75	9.0	0.35	35	68	192	380	0	0
13	17330	77	9.3	0.35	34	61	191	336	0	0
14	17330	75	9.0	0.36	35	62	197	347	0	0
15	17330	76	9.1	0.35	35	68	193	380	0	0
16	17330	77	9.3	0.34	34	69	189	383	0	0
17	17330	81	9.7	0.33	33	71	183	394	0	0
18	17330	80	9.6	0.33	33	64	183	354	0	0
19	17330	81	9.7	0.33	33	61	183	341	0	0
20	17330	78	9.4	0.33	33	69	184	385	0	0
21	17330	81	9.7	0.33	33	65	183	363	0	0
22	17330	83	9.9	0.32	32	66	179	367	0	0
23	17330	82	9.9	0.32	32	64	180	358	0	0
24	17330	83	10.0	0.31	31	67	174	374	0	0
25	17330	89	10.7	0.29	29	66	163	364	0	0
26	17330	83	9.9	0.32	32	64	179	354	0	0
27	17330	88	10.6	0.30	30	61	168	339	0	0
28	17330	90	10.8	0.30	30	65	165	361	0	0
29	17330	87	10.4	0.31	31	70	170	387	0	0
30	17330	90	10.8	0.30	30	61	164	340	0	0
31	17330	88	10.6	0.30	30	57	167	318	0	0
32	17330	93	11.1	0.29	29	57	160	316	0	0
33	17330	86	10.3	0.31	31	57	172	318	0	0
34	17330	92	11.0	0.29	29	55	161	304	0	0
35	17330	87	10.4	0.31	31	57	170	317	0	0
36	17330	92	11.0	0.29	29	53	162	296	0	0
37	17330	95	11.4	0.28	28	55	156	304	0	0
38	17330	89	10.7	0.30	30	57	166	316	0	0
39	17330	92	11.0	0.29	29	55	162	305	0	0
40	17330	94	11.3	0.28	28	63	158	348	0	0
41	17330	94	11.2	0.28	28	56	158	312	0	0
42	17330	95	11.4	0.28	28	57	156	318	0	0
43	17330	93	11.2	0.28	28	61	158	339	0	0
44	17330	91	10.9	0.29	29	54	160	301	0	0
45	17330	93	11.1	0.29	29	55	160	307	0	0
46	17330	95	11.4	0.28	28	59	156	328	0	0
47	17330	93	11.1	0.28	29	57	160	315	0	0
48	17330	95	11.4	0.28	28	56	156	312	0	0
49	17330	98	11.8	0.27	27	58	151	323	0	0
50	17330	94	11.3	0.28	28	60	157	333	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	2/3/2007	
Time	2:21:33 PM	
Project Name	IIT	
Part No	A1 A4 MEDIUM	
Batch Number	A1 A4 MEDIUM	
Brake Speed	1450	RPM
Brake Pressure	8.89	kg/sq.cm
Brake Force	83	kgf
File Name	A1 A4 MEDIUM_2_3_2007_2_21_33 PM	

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	20524	223	18.5	0.34	17	38	95	213	0	203
Min	20524	181	16	0.27	14	27	78	150	0	0
Avg	20524	207	17.2	0.29	15	31	84	172	0	100

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.32	6.02	0.3	2405	2402	3
2	5.98	5.82	0.16	2395	2392	3

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/3/2007	
Time	2:21:33 PM	
Project Name	IIT	
Part No	A1 A4 MEDIUM	
Batch Number	A1 A4 MEDIUM	
Brake Speed	1450	RPM
Brake Pressure	8.89	kg/sq.cm
Brake Force	83	Kgf
File Name	A1 A4 MEDIUM_2_3_2007_2_21_33 PM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	20524	183	15.1	0.33	17	35	93	194	0	50
2	20524	181	15.0	0.34	17	33	95	185	0	51
3	20524	185	15.3	0.34	17	31	96	172	0	53
4	20524	184	15.2	0.33	17	35	94	194	0	55
5	20524	188	15.6	0.32	17	34	92	191	0	55
6	20524	188	15.6	0.32	17	32	92	176	0	57
7	20524	189	15.7	0.32	16	38	91	211	0	61
8	20524	194	16.1	0.31	16	29	89	159	0	63
9	20524	196	16.2	0.31	16	34	88	188	0	64
10	20524	193	16.0	0.31	16	35	89	193	0	68
11	20524	195	16.1	0.31	16	28	89	154	0	65
12	20524	196	16.3	0.31	16	33	88	185	0	71
13	20524	193	16.0	0.31	16	32	89	177	0	72
14	20524	201	16.6	0.30	16	30	86	169	0	75
15	20524	203	16.8	0.30	15	30	88	165	0	78
16	20524	200	16.6	0.30	16	29	89	162	0	72
17	20524	206	17.1	0.29	15	28	84	154	0	72
18	20524	207	17.1	0.29	15	31	84	174	0	76
19	20524	204	16.9	0.30	15	33	85	184	0	82
20	20524	208	17.2	0.29	15	30	83	167	0	105
21	20524	216	17.9	0.28	14	30	80	169	0	86
22	20524	213	17.6	0.28	15	31	81	172	0	87
23	20524	213	17.6	0.28	15	28	82	156	0	132
24	20524	214	17.7	0.28	15	28	81	155	0	139
25	20524	212	17.5	0.28	15	29	82	159	0	86
26	20524	212	17.6	0.28	15	28	82	156	0	91
27	20524	220	18.2	0.27	14	31	79	172	0	87
28	20524	217	17.9	0.28	14	28	80	156	0	152
29	20524	218	18.0	0.27	14	38	79	213	0	101
30	20524	222	18.3	0.27	14	29	78	160	0	154
31	20524	217	17.9	0.28	14	28	80	154	0	138
32	20524	221	18.3	0.27	14	28	79	154	0	192
33	20524	213	17.6	0.28	15	29	81	163	0	0
34	20524	207	17.2	0.29	15	31	83	174	0	95
35	20524	214	17.7	0.28	15	29	81	161	0	102
36	20524	216	17.9	0.27	14	27	79	150	0	203
37	20524	223	18.5	0.27	14	32	78	180	0	203
38	20524	222	18.4	0.27	14	29	78	161	0	0
39	20524	218	18.0	0.28	14	30	79	164	0	47
40	20524	215	17.8	0.28	15	30	81	168	0	130
41	20524	215	17.8	0.28	14	30	80	167	0	101
42	20524	213	17.6	0.28	15	34	81	188	0	161
43	20524	222	18.4	0.27	14	29	78	163	0	154
44	20524	219	18.2	0.27	14	36	78	198	0	203
45	20524	217	17.9	0.28	14	30	80	168	0	199
46	20524	210	17.4	0.29	15	37	83	207	0	141
47	20524	218	18.0	0.28	14	32	80	179	0	105
48	20524	216	17.8	0.28	14	30	80	166	0	0
[illegible]	20524	213	17.6	0.29	15	29	82	161	0	203
50	20524	214	17.7	0.28	14	29	80	163	0	181

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM14A

Date	2/3/2007	
Time	9:49:19 AM	
Project Name	IIT	
Part No	[illegible]/HIGH	
Batch Number	A21 A52 MEDIUM	
Brake Speed	1450	RPM
Brake Pressure	8.24	kg/sq.cm
Brake Force	83	kgf
File Name	A21 A52 MEDIUM_2_3_2007_9_49_19 AM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	20524	203	16.8	0.37	20	64	108	356	0	203
Min	20524	160	13.2	0.29	15	32	86	180	0	0
Avg	20524	181	15	0.32	17	39	96	217	0	99

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.38	6.16	0.22	2407	2403	4
2	7.11	6.88	0.23	2416	2413	3

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/3/2007	
Time	9:40:10 AM	
Project Name	IIT	
Part No	A21 A52 MEDIUM	
Batch Number	A21 A52 MEDIUM	
Brake Speed	1450	RPM
Brake Pressure	9.24	kg/sq.cm
Brake Force	83	Kgf
File Name	A21 A52 MEDIUM_2_3_2007_9_49_19 AM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	20524	180	14.9	0.32	17	64	96	354	0	71
2	20524	170	14.1	0.34	18	36	100	202	0	50
3	20524	163	13.5	0.36	19	36	106	201	0	53
4	20524	166	13.7	0.35	19.	36	105	199	0	52
5	20524	160	13.3	0.36	19	37	107	205	0	54
6	20524	162	13.4	0.36	19	36	108	197	0	59
7	20524	160	13,2	0.37	20	39	108	216	0	63
8	20524	164	13.5	0.36	19	37	106	206	0	66
9	20524	166	13.7	0.35	19	39	104	217	0	83
10	20524	168	13.9	0.35	19	37	103	204	0	72
11	20524	169	14.0	0.35	18	38	103	212	0	75
12	20524	169	14.0	0.34	18	36	102	198	0	86
13	20524	173	14.3	0.34	18	40	101	222	0	164
14	20524	174	14.4	0.33	18	38	100	212	0	95
15	20524	182	15.1	0.32	17	48	95	266	0	84
16	20524	172	14.3	0.34	18	35	101	194	0	82
17	20524	179	14.8	0.32	17	36	97	199	0	115
18	20524	177	14.7	0.33	18	39	98	216	0	114
19	20524	182	15.0	0.32	17	39	96	214	0	143
20	20524	175	14.5	0.33	18	48	99	268	0	171
21	20524	171	14.1	0.33	18	38	99	212	0	185
22	20524	176	14.6	0.33	18	38	98	211	0	201
23	20524	178	14.7	0.33	18	36	98	200	0	86
24	20524	172	14.2	0.33	18	44	99	247	0	195
25	20524	179	14.8	0.33	17	36	97	197	0	169
26	20524	177	14.7	0.33	18	50	97	276	0	100
27	20524	183	15.1	0.32	17	37	95	205	0	190
28	20524	179	14.8	0.33	17	33	97	182	0	80
29	20524	170	14.1	0.34	18	36	101	200	0	0
30	20524	185	15.3	0.32	17	36	94	201	0	0
31	20524	185	15.3	0.32	17	34	94	191	0	0
32	20524	194	16.0	0.30	16	36	90	201	0	200
33	20524	192	15.9	0.30	16	34	89	189	0	144
34	20524	191	15.8	0.31	16	34	91	188	0	198
35	20524	202	16.7	0.29	16	57	86	316	0	155
36	20524	196	16.2	0.30	16	37	89	203	0	0
37	20524	194	16.0	0.30	16	35	88	197	0	189
38	20524	198	16.4	0.30	16	32	88	180	0	53
39	20524	189	15.7	0.31	17	37	92	207	0	200
40	20524	196	16.2	0.30	16	41	89	228	0	200
41	20524	195	16.1	0.30	16	37	89	204	0	169
42	20524	189	15.6	0.31	16	41	91	226	0	201
43	20524	199	16.5	0.29	16	38	87	209	0	66
44	20524	201	16.6	0.29	16	35	86	194	0	0
45	20524	193	16.0	0.30	16	35	90	193	0	203
46	20524	195	16.1	0.30	16	34	89	191	0	0
47	20524	192	15.9	0.30	16	39	90	218	0	0
48	20524	195	16.1	0.30	16	37	89	207	0	0
49	20524	193	16.0	0.30	16	36	89	203	0	0
50	20524	203	16.8	0.29	15	64	86	356	0	0

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HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	2/3/2007
Time	12:45:05 PM
Project Name	IIT
Part No	A32 A42 MEDIUM
Batch Number	A32 A42 MEDIUM
Brake Speed	1450 RPM
Brake Pressure	9.02 kg/sq.cm
Brake Force	83 kgf
File Name	A32 A42 MEDIUM_2_3_2007_12_45_05 PM

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	20524	216	17.9	0.33	17	78	94	431	0	202
Min	20524	183	15.1	0.28	14	26	80	144	0	6
Avg	20524	205	16.9	0.29	15	36	85	197	0	93

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.04	6.8	0.24	2417	2414	[illegible]
2	6.74	6.43	0.31	2410	2406	4

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/3/2007	
Time	12:45:05 PM	
Project Name	IIT	
Part No	A32 A42 MEDIUM	
Batch Number	A32 A42 MEDIUM	
Brake Speed	1450	RPM
Brake Pressure	9.02	kg/sq.cm
Brake Force	83	Kgf
File Name	A32 A42 MEDIUM_2_3_2007_12_45_05 PM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	20524	201	16.6	0.30	16	48	86	269	0	49
2	20524	190	15.7	0.31	16	34	91	188	0	48
3	20524	186	15.4	0.32	17	32	92	176	0	49
4	20524	185	15.3	0.32	17	35	94	192	0	46
5	20524	187	15.5	0.32	17	33	92	182	0	44
6	20524	183	15.1	0.33	17	35	94	195	0	58
7	20524	190	15.7	0.31	16	34	89	190	0	59
8	20524	195	16.1	0.31	16	34	89	183	0	61
9	20524	198	16.4	0.30	16	34	88	180	0	67
10	20524	194	16.0	0.31	16	34	89	163	0	66
11	20524	197	16.3	0.30	16	30	88	169	0	64
12	20524	196	16.2	0.31	16	33	88	183	0	70
13	20524	202	16.7	0.29	15	69	85	381	0	70
14	20524	208	17.2	0.29	15	78	83	431	0	67
15	20524	207	17.1	0.29	15	31	84	171	0	68
16	20524	199	16.5	0.29	15	30	85	168	0	70
17	20524	203	16.8	0.29	15	29	85	162	0	78
18	20524	203	16.8	0.29	15	30	85	165	0	72
19	20524	204	16.9	0.29	15	28	85	154	0	75
20	20524	204	16.9	0.29	15	31	85	172	0	99
21	20524	206	17.1	0.29	15	32	84	181	0	75
22	20524	204	16.9	0.29	15	30	84	164	0	78
23	20524	200	16.5	0.30	16	34	87	188	0	85
24	20524	203	16.8	0.29	15	32	85	176	0	82
25	20524	209	17.3	0.29	15	54	83	301	0	82
26	20524	212	17.5	0.28	15	52	82	291	0	85
27	20524	213	17.7	0.28	15	64	81	354	0	90
28	20524	208	17.2	0.28	15	34	83	187	0	89
29	20524	210	17.4	0.28	15	33	83	181	0	90
30	20524	208	17.2	0.29	15	29	84	160	0	191
31	20524	208	17.2	0.29	15	32	83	177	0	90
32	20524	214	17.7	0.28	15	48	81	269	0	143
33	20524	207	17.1	0.29	15	30	84	167	0	142
34	20524	213	17.7	0.28	15	30	81	167	0	105
35	20524	206	17.1	0.28	15	31	81	170	0	123
36	20524	215	17.8	0.28	15	44	81	247	0	6
37	20524	211	17.5	0.28	15	28	82	156	0	93
38	20524	213	17.7	0.28	15	28	81	157	0	111
39	20524	206	17.1	0.29	15	31	83	172	0	49
40	20524	213	17.6	0.28	15	29	82	161	0	136
41	20524	216	17.9	0.28	14	48	80	268	0	89
42	20524	213	17.6	0.28	15	27	81	150	0	162
43	20524	205	17.0	0.29	15	31	84	170	0	201
44	20524	210	17.4	0.28	15	27	82	149	0	202
45	20524	208	17.2	0.28	15	27	82	152	0	202
46	20524	215	17.8	0.28	15	28	81	154	0	139
47	20524	212	17.5	0.28	15	27	82	152	0	127
48	20524	214	17.7	0.28	15	29	81	163	0	88
49	20524	210	17.3	0.29	15	38	83	212	0	123
50	20524	215	17.8	0.28	15	26	81	144	0	107

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HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	2/1/2007	
Time	5:04:32 PM	
Project Name	IIT	
Part No	A12 A61 HIGH	
Batch Number	A12 A61 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.65	kg/sq.cm
Brake Force	150	kgf
File Name	A12 A61 HIGH_2_1_2007_5_04_32 PM	

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	179	16.5	0.27	28	63	154	349	0	0
Min	29158	162	14.9	0.24	25	41	139	227	0	0
Avg	29158	172	15.8	0.26	26	49	145	270	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	9.99	9.85	0.14	2458	2456	2
2	6.2	6.04	0.16	2403	2401	2

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT : [signature]

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/1/2007	
Time	5:04:32 PM	
Project Name	IIT	
Part No	A12 A61 HIGH	
Batch Number	A12 A61 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.65	kg/sq.cm
Brake Force	150	Kgf
File Name	A12 A61 HIGH_2_1_2007_5_04_32 PM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	163	15.1	0.27	27	57	152	319	0	0
2	29158	170	15.7	0.26	26	51	147	284	0	0
3	29158	169	15.6	0.26	27	55	148	308	0	0
4	29158	173	16.0	0.25	26	53	142	293	0	0
5	29158	172	15.9	0.26	26	63	145	349	0	0
6	29158	179	16.5	0.24	25	53	139	294	0	0
7	29158	177	16.4	0.25	25	54	141	302	0	0
8	29158	172	15.9	0.25	26	56	145	311	0	0
9	29158	171	15.8	0.26	26	54	146	298	0	0
10	29158	172	15.8	0.25	26	50	145	278	0	0
11	29158	175	16.1	0.25	26	51	143	284	0	0
12	29158	169	15.6	0.26	27	51	147	282	0	0
13	29158	173	15.9	0.25	26	51	145	282	0	0
14	29158	172	15.8	0.26	26	48	145	268	0	0
15	29158	172	15.9	0.26	26	49	145	273	0	0
16	29158	174	16.1	0.25	26	47	143	258	0	0
17	29158	162	14.9	0.27	28	51	154	282	0	0
18	29158	162	15.0	0.27	27	51	152	284	0	0
19	29158	170	15.7	0.26	27	50	147	280	0	0
20	29158	171	15.8	0.25	26	49	143	274	0	0
21	29158	169	15.6	0.26	27	48	147	268	0	0
22	29158	173	16.0	0.25	26	50	144	276	0	0
23	29158	172	15.9	0.25	26	53	145	296	0	0
24	29158	171	15.8	0.25	26	48	145	268	0	0
25	29158	169	15.6	0.26	27	45	148	249	0	0
26	29158	172	15.9	0.25	26	50	144	275	0	0
27	29158	174	16.0	0.25	26	44	144	247	0	0
28	29158	169	15.6	0.26	27	51	148	285	0	0
29	29158	176	16.3	0.25	25	48	141	266	0	0
30	29158	174	16.0	0.25	26	44	144	246	0	0
31	29158	173	16.0	0.25	26	45	143	249	0	0
32	29158	171	15.8	0.26	26	47	146	263	0	0
33	29158	173	16.0	0.25	26	43	144	238	0	0
34	29158	173	15.9	0.25	26	48	144	264	0	0
35	29158	169	15.6	0.26	26	43	146	236	0	0
36	29158	175	16.1	0.25	26	48	142	267	0	0
37	29158	171	15.7	0.25	26	44	144	244	0	0
38	29158	174	16.1	0.25	26	47	143	258	0	0
39	29158	176	16.3	0.25	26	48	142	266	0	0
40	29158	171	15.8	0.26	26	43	146	238	0	0
41	29158	170	15.7	0.26	26	45	147	248	0	0
42	29158	170	15.7	0.26	26	45	147	248	0	0
43	29158	171	15.7	0.26	26	45	146	251	0	0
44	29158	172	15.9	0.26	26	46	145	254	0	0
45	29158	168	15.5	0.26	27	49	148	271	0	0
46	29158	170	15.7	0.26	26	41	146	227	0	0
47	29158	172	15.8	0.25	26	46	143	257	0	0
48	29158	177	16.4	0.25	25	46	140	254	0	0
49	29158	171	15.8	0.25	26	41	143	228	0	0
50	29158	173	16.0	0.25	26	51	143	283	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	2/1/2007		
Time	6:12:20 PM		Brake pad material –FM14A
Project Name	IIT		
Part No	A32 A42 HIGH		
Batch Number	A32 A42 HIGH		
Brake Speed	1300	RPM	
Brake Pressure	17.57	kg/sq.cm	
Brake Force	150	kgf	
File Name	A32 A42 HIGH_2_1_2007_6_12_20 PM		

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	183	16.9	0.29	29	59	161	328	0	0
Min	29158	154	14.2	0.24	25	44	136	242	0	0
Avg	29158	168	15.5	0.26	27	50	148	277	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.23	6.98	0.25	2419	2416	3
2	6.86	6.71	0.15	2412	2410	2

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/1/2007	
Time	6:12:20 PM	
Project Name	IIT	
Part No	A32 A42 HIGH	
Batch Number	A32 A42 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.57	kg/sq.cm
Brake Force	150	Kgf
File Name	A32 A42 HIGH_2_1_2007_6_12_20 PM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	175	16.2	0.25	25	50	141	275	0	0
2	29158	183	16.9	0.24	25	51	136	285	0	0
3	29158	181	16.7	0.24	25	57	138	315	0	0
4	29158	175	16.2	0.25	25	56	141	311	0	0
5	29158	172	15.9	0.25	26	58	144	323	0	0
6	29158	174	16.0	0.25	26	56	144	309	0	0
7	29158	177	16.4	0.25	25	59	141	328	0	0
8	29158	179	16.5	0.25	25	50	140	280	0	0
9	29158	177	16.4	0.25	25	53	141	296	0	0
10	29158	177	16.3	0.25	25	50	141	275	0	0
11	29158	177	16.3	0.25	25	49	142	271	0	0
12	29158	178	16.4	0.25	25	47	140	262	0	0
13	29158	174	16.1	0.25	26	52	144	291	0	0
14	29158	169	15.6	0.26	27	52	149	291	0	0
15	29158	172	15.9	0.26	26	50	145	279	0	0
16	29158	174	16.0	0.25	26	47	144	261	0	0
17	29158	172	15.8	0.26	26	48	145	266	0	0
18	29158	171	15.8	0.26	26	52	146	286	0	0
19	29158	171	15.8	0.25	26	51	145	282	0	0
20	29158	170	15.7	0.26	26	48	147	264	0	0
21	29158	171	15.8	0.26	26	50	146	276	0	0
22	29158	169	15.6	0.26	27	48	148	267	0	0
23	29158	175	16.1	0.25	26	50	143	278	0	0
24	29158	170	15.7	0.26	26	48	147	265	0	0
25	29158	170	15.7	0.26	27	54	147	300	0	0
26	29158	169	15.6	0.26	27	49	148	275	0	0
27	29158	162	14.9	0.27	28	48	154	265	0	0
28	29158	169	15.6	0.26	27	45	148	251	0	0
29	29158	168	15.5	0.26	27	47	148	260	0	0
30	29158	160	14.8	0.28	28	49	156	275	0	0
31	29158	167	15.4	0.26	27	47	150	260	0	0
32	29158	155	14.3	0.28	29	51	159	286	0	0
33	29158	165	15.2	0.27	27	48	151	267	0	0
34	29158	156	14.4	0.29	29	57	161	319	0	0
35	29158	156	14.4	0.28	29	50	160	278	0	0
36	29158	165	15.3	0.27	27	47	151	261	0	0
37	29158	160	14.7	0.28	28	52	157	287	0	0
38	29158	159	14.7	0.28	28	48	157	268	0	0
39	29158	164	15.1	0.27	27	50	152	275	0	0
40	29158	160	14.8	0.27	28	46	155	253	0	0
41	29158	168	15.5	0.26	27	47	149	263	0	0
42	29158	164	15.1	0.27	27	48	153	264	0	0
43	29158	158	14.5	0.28	29	48	159	268	0	0
44	29158	161	14.9	0.27	27	44	152	242	0	0
45	29158	164	15.1	0.27	27	48	152	268	0	0
46	29158	165	15.2	0.27	27	49	150	272	0	0
47	29158	169	15.6	0.26	27	53	148	292	0	0
48	29158	161	14.9	0.27	28	45	155	250	0	0
49	29158	154	14.2	0.28	29	47	160	262	0	0
50	29158	171	15.8	0.26	26	46	146	255	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM14A

Date	2/1/2007	
Time	7:27:42 PM	
Project Name	IIT	
Part No	A21 A52 HIGH	
Batch Number	A21 A52 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.7	kg/sq.cm
Brake Force	150	kgf
File Name	A21 A52 HIGH_2_1_2007_7_27_42 PM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	187	17.3	0.27	28	61	154	341	0	0
Min	29158	162	15	0.23	24	41	134	229	0	0
Avg	29158	171	15.8	0.26	26	49	146	275	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.27	7.09	0.18	2418	2416	2
2	6.6	6.37	0.23	2408	2406	2

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/1/2007	
Time	7:27:42 PM	
Project Name	IIT	
Part No	A21 A52 HIGH	
Batch Number	A21 A52 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.7	kg/sq.cm
Brake Force	160	Kgf
File Name	A21 A52 HIGH_2_1_2007_7_27_42 PM	

Brake pad material –FM14A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	181	16.7	0.24	25	55	138	307	0	0
2	29158	180	16.6	0.24	25	61	139	341	0	0
3	29158	187	17.3	0.23	24	51	134	282	0	0
4	29158	172	15.9	0.26	26	53	145	296	0	0
5	29158	177	16.3	0.25	26	48	142	264	0	0
6	29158	175	16.1	0.25	26	46	143	254	0	0
7	29158	173	16.0	0.25	26	50	144	280	0	0
8	29158	176	16.2	0.25	25	58	141	323	0	0
9	29158	172	15.9	0.26	26	50	145	279	0	0
10	29158	171	15.8	0.26	26	58	146	322	0	0
11	29158	173	16.0	0.25	26	53	143	296	0	0
12	29158	170	15.7	0.26	26	49	147	273	0	0
13	29158	169	15.6	0.26	27	51	148	282	0	0
14	29158	170	15.7	0.26	27	52	148	291	0	0
15	29158	167	15.4	0.26	27	49	150	275	0	0
16	29158	167	15.4	0.26	27	51	149	283	0	0
17	29158	169	15.6	0.26	27	51	148	282	0	0
18	29158	162	15.0	0.27	27	53	152	296	0	0
19	29158	167	15.4	0.26	27	50	149	278	0	0
20	29158	163	15.1	0.27	28	52	153	291	0	0
21	29158	167	15.4	0.26	27	49	149	272	0	0
22	29158	167	15.4	0.26	27	56	150	309	0	0
23	29158	165	15.3	0.27	27	48	151	265	0	0
24	29158	168	15.5	0.26	27	49	148	270	0	0
25	29158	169	15.6	0.26	27	50	148	276	0	0
26	29158	171	15.7	0.26	26	50	146	276	0	0
27	29158	163	15.0	0.27	27	60	152	332	0	0
28	29158	170	15.7	0.26	26	45	146	253	0	0
29	29158	165	15.2	0.27	27	47	152	258	0	0
30	29158	166	15.3	0.27	27	44	151	245	0	0
31	29158	171	15.8	0.26	26	49	146	271	0	0
32	29158	169	15.6	0.26	27	47	147	263	0	0
33	29158	169	15.6	0.26	27	45	148	249	0	0
34	29158	163	15.0	0.27	28	52	154	286	0	0
35	29158	177	16.3	0.24	25	43	140	237	0	0
36	29158	169	15.6	0.26	26	47	146	263	0	0
37	29158	168	15.5	0.26	27	52	149	290	0	0
38	29158	167	15.5	0.26	27	53	149	293	0	0
39	29158	168	15.5	0.26	27	44	149	243	0	0
40	29158	168	15.5	0.26	27	46	149	254	0	0
41	29158	171	15.7	0.26	26	48	147	268	0	0
42	29158	168	15.5	0.26	27	46	148	257	0	0
43	29158	173	16.0	0.25	26	48	145	267	0	0
44	29158	178	16.5	0.25	25	48	140	266	0	0
45	29158	170	15.7	0.26	26	46	147	255	0	0
46	29158	169	15.6	0.26	27	46	148	254	0	0
47	29158	173	16.0	0.25	26	42	144	232	0	0
48	29158	170	15.7	0.26	26	46	145	255	0	0
49	29158	177	16.4	0.24	25	41	139	229	0	0
50	29158	181	16.7	0.24	25	44	138	243	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	2/1/2007
Time	3:56:06 PM
Project Name	IIT
Part No	A1 A4 HIGH
Batch Number	A1 A4 HIGH
Brake Speed	1300 RPM
Brake Pressure	17.73 kg/sq.cm
Brake Force	150 kgf
File Name	A1 A4 HIGH _2_1_2007_3_55_06 PM

Brake pad material –FM14A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	180	16.7	0.38	38	69	209	385	0	0
Min	29158	120	11	0.24	25	43	139	242	0	0
Avg	29158	160	14.8	0.28	28	53	157	292	0	0

WEAR REPORT

PAD No	THICKNESS in mm Initial	Final	Wear	WEIGHT IN grams Initial	Final	Wear
1	6.83	6.29	0.54	2412	2405	7
2	6.39	6.05	0.34	2400	2395	5

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/1/2007	
Time	3:56:06 PM	
Project Name	IIT	
Part No	A1 A4 HIGH	
Batch Number	A1 A4 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.73	kg/sq.cm
Brake Force	160	Kgf
File Name	A1 A4 HIGH _2_1_2007_3_56_06 PM	

Brake pad material –FM14A

Sl No	Kinetic Energy (kgfm)	RD rev	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	154	14.2	0.29	29	51	162	281	0	0
2	29158	138	12.8	0.32	32	61	180	339	0	0
3	29158	126	11.7	0.35	36	58	198	320	0	0
4	29158	120	11.0	0.38	38	56	209	312	0	0
5	29158	124	11.4	0.36	36	62	202	346	0	0
6	29158	132	12.2	0.34	34	61	189	341	0	0
7	29158	133	12.2	0.33	34	67	188	374	0	0
8	29158	140	12.9	0.32	32	60	179	335	0	0
9	29158	144	13.3	0.31	31	69	173	385	0	0
10	29158	151	13.9	0.29	30	59	166	330	0	0
11	29158	158	14.6	0.28	29	61	158	341	0	0
12	29158	151	14.0	0.29	29	65	163	359	0	0
13	29158	159	14.7	0.28	28	56	157	308	0	0
14	29158	157	14.5	0.28	29	56	159	312	0	0
15	29158	160	14.7	0.28	28	52	156	290	0	0
16	29158	169	15.6	0.26	26	51	146	283	0	0
17	29158	168	15.5	0.26	26	60	146	333	0	0
18	29158	169	15.6	0.26	27	54	148	299	0	0
19	29158	169	15.6	0.26	27	54	148	299	0	0
20	29158	168	15.5	0.26	27	51	149	282	0	0
21	29158	160	14.8	0.27	28	59	156	327	0	0
22	29158	166	15.3	0.26	27	53	151	297	0	0
23	29158	159	14.7	0.28	28	53	157	297	0	0
24	29158	166	15.4	0.26	27	50	150	278	0	0
25	29158	168	15.5	0.26	27	50	148	278	0	0
26	29158	169	15.6	0.26	27	53	147	293	0	0
27	29158	175	16.1	0.25	26	46	143	254	0	0
28	29158	180	16.7	0.24	25	49	139	272	0	0
29	29158	169	15.6	0.26	27	50	147	277	0	0
30	29158	169	15.6	0.26	27	45	148	251	0	0
31	29158	166	15.4	0.27	27	49	150	272	0	0
32	29158	165	15.2	0.26	27	53	149	295	0	0
33	29158	163	15.0	0.27	28	49	154	271	0	0
34	29158	169	15.6	0.26	27	49	148	272	0	0
35	29158	169	15.6	0.26	27	46	148	258	0	0
36	29158	171	15.8	0.26	26	48	146	266	0	0
37	29158	165	15.3	0.26	27	45	148	250	0	0
38	29158	166	15.3	0.27	27	48	151	266	0	0
39	29158	164	15.2	0.26	27	46	150	258	0	0
40	29158	170	15.7	0.26	26	46	147	256	0	0
41	29158	163	15.0	0.27	27	49	153	275	0	0
42	29158	164	15.1	0.27	27	52	153	287	0	0
43	29158	168	15.5	0.26	27	48	148	268	0	0
44	29158	167	15.4	0.26	27	43	149	242	0	0
45	29158	162	14.9	0.27	28	49	154	274	0	0
46	29158	170	15.7	0.26	26	50	147	275	0	0
47	29158	158	14.6	0.27	28	48	156	269	0	0
48	29158	167	15.4	0.26	27	46	150	257	0	0
49	29158	167	15.4	0.26	27	46	150	256	0	0
50	29158	171	15.8	0.26	26	44	146	247	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM15A

Date	1/29/2007
Time	2:18:18 PM
Project Name	B11 B12 LOW
Part No	B11 B12 LOW
Batch Number	IIT
Brake Speed	1000 RPM
Brake Pressure	17.54 kg/sq.cm
Brake Force	150 kgf
File Name	IIT _1_29_2007_2_18_18 PM

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	116	13.9	0.25	25	48	141	267	203	168
Min	17330	104	12.5	0.23	23	36	128	201	0	0
Avg	17330	107	12.9	0.25	25	41	138	229	98	15

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.46	4.34	2.12	2401	2370	31
2	6.85	4.36	2.49	2409	2378	31

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED BANGALORE

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FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/29/2007
Time	2:18:18 PM
Project Name	B11 B12 LOW
Part No	B11 B12 LOW
Batch Number	IIT
Brake Speed	1000 RPM
Brake Pressure	17.54 kg/sq.cm
Brake Force	150 Kgf
File Name	IIT _1_29_2007_2_18_18 PM

Brake pad material –FM15A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	114	13.7	0.23	23	45	128	248	48	58
2	17330	115	13.8	0.23	23	48	128	267	48	71
3	17330	116	13.9	0.23	23	45	128	247	49	58
4	17330	113	13.6	0.23	24	42	131	232	50	66
5	17330	108	13.0	0.24	24	44	134	244	52	0
6	17330	111	13.3	0.24	24	42	133	234	53	0
7	17330	109	13.1	0.24	24	42	134	235	54	0
8	17330	111	13.3	0.24	24	40	133	224	55	0
9	17330	109	13.1	0.24	24	39	136	216	57	0
10	17330	108	12.9	0.24	25	43	137	237	57	168
11	17330	107	12.8	0.25	25	43	139	239	59	71
12	17330	106	12.7	0.25	25	46	139	254	62	69
13	17330	107	12.8	0.25	25	37	139	208	64	84
14	17330	107	12.9	0.25	25	40	138	221	69	122
15	17330	107	12.9	0.25	25	41	138	228	72	0
16	17330	106	12.7	0.25	25	37	140	207	70	0
17	17330	107	12.8	0.25	25	38	138	209	76	0
18	17330	106	12.7	0.25	25	42	139	231	80	0
19	17330	108	12.9	0.24	25	42	137	231	80	0
20	17330	108	12.9	0.25	25	41	138	226	82	0
21	17330	105	12.6	0.25	25	39	141	214	85	0
22	17330	105	12.6	0.25	25	41	140	229	84	0
23	17330	107	12.8	0.25	25	38	139	213	88	0
24	17330	106	12.8	0.25	25	41	139	229	84	0
25	17330	106	12.8	0.25	25	43	139	239	127	0
26	17330	106	12.7	0.25	25	39	140	215	93	0
27	17330	106	12.8	0.25	25	40	139	224	96	0
28	17330	105	12.6	0.25	25	44	141	244	0	0
29	17330	106	12.7	0.25	25	39	140	216	157	0
30	17330	106	12.7	0.25	25	44	140	243	11	0
31	17330	108	12.9	0.24	25	38	137	211	188	0
32	17330	106	12.7	0.25	25	42	140	233	203	0
33	17330	106	12.8	0.25	25	40	139	220	100	0
34	17330	106	12.7	0.25	25	44	140	245	130	0
35	17330	105	12.6	0.25	25	44	140	242	192	0
36	17330	106	12.7	0.24	25	41	138	228	203	0
37	17330	106	12.7	0.25	25	38	139	213	155	0
38	17330	107	12.8	0.25	25	41	139	228	136	0
39	17330	106	12.7	0.25	25	40	139	222	4	0
40	17330	107	12.8	0.25	25	42	138	233	199	0
41	17330	107	12.8	0.25	25	41	139	226	0	0
42	17330	108	13.0	0.24	25	38	137	213	203	0
43	17330	104	12.5	0.25	25	42	140	233	202	0
44	17330	107	12.8	0.25	25	37	138	206	131	0
45	17330	105	12.6	0.25	25	47	141	262	40	0
46	17330	107	12.8	0.25	25	36	139	201	168	0
47	17330	108	12.9	0.24	25	37	137	203	202	0
48	17330	106	12.7	0.25	25	41	140	226	198	0
49	17330	108	12.9	0.25	25	40	138	223	192	0
50	17330	107	12.9	0.24	25	46	138	258	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	1/30/2007	
Time	4:58:01 PM	
Project Name	IIT	
Part No	B32 B42 LOW	
Batch Number	B32 B42 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	150	kgf
File Name	B32 B42 LOW	_1_30_2007_4_58_01 PM

Brake pad material –FM15A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	101	12.1	0.32	32	56	179	314	0	55
Min	17330	83	9.9	0.26	26	37	146	207	0	0
Avg	17330	96	11.6	0.27	28	44	153	242	0	1

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.72	4.99	1.73	2409	2382	27
2	7.4	5.66	1.74	2419	2392	27

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

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FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/30/2007	
Time	4:58:01 PM	
Project Name	IIT	
Part No	B32 B42 LOW	
Batch Number	B32 B42 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.38	kg/sq.cm
Brake Force	150	Kgf
File Name	B32 B42 LOW	_1_30_2007_4_58_01 PM

Brake pad material –FM15A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	84	10.1	0.32	32	56	175	314	0	55
2	17330	83	9.9	0.32	32	50	179	275	0	0
3	17330	88	10.5	0.31	30	48	169	266	0	0
4	17330	93	11.2	0.29	29	47	159	263	0	0
5	17330	92	11.0	0.29	29	48	161	267	0	0
6	17330	93	11.2	0.29	29	44	159	246	0	0
7	17330	94	11.3	0.28	28	46	157	258	0	0
8	17330	92	11.0	0.29	29	46	159	256	0	0
9	17330	95	11.4	0.28	28	48	156	267	0	0
10	17330	94	11.2	0.28	28	42	157	235	0	0
11	17330	93	11.2	0.28	29	43	158	241	0	0
12	17330	94	11.2	0.28	28	45	158	251	0	0
13	17330	94	11.3	0.28	28	43	157	238	0	0
14	17330	93	11.2	0.28	28	45	157	253	0	0
15	17330	95	11.4	0.28	28	40	155	221	0	0
16	17330	96	11.5	0.28	28	43	154	236	0	0
17	17330	98	11.7	0.27	27	41	151	230	0	0
18	17330	96	11.5	0.27	27	47	152	260	0	0
19	17330	96	11.6	0.27	27	45	150	249	0	0
20	17330	99	11.9	0.27	27	42	149	236	0	0
21	17330	96	11.5	0.27	27	44	149	247	0	0
22	17330	97	11.6	0.27	27	43	152	241	0	0
23	17330	96	11.5	0.27	27	43	152	239	0	0
24	17330	98	11.7	0.27	27	46	151	254	0	0
25	17330	98	11.7	0.27	27	44	151	243	0	0
26	17330	99	11.8	0.27	27	42	149	231	0	0
27	17330	98	11.8	0.27	27	40	150	222	0	0
28	17330	99	11.9	0.27	27	43	149	238	0	0
29	17330	99	11.9	0.27	27	42	149	236	0	0
30	17330	101	12.1	0.26	26	45	147	247	0	0
31	17330	100	12.0	0.26	26	54	146	302	0	0
32	17330	100	12.0	0.26	26	41	147	226	0	0
33	17330	99	11.9	0.27	27	38	148	213	0	0
34	17330	100	12.0	0.27	27	50	148	280	0	0
35	17330	98	11.7	0.27	27	41	151	230	0	0
36	17330	99	11.8	0.27	27	40	149	224	0	0
37	17330	96	11.5	0.27	27	43	152	237	0	0
38	17330	99	11.9	0.27	27	41	150	226	0	0
39	17330	100	11.9	0.26	27	42	148	231	0	0
40	17330	98	11.8	0.27	27	39	150	216	0	0
41	17330	99	11.9	0.26	27	43	148	238	0	0
42	17330	100	12.0	0.26	27	39	148	219	0	0
43	17330	101	12.1	0.26	26	41	146	228	0	0
44	17330	98	11.7	0.27	27	45	150	250	0	0
45	17330	98	11.7	0.26	27	37	149	207	0	0
46	17330	98	11.7	0.27	27	40	149	223	0	0
47	17330	101	12.1	0.26	26	39	146	215	0	0
48	17330	100	11.9	0.27	27	41	148	227	0	0
49	17330	97	11.7	0.27	27	44	151	245	0	0
50	17330	97	11.7	0.27	27	39	151	215	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM15A

Date	1/29/2007	
Time	3:51:56 PM	
Project Name	IIT	
Part No	B21 B22 HIGH	
Batch Number	B21 B22 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.76	kg/sq.cm
Brake Force	150	kgf
File Name	B21 B22 HIGH	_1_29_2007_3_51_56 PM

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	191	17.6	0.25	25	53	141	294	204	60
Min	29158	0	0	0.23	24	12	131	65	0	0
Avg	29158	180	16.7	0.24	24	42	136	231	30	2

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	7.01	3.95	3.06	2415	2368	47
2	6.98	3.89	3.09	2414	2368	46

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/29/2007	
Time	3:51:56 PM	
Project Name	IIT	
Part No	B21 B22 HIGH	
Batch Number	B21 B22 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.75	kg/sq.cm
Brake Force	160	Kgf
File Name	B21 B22 HIGH	_1_29_2007_3_51_56 PM

Brake pad material –FM15A

Sl no	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	191	17.6	0.23	24	53	131	294	55	60
2	29158	0	0.0	0.23	24	12	131	65	54	54
3	29158	184	17.0	0.24	25	44	136	243	62	0
4	29158	178	16.4	0.25	25	45	141	248	62	0
5	29158	177	16.4	0.25	25	48	141	266	60	0
6	29158	179	16.5	0.24	25	53	140	292	63	0
7	29158	180	16.6	0.24	25	46	139	258	72	0
8	29158	179	16.6	0.24	25	46	139	256	103	0
9	29158	179	16.5	0.24	25	43	140	241	146	0
10	29158	182	16.8	0.24	25	41	137	229	74	0
11	29158	180	16.6	0.24	25	40	139	224	150	0
12	29158	179	16.5	0.24	25	44	137	246	140	0
13	29158	179	16.5	0.24	25	45	138	248	90	0
14	29158	186	17.2	0.23	24	47	134	260	204	0
15	29158	185	17.1	0.24	24	48	135	267	0	0
16	29158	187	17.2	0.23	24	40	134	221	0	0
17	29158	182	16.8	0.24	25	49	137	272	159	0
18	29158	184	17.0	0.24	25	40	136	223	0	0
19	29158	183	16.9	0.24	25	41	137	227	0	0
20	29158	186	17.1	0.24	24	44	135	244	0	0
21	29158	187	17.2	0.23	24	46	134	255	0	0
22	29158	183	16.9	0.24	25	43	136	240	0	0
23	29158	184	17.0	0.24	24	42	136	232	0	0
24	29158	184	17.0	0.24	24	44	136	245	0	0
25	29158	186	17.2	0.24	24	42	135	235	0	0
26	29158	187	17.3	0.23	24	46	134	257	0	0
27	29158	189	17.4	0.23	24	42	133	232	0	0
28	29158	187	17.2	0.23	24	40	134	223	0	0
29	29158	188	17.3	0.23	24	41	133	225	0	0
30	29158	188	17.3	0.23	24	41	133	226	0	0
31	29158	187	17.3	0.23	24	38	134	211	0	0
32	29158	189	17.5	0.23	24	40	132	221	0	0
33	29158	187	17.3	0.23	24	45	133	252	0	0
34	29158	184	17.0	0.24	24	38	136	213	0	0
35	29158	184	17.0	0.24	24	41	136	226	0	0
36	29158	186	17.2	0.24	24	38	135	212	0	0
37	29158	187	17.3	0.24	24	38	134	211	0	0
38	29158	189	17.4	0.23	24	36	133	202	0	0
39	29158	187	17.3	0.23	24	38	134	209	0	0
40	29158	186	17.1	0.24	24	39	135	219	0	0
41	29158	184	17.0	0.23	24	39	134	214	0	0
42	29158	182	16.8	0.24	24	39	136	215	0	0
43	29158	185	17.1	0.24	24	39	135	215	0	0
44	29158	182	16.8	0.24	24	39	135	217	0	0
45	29158	184	16.9	0.24	24	42	135	235	0	0
46	29158	184	17.0	0.24	24	38	135	210	0	0
47	29158	182	16.8	0.24	25	40	137	223	0	0
48	29158	186	17.2	0.24	24	40	135	224	0	0
49	29158	183	16.9	0.24	25	40	136	222	0	0
50	29158	183	16.9	0.24	25	41	137	229	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

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FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM15A

Date	2/1/2007	
Time	2:42:51 PM	
Project Name	IIT	
Part No	B31 B41 HIGH	
Batch Number	B31 B41 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.83	kg/sq.cm
Brake Force	150	kgf
File Name	B31 B41 HIGH	_2_1_2007_2_42_51 PM

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	185	17.1	0.25	26	50	146	279	0	0
Min	29158	171	15.8	0.23	24	40	135	220	0	0
Avg	29158	176	16.3	0.25	25	44	141	244	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.78	3.91	2.87	2409	2365	44
2	6.53	3.23	3.3	2407	2359	48

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	2/1/2007	
Time	2:42:51 PM	
Project Name	IIT	
Part No	B31 B41 HIGH	
Batch Number	B31 B41 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.83	kg/sq.cm
Brake Force	150	Kgf
File Name	B31 B41 HIGH	_2_1_2007_2_42_51 PM

Brake pad material –FM15A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	29158	177	16.4	0.25	25	43	141	241	0	0
2	29158	182	16.8	0.24	25	42	138	234	0	0
3	29158	177	16.3	0.25	26	48	142	269	0	0
4	29158	176	16.2	0.25	26	42	142	234	0	0
5	29158	175	16.2	0.25	26	44	143	243	0	0
6	29158	171	15.8	0.25	26	46	146	257	0	0
7	29158	171	15.8	0.25	26	44	145	243	0	0
8	29158	171	15.8	0.25	26	42	146	231	0	0
9	29158	171	15.8	0.25	26	46	145	257	0	0
10	29158	175	16.1	0.25	26	43	143	241	0	0
11	29158	174	16.1	0.25	26	43	144	237	0	0
12	29158	173	15.9	0.25	26	45	145	250	0	0
13	29158	172	15.9	0.25	26	44	145	242	0	0
14	29158	173	16.0	0.25	26	46	144	254	0	0
15	29158	172	15.9	0.25	26	46	143	258	0	0
16	29158	175	16.2	0.25	26	45	142	252	0	0
17	29158	174	16.0	0.25	26	46	144	257	0	0
18	29158	175	16.2	0.25	26	48	143	269	0	0
19	29158	175	16.2	0.25	26	40	143	220	0	0
20	29158	179	16.6	0.24	25	43	139	241	0	0
21	29158	176	16.3	0.25	25	41	142	230	0	0
22	29158	173	16.0	0.25	26	41	143	225	0	0
23	29158	176	16.2	0.25	26	42	142	233	0	0
24	29158	179	16.5	0.24	25	47	139	260	0	0
25	29158	177	16.3	0.25	25	42	141	233	0	0
26	29158	179	16.5	0.24	25	42	139	232	0	0
27	29158	181	16.7	0.24	25	42	138	234	0	0
28	29158	177	16.4	0.24	25	45	140	249	0	0
29	29158	177	16.3	0.25	25	47	141	259	0	0
30	29158	175	16.1	0.25	26	42	142	233	0	0
31	29158	179	16.5	0.24	25	44	140	245	0	0
32	29158	177	16.3	0.24	25	50	140	279	0	0
33	29158	179	16.5	0.24	25	40	140	225	0	0
34	29158	176	16.3	0.25	26	41	142	230	0	0
35	29158	176	16.2	0.25	25	40	141	224	0	0
36	29158	175	16.1	0.25	26	45	143	251	0	0
37	29158	173	16.0	0.25	26	44	143	245	0	0
38	29158	179	16.5	0.24	25	48	140	268	0	0
39	29158	177	16.4	0.25	25	40	141	223	0	0
40	29158	173	16.0	0.25	26	44	143	247	0	0
41	29158	178	16.4	0.24	25	42	140	232	0	0
42	29158	178	16.5	0.24	25	48	140	269	0	0
43	29158	179	16.6	0.24	25	43	139	241	0	0
44	29158	178	16.4	0.25	25	45	140	248	0	0
45	29158	179	16.5	0.24	25	44	140	247	0	0
46	29158	179	16.5	0.24	25	44	139	247	0	0
47	29158	178	16.4	0.24	25	47	140	263	0	0
48	29158	184	17.0	0.24	24	42	136	236	0	0
49	29158	181	16.7	0.24	25	42	138	233	0	0
50	29158	185	17.1	0.23	24	43	135	236	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Date	1/30/2007	
Time	3:53:18 PM	
Project Name	IIT	
Part No	C32 C41 LOW	
Batch Number	C32 C41 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.29	kg/sq.cm
Brake Force	150	kgf
File Name	C32 C41 LOW	_1_30_2007_3_53_18 PM

Brake pad material –FM16A

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	17330	105	12.6	0.28	28	62	156	343	0	51
Min	17330	92	11	0.25	25	42	141	234	0	0
Avg	17330	98	11.7	0.27	27	47	150	263	0	1

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	6.39	4.97	1.42	2406	2385	21
2	6.51	5.22	1.29	2412	2392	20

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

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FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	1/30/2007	
Time	3:53:18 PM	
Project Name	IIT	
Part No	C32 C41 LOW	
Batch Number	C32 C41 LOW	
Brake Speed	1000	RPM
Brake Pressure	17.29	kg/sq.cm
Brake Force	160	Kgf
File Name	C32 C41 LOW	_1_30_2007_3_53_18 PM

Brake pad material –FM16A

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	17330	105	12.6	0.25	25	49	141	272	0	0
2	17330	96	11.5	0.27	27	54	151	298	0	0
3	17330	97	11.6	0.27	27	63	157	297	0	0
4	17330	98	11.8	0.27	27	47	150	260	0	0
5	17330	98	11.7	0.27	27	50	151	280	0	51
6	17330	99	11.8	0.27	27	50	150	275	0	0
7	17330	98	11.8	0.27	27	46	151	258	0	0
8	17330	99	11.9	0.26	26	45	146	249	0	0
9	17330	102	12.2	0.26	26	47	145	263	0	0
10	17330	99	11.9	0.27	27	47	149	260	0	0
11	17330	99	11.9	0.27	27	47	150	260	0	0
12	17330	95	11.4	0.28	28	46	155	258	0	0
13	17330	98	11.7	0.27	27	46	149	255	0	0
14	17330	98	11.8	0.27	27	48	150	264	0	0
15	17330	100	12.0	0.26	27	46	148	254	0	0
16	17330	97	11.6	0.27	27	48	152	267	0	0
17	17330	99	11.9	0.27	27	44	149	242	0	0
18	17330	100	12.0	0.26	27	50	147	276	0	0
19	17330	96	11.5	0.28	28	45	155	252	0	0
20	17330	98	11.7	0.27	27	52	151	290	0	0
21	17330	99	11.9	0.27	27	48	149	268	0	0
22	17330	98	11.8	0.27	27	45	150	252	0	0
23	17330	101	12.1	0.26	26	46	146	254	0	0
24	17330	96	11.5	0.26	26	42	146	234	0	0
25	17330	95	11.3	0.28	28	46	154	254	0	0
26	17330	98	11.7	0.27	27	46	151	258	0	0
27	17330	98	11.7	0.27	27	45	151	253	0	0
28	17330	101	12.1	0.26	26	46	146	256	0	0
29	17330	97	11.7	0.27	27	45	151	248	0	0
30	17330	99	11.8	0.27	27	46	150	257	0	0
31	17330	99	11.9	0.27	27	44	149	246	0	0
32	17330	98	11.8	0.27	27	44	150	244	0	0
33	17330	100	12.0	0.26	27	44	148	244	0	0
34	17330	97	11.6	0.27	27	45	153	253	0	0
35	17330	97	11.6	0.27	27	44	152	244	0	0
36	17330	93	11.2	0.28	28	46	154	257	0	0
37	17330	97	11.6	0.27	27	44	150	246	0	0
38	17330	98	11.7	0.27	27	46	151	255	0	0
39	17330	100	12.0	0.26	26	48	147	269	0	0
40	17330	99	11.8	0.27	27	47	150	261	0	0
41	17330	97	11.6	0.27	27	45	150	248	0	0
42	17330	96	11.5	0.28	28	45	154	249	0	0
43	17330	97	11.6	0.27	27	46	153	254	0	0
44	17330	98	11.8	0.27	27	50	150	280	0	0
45	17330	96	11.5	0.27	27	49	151	272	0	0
46	17330	96	11.5	0.28	28	52	154	290	0	0
47	17330	92	11.0	0.28	28	50	156	275	0	0
48	17330	96	11.5	0.28	28	45	154	251	0	0
49	17330	96	11.5	0.28	28	62	154	343	0	0
50	17330	96	11.5	0.28	28	51	155	286	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –FM16A

Date	1/31/2007	
Time	5:15:09 PM	
Project Name	IIT	
Part No	C11 C31 HIGH	
Batch Number	C11 C31 HIGH	
Brake Speed	1300	RPM
Brake Pressure	17.68	kg/sq.cm
Brake Force	150	kgf
File Name	C11 C31 HIGH	_1_31_2007_5_15_09 PM

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	29158	189	17.5	0.29	30	60	165	336	0	5
Min	29158	151	14	0.23	24	38	132	211	0	0
Avg	29158	179	16.5	0.26	25	49	140	271	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	5.77	3.87	1.9	2400	2369	31
2	6.13	4.86	1.27	2404	2380	24

Total Number of Cycles completed: 50

DISPOSITION :

PRODUCTION/DEVELOPMENT :

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/29/2006	
Time	9:58:42 AM	
Project Name	DMRL	
Part No	M11M12	
Batch Number	M11M12	
Brake Speed	1400	RPM
Brake Pressure	18.86	kg/sq.cm
Brake Force	166	Kgf
File Name	M11M21_7_29_2006_9_58_42 AM	

Brake pad material –MIG 21

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	32000	147	12.6	0.30	33	45	184	250	0	0
2	32000	137	11.7	0.33	36	52	200	287	0	0
3	32000	136	11.7	0.33	36	56	199	311	0	0
4	32000	140	12.0	0.32	35	60	195	334	0	0
5	32000	138	11.8	0.33	36	48	198	266	0	0
6	32000	136	11.6	0.33	36	52	202	286	0	0
7	32000	135	11.5	0.33	37	52	203	290	0	0
8	32000	134	11.5	0.34	37	53	204	295	0	0
9	32000	132	11.3	0.34	37	52	204	290	0	0
10	32000	136	11.7	0.33	36	57	198	314	0	0
11	32000	138	11.9	0.32	36	57	198	316	0	0
12	32000	136	11.7	0.33	36	67	199	370	0	0
13	32000	141	12.1	0.32	35	54	193	301	0	0
14	32000	142	12.2	0.32	35	51	193	284	0	0
15	32000	142	12.2	0.32	35	53	193	292	0	0
16	32000	144	12.4	0.31	34	51	189	283	0	0
17	32000	144	12.4	0.31	34	69	190	382	0	0
18	32000	144	12.3	0.31	34	54	188	299	0	0
19	32000	140	12.0	0.32	35	53	195	292	0	0
20	32000	148	12.7	0.31	33	52	185	288	0	0
21	32000	147	12.6	0.31	34	52	187	286	0	0

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST CONSOLIDATED REPORT

Brake pad material –MIG 21

Date	7/31/2006	
Time	2:14:44 PM	
Project Name	IIT Roorkee	
Part No	M21M22	
Batch Number	M21M22	
Brake Speed	870	RPM
Brake Pressure	71.33	kg/sq.cm
Brake Force	600	kgf
File Name	M21M22_7_31_2006_2_14_44 PM	

	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
Max	13060	19	2.6	0.29	124	202	687	1123	0	0
Min	13060	15	2.1	0.11	49	129	272	719	0	0
Avg	13060	17	2.3	0.19	81	185	450	1028	0	0

WEAR REPORT

PAD	THICKNESS in mm			WEIGHT IN grams		
No	Initial	Final	Wear	Initial	Final	Wear
1	4.8	3.74	1.06	2475	2457	18
2	4.51	3.4	1.11	2461	2440	21

Total Number of Cycles completed: 20

DISPOSITION : Released for academic work

PRODUCTION/DEVELOPMENT :

[signature] 2/8/06

HINDUSTAN AERONAUTICS LIMITED - BANGALORE

FOUNDRY AND FORGE DIVISION

FRICTION TEST FINAL REPORT

Date	7/31/2006	
Time	2:14:44 PM	
Project Name	IIT Roorkee	
Part No.	M21M22	
Batch Number	M21M22	
Brake Speed	870	RPM
Brake Pressure	71.33	kg/sq.cm
Brake Force	600	Kgf
File Name	M21M22_7_31_2006_2_14_44 PM	

Brake pad material –MIG 21

Sl NO	Kinetic Energy (kgfm)	RD rev.	RD time (sec)	Coefficient of friction	Mean Torque (kgfm)	Peak Torque (kgfm)	Mean Drag (kgf)	Peak Drag (kgf)	Pad1-Temp (DegC)	Pad2-Temp (DegC)
1	13060	19	2.6	0.23	104	129	579	719	0	0
2	13060	15	2.1	0.29	124	153	687	847	0	0
3	13060	19	2.6	0.11	49	199	272	1106	0	0
4	13060	18	2.4	0.13	54	188	303	1044	0	0
5	13060	15	2.1	0.16	69	191	386	1061	0	0
6	13060	17	2.3	0.17	73	185	405	1026	0	0
7	13060	17	2.4	0.16	67	198	371	1101	0	0
8	13060	17	2.3	0.19	79	190	439	1057	0	0
9	13060	17	2.4	0.17	73	184	407	1024	0	0
10	13060	17	2.3	0.20	84	184	466	1024	0	0
11	13060	16	2.2	0.19	82	188	458	1045	0	0
12	13060	17	2.3	0.18	78	189	431	1051	0	0
13	13060	17	2.4	0.19	78	202	436	1123	0	0
14	13060	17	2.3	0.19	79	187	441	1037	0	0
15	13060	17	2.4	0.21	86	198	480	1099	0	0
16	13060	17	2.3	0.22	90	186	498	1034	0	0
17	13060	17	2.3	0.25	104	186	578	1034	0	0
18	13060	17	2.3	0.18	75	200	416	1111	0	0
19	13060	17	2.3	0.23	95	180	528	998	0	0
20	13060	18	2.5	0.18	74	182	413	1009	0	0

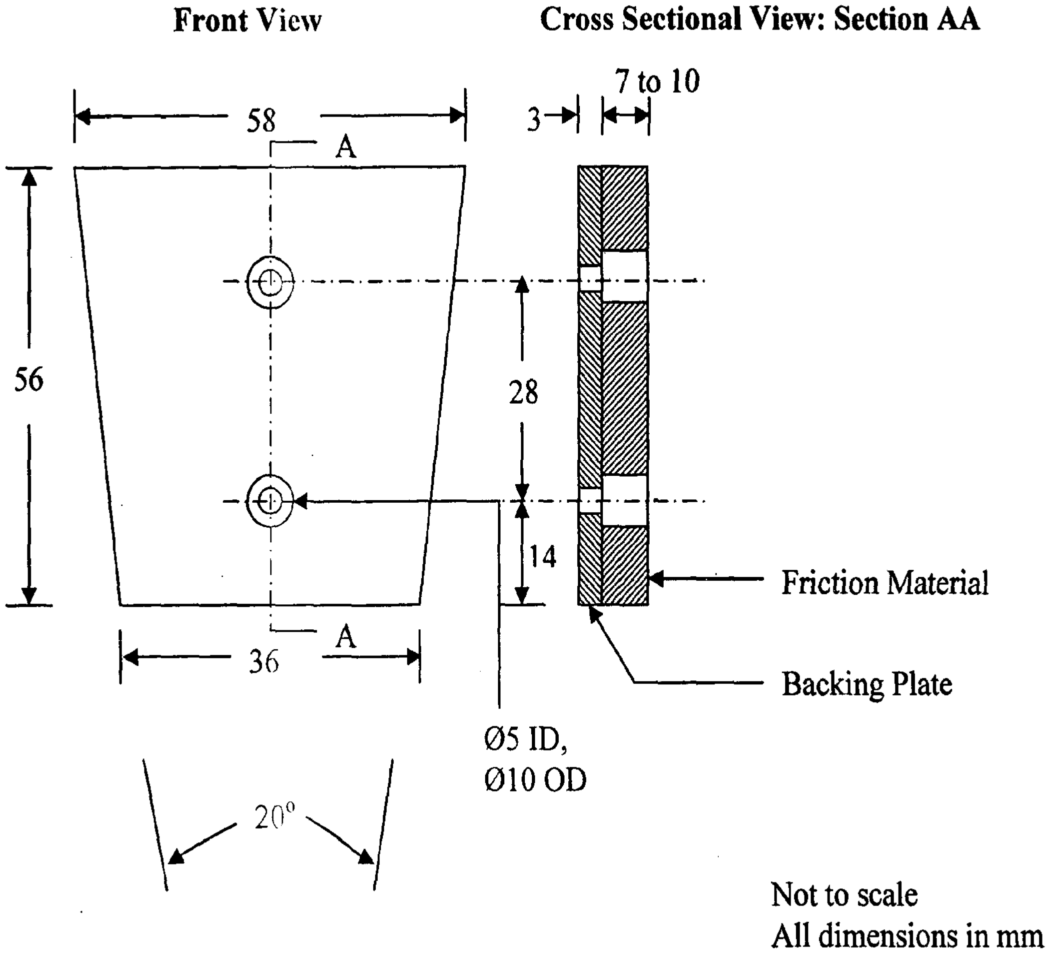

Fig. 5.4(A) Schematic diagram of tested sample