AIRCRAFT BRAKE PADS

(A COMPENDIUM)

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Foreword

A wide variety of components made from a variety of materials are used in realization of an aircraft. Numerous processing technologies are also used to manufacture such critical and non critical components in the aircraft industry. Brake pad is a safety critical component which is manufactured through powder metallurgy processing route. Earlier brake pads for certain type of military aircraft were made as cast bimetallic sector. Advances in powder metallurgy techniques, advantages of the powder processed products and the diverse demands to be met in a component like brake pad in an aircraft, have made powder metallurgy an attractive and unique choice.

Brake pad as a component in aircraft is a consumable. India has a wide variety of military aircraft in its inventory as indigenously developed, bought and manufactured under license programmes from a few countries. In the development of brake pads, initial indigenization efforts started at Defense Metallurgical Research Laboratory at Hyderabad and initial manufacturing technology was vested with Hindustan Aeronautics Ltd., at Hyderabad. To meet the growing demand for this critical consumable for wide range of military aircraft inventory, thrust was given to study the characteristics in terms of shape, size, performance characteristics of ingredients, energy needs and lifing for replacement schedules at the Foundry & Forge division of HAL, Bangalore in the year 1986. Drawing inspiration from the successful research work at DMRL, Hyderabad, a dedicated group complimented with inspiring and committed management at HAL, tasked to build self sufficiency in brake pads manufacturing technology for all the aircraft manufactured and overhauled in the country.

The development work ranged from characterizing to establishing manufacturing process to stipulating comprehensive certification tests for verifying the compliance to performance needs of each aircraft. The development of brake pads is essentially pivoted on the understanding of conversion of kinetic energy to thermal energy in mechanical subsystem of the vehicle.

The complexity in aircraft assumes significance due to sheer magnitude of energy level, thermal capacity, thermal conductivity and short turn around aspects which are much needed but conflicting and compelling in the brake pads. Tailoring to such diverse essential properties needed has led to thorough understanding of the functional additives like friction materials, lubricating additives, inter-particle bonding agent in the base material possessing bulk strength and desirable thermal properties. While the component like brake pad is configured through compaction, properties like density, strength and interparticle bonding is achieved through sintering.

Thus, for a variety of aircraft depending on the energy levels associated, powder compacts have been of functional additives in either polymer based matrix materials or metal based powder matrix. The compendium is collation of type of brake pads indigenously developed for military aircraft operated in our country indicating the Airworthiness approvals and applicable Joint Services Specification references.

The compendium gives a brief about carbon-carbon brake which is emerging for the future aircraft. This compendium is intended to serve as a quick reference on brake pads used in military aircraft with their Airworthiness Approvals in our country. The compendium could be updated with wider emerging applications of frictional materials of which brake pad is significant one.

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CHAPTER: 1

INTRODUCTION

Aircraft brakes are designed to stop an aircraft by means of converting the kinetic energy of a motion into heat. The heat thus generated at the sliding interface of the rotor and friction material of the brake is dissipated primarily by conduction through various components of the brake, by convection to the atmosphere and by radiation to the atmosphere and adjacent components; it is also absorbed by chemical, metallurgical and wear process occurring at the interface. In addition, some of the kinetic energy is absorbed by the engine, tyres and viscous drag of the mechanical components.

Aircraft brakes were composed of multiple disk pairs, which are commonly referred to as the brake heat sink, in different sizes and configurations depending on the application. The majority of aircraft brakes use full-circle rotors and stators. The stators carry the metallic friction material and the rotors are composed of high-strength high-temperature alloy steels, commonly called the mating surface. Some designs have the rotors carrying the metallic friction material. The opposing steel typically lasts two to three times longer than the metallic friction material lining. The selection of the metallic friction material influences the brake design and must be carefully considered in order to obtain optimum dynamic performance, friction coefficient stability and wear rate of the friction pair.

Brake housings normally contain several pistons for applications of the normal force needed to develop the brake torque. The high levels of torque developed to stop an aircraft require the conversion of large amounts of kinetic energy into thermal energy over a short period of time. This energy conversion process produces very high energy fluxes at the multiple friction interfaces, resulting in high temperatures and stresses in the brake heat sink.

The brake pad material is a complex composite material and consisting of Iron, Copper, phenolic resin and carbon based as matrix or base material, reinforced with fibers and various other metallic, non-metallic and ceramic additives that impart such diverse properties as friction and wear stability, thermal stability, solid lubrication, noise or squeal reduction etc. Depending on the design and requirements of the aircraft, various classes of brake pad materials with specific types of performance characteristics, such as friction level, friction stability, wear resistance and noise behavior, in various temperature ranges are developed.

The general characteristics of aircraft brake pad material are summarized as follows:

a) High and stable coefficient of dynamic friction and its stability over a wide range of speeds, loads and brake temperatures
b) Fade-recovery characteristics, i.e. the ability to resist friction level deterioration when subjected to extreme elevated temperatures (the fade) and then return to the pre-fade friction level on cooling (the recovery).
c) High and thermally stable wear rate for long life
d) Adequate mechanical strength at room and elevated temperature
e) High refractoriness(melting point)
f) Good anti-seizure property with mating member material
g) High specific heat and thermal conductivity
h) Low coefficient of thermal expansion and tolerance to steep thermal gradients
i) Compatibility and conformability with mating part to avoid judder
j) Embedability property to hard ceramic particles or wear debris
k) Tolerance to high ceramic and non-metallic additions
l) Good wear properties for long life, without excessive wear or grooving on the mating disc
m) Low noise, chatter and vibration
n) Low sensitivity to moisture
o) Ease of manufacture

The existence of numerous brake designs provides another level of complexity in formulating brake pad material. In brake pad material development, an attempt to improve one characteristic often results in the deterioration of other characteristics. The development of brake pad materials is therefore a complex iterative process in which an optimized combination of interdependent properties is sought.

The methodology of development of the unique brake pad material for a given aircraft brake, therefore, starts with an in-depth study of the brake design specification. A step by step approach is then followed for derivation of the physical and metallurgical properties of the candidate brake pad material from the brake specification. Thus the brake design parameters such as the brake energy and the allowable heat sink mass help one to decide on the density, specific heat and melting point of the brake pad material. The area energy loading, loading rate and brake torque requirements determine the coefficient of friction, thermal conductivity and stability properties of the material.

Once developed, the brake pad material needs to undergo rigorous and repeated testing to prove reliability and reproducibility of its performance in actual service. For this, the brake pads material are mounted on actual aircraft brake and are subjected to real time brake dynamometer tests simulating the actual kinetic energies of aircraft braking under various conditions of operation such as normal landing, emergency landing, rejected take-off etc. The dynamometer tests are followed by actual taxy trials on aircraft to evaluate true field performance, landing characteristics and pilot's feel of the newly developed brake pad material.

CHAPTER: 2

TYPES OF THE BRAKE PAD USED IN THE AIRCRAFT

Depending on the level of kinetic energy to be absorbed and the limit of temperature generated on the brake pad surface, four basic friction materials are presently being used in aircraft braking application. These are:

2.1 Organic friction materials
2.2 Metalloceramic friction materials
2.3 Bimetallic(Cast based) friction materials
2.4 Carbon-Carbon Composite friction materials

2.1 Organic friction materials:

Organic brake linings were the earliest friction materials developed and used extensively on light weight low speed trainer aircraft and in helicopter rotor brakes. These brake pad materials are still used for light to moderate duty braking applications where kinetic energy absorption requirement, brake temperature and speeds are on the lower side.

The organic based brake pad material consists of more than five ingredients with phenolic resin as the binder or matrix. Each ingredient is added to promote different physical, mechanical and thermal properties. These components are usually compacted in a hydraulic press followed by curing and post curing in furnace.

These organic friction materials possess a working surface limit temperature of about 600^0C and suffer from poor thermal conductivity and specific heat. These resin bonded brake pads tends to fade away above 400^0C and thus cannot be used in high speed combat aircraft braking application.

Table 2.1 gives the compositions of typical organic brake pad materials used in aircraft and helicopter brake applications.

Table 2.1:Typical organic brake pad materials used in aircraft applications

SL no	Composition in Wt%							
	Phenolic resin	$BaSO_4$	$CaSO_4$	Bronze powder	Friction dust	Asbestos fiber	Brass Powder	Other additives
1	21-22	24-25	6-8	20-22	5-7	20-22	-	Carbon black-1.5
2	20-22	15-17	5-7	-	2-4	48-50	10-12	Glass fiber-15-17
3	12-14	38-40	10-12	-	8-10	-	5-7	Glass fiber-16-18,$ZrSiO_4$-10-12,Carbon black-1-2

2.2 Metalloceramic friction materials:

The metal based sintered Metalloceramic material is the most widely used friction material in aircraft braking application. These are much stronger and more heat resistant and were developed in response to energy inputs and temperature which exceed the capabilities of organic friction materials. Metalloceramic friction materials are used as “speed brakes” of majority of military and civilian aircraft. The steel brake heat sink consists of a sintered metalloceramic friction material bonded to a steel supporting backing plate.

This class of brake pad materials is made by the modern route of Powder Metallurgy (P/M) and can be further classified in to two categories depending on the metallic matrix material used. These are iron and copper friction materials.

2.1.1 Iron Based Material

Iron based friction materials consist of ceramic additives, solid lubricant and friction modifiers in Iron rich matrix. Iron based sintered friction materials are used under harsher operating conditions since they allow higher operating temperatures of up to 900^0C and in some emergency cases even higher.

Iron, as the friction material matrix, is used because of its high melting point and other properties such as, strength, hardness, heat resistance and stability, which can be regulated by alloying with different metals to promote specific properties.

A significant characteristic of iron is demonstrated at the moment of the braking action when the oxide, located on the friction surfaces, protects the brake from sudden impact by forming a thin film which simultaneously enables slipping.

These friction materials are usually compacted in a hydraulic press followed by pressure sintering in the bell type sintering furnace.

Table 2 gives the composition of certain iron based brake pad materials used in the aircraft brake application

Table 2.2: Typical Iron based brake pad material used in aircraft application

SL no	M/L Designation	Composition in Wt%						
		Fe	Cu	Ni	C	SiO_2	Asbestos	Other additives
1	FMK-11	64	15	0	7	3	3	$BaSo_4$-6%,
2	MKV-50A	64	15	0	8	0	3	$FeSo_4$-5,SiC-5,B_4C-5
3	SMK-83	54	20	0	0	0	0	Mn-7,MoS_2-2,BN-6.5,B_4C-9.5,SiC-1

2.1.2 Copper based friction material

Copper based friction material consists of ceramic, solid lubricant and friction modifiers in Copper rich matrix.

Copper based friction materials have many advantages, such as better heat conductivity for efficient heat dissipation and higher anti-wear property compared to iron based materials.

These friction materials are usually compacted in a hydraulic press followed by sintering in the bell type or pusher type sintering furnace.

Table 3 gives the composition of certain copper based brake pad materials used in the aircraft brake application

Table2.3: Typical Copper based brake pad material used in aircraft application

SL no	Composition in Wt%							
	Cu	Sn	Pb	Fe	C	Asbestos	SiO_2	Other additives
1	50-80	0	10	20	5-15	0	5	MoS_2-20%,Ti-2-10
2	61-62	6	0	7-8	6	0	0	Mullite-7,Zn-12
3	70	7	8	0	8	0	7	TiO_2-10

2.3 Bi-Metallic friction materials:

The earlier Bi-metallic friction material is of grey cast iron type being used in the aircraft. The cast bi-metallic pads are now replaced with the Powder Metallurgy (P/M) route as later enables non-stoichiometric combination, better interfacial bonding, near net shape processing, clean manufacturing environment, increased productivity and other techno-economic advantages. Hence powder metallurgy route is fast replacing bimetallic casting route. Bimetallic cast brake pads route is essentially conventional grey cast iron foundry technique.

2.4 Carbon-Carbon Composite friction materials:

The carbon/carbon fiber composites friction materials are the latest entry in to the field of friction materials and have been developed mainly to cater to the severest operating conditions encountered in modern day supersonic jet fighters and very large and heavy commercial jet liners. The carbon brake is lighter in weight with excellent high temperature performance, low wear rate, and high cost per brake landing. Steel brake is heavier with higher wear rate and lower cost per brake landing compared to the carbon brake.

Carbon-carbon friction materials are composites comprising of high-density carbon fibers embedded in a carbon matrix. The carbon fibers used in carbon brakes are made from two precursors: polyacrylonitrile (PAN) or pitch. Fiber properties are normally controlled by the manufacturing process of the fiber. In brakes, woven fabrics, short length yarns, chopped fabrics and woven three-dimensional preforms are used.

Typical fabrication process includes carbonizing, PAN-fabrics to 1000^0C, cutting the fabric to shape, impregnating with a polymer, carbonizing and densifying by Chemical Vapour Deposition (CVD) by the decomposition of natural gas at low pressure.

CHAPTER: 3

INGREDIENTS OF AIRCRAFT BRAKE FRICTION MATERIAL

This chapter deals broadly with the ingredients of the friction materials used in aircraft brake. Ingredients used are broadly classified as follows

3.1 Matrix Material

3.2 Abrasive Material

3.3 Solid Lubricant and Stabilizer

3.4 Filler Material

3.5 Wear Resistant Material

3.1 Matrix Material

Matrix material imparts the basic physical and mechanical properties such as strength, friction, specific heat, thermal conductivity and melting point to the brake pad material and normally accounts for 50-80% of the weight (more than 40% of volume) of the friction material.

The metal matrix represents a flat surface on which deformation and additional destruction occurs, producing wear products. In the case of the metalloceramic materials the choice of the metallic matrix is restricted to either an iron base or a copper base or a judicious combination of the two bases. In carbon-carbon friction material, the matrix is carbon and in the organic based material the matrix consists of mainly phenolic resin.

3.1.1 Iron Powder

The sponge iron powder or electrolytic iron powders are used as a matrix for the manufacture of iron based friction materials.

Sintered friction materials made of fine grained iron powders possess high mechanical strength and very good friction properties because of higher surface energy that results in increasing activity during sintering.

The typical characteristics of iron used as friction material matrix in aircraft brake pads is shown in the table 3.1

Table 3.1: Characteristic of the Iron used as friction material matrix in aircraft brake

Characteristics	**Value**
Thermal Conductivity at R.T	59 J/M/Sec/^{0}K
Specific Heat at Room Temp (R.T)	0.59 J/gm/^{0}K
Purity	98% Fe Minimum
Apparent density	2.3-3.5 g/cm^3
Flow rate	44s/50 g
Characteristic Shape	Sponge or electrolytic
Heat Sink Loading Capacity	450,000 Joules/Kg
Green strength	23.2 MN/m^2
Pressability	6.8 g/cm^3
Size	(-100+300) BS
Melting Temperature	1539^{0}C
Coefficient of Linear Expansion	14*10^{-6} /^{0}K
Tensile Strength	410 MPa
Antiseizure Property	Good
Tolerance to Ceramic/non-metallic addition	Poor
Density	7.8 g/ cm^3
Softening Resistance at Elevated Temperature	Good
Ease of Manufacture in to Pad Materials	Poor

3.1.2 Copper Powder

The electrolytic Copper powder is used as a matrix material in the copper base brake pad. Copper as a matrix, ensures basic strength, conductivity properties and also embeddability for hard ceramic ingredients. The typical characteristics of the Copper used as a friction material matrix in aircraft brake pads is shown in the table 3.2

Table 3.2: Characteristic of the Copper powder used as friction material matrix in aircraft brake

Characteristics	**Value**
Specific Heat at Room Temp(R.T)	0.42 J/gm/^{0}K
Thermal Conductivity at R.T	346 J/M/Sec/^{0}C
Purity	99.5% Cu Minimum
Apparent density	1.3-2.4g/cm^3
Characteristic Shape	Electrolytic
Heat Sink Loading Capacity	280,000 Joules/Kg
Green strength	24 MN/m^2
Pressability	7.5 g/cm^3
Size	(-250+300) BS
Melting Temperature	1083^{0}C
Coefficient of Linear Expansion	18*10^{-6} /^{0}K
Tensile Strength	240 MPa
Antiseizure Property	Poor
Density	8.96 g/ cm^3
Tolerance to Ceramic/non-metallic addition	Good
Softening Resistance at Elevated Temperature	Poor
Ease of Manufacture in to Pad Materials	Good

3.1.3 Phenolic Resin:

Phenolic resin as shown in fig 3.1 is a reaction product of phenol and an aldehyde, usually formaldehyde (HCHO), in acid solution. They have good wetting ability and bonds the fillers and fibers in the matrix. Contributes for friction performance and improves wear resistance. A criterion for selection of grade is based on the process used to manufacture and also depends on the final properties. Depending on their composition phenol resins harden at temperatures between 180° and 250° C. The hardening process for phenol resins requires a temperature in excess of 100° C. Phenol resins are distinguished by high adhesive stability and good mechanical properties. Furthermore they show good heat-resistance up to 250° C.

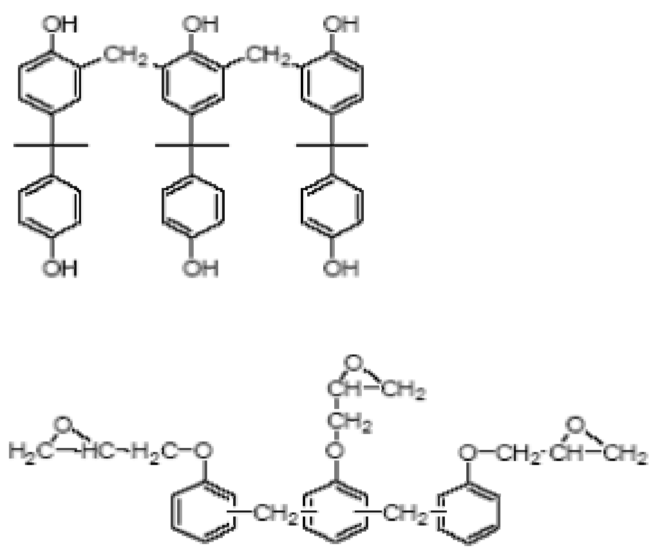


Figure 3.1 Phenolic resin structures.

The typical characteristics of the Phenolic resin used as a matrix in aircraft brake pad is shown in the table 3.3

Table 3.3: Characteristic of the Phenolic Resin used as friction material matrix in aircraft brake

Characteristics	Value
Softening Point	90-105^{0}C
Flow	15-40 m/m
Gelation time	35-80 sec
Size	(-250) BS
Melting Range	70-150^{0}C
Coefficient of Linear Expansion	80*10^{-6} /^{0}K
Thermal Conductivity	0.16 W/m.K
Yield Strength	133 MPa
Specific Heat at Room Temp	1.19 kJ · kg^{-1} K^{-1}
Antiseizure Property	Poor
Density	0.1-0.6 g/ cm^3

The properties of the final material can be varied by modifying the resin, altering the phenol-formaldehyde ratio, changing the catalyst, or changing the polymerizing conditions.

3.2 Abrasive Materials

These are added to the brake pad material to give rise to friction and also help to prevent local welding and metal transfer of the metallic matrix material on to the mating part-rubbing surface during braking.

The advantages related to abrasives, utilization in the brake friction materials are as follows

1. The enhancement and stabilization of μ (coefficient of friction) value at elevated temperatures
2. Renew of the disc rotor surfaces.
3. Coefficient of friction (μ) increases value with increasing amount of abrasives.

Higher value of μ is very important to the brake friction materials because the braking is done by the direct contact of friction materials with the rotating disc and deceleration of the disc by means of friction.

Disadvantages of the higher abrasives content in the brake pad material are as follows:

1. They enhance the specific wear rate of friction materials
2. Damage the mating disc(enhance the specific wear rate of the disc) and transfer debris from the disc to the surface of the friction materials
3. Unstable variation of coefficient of friction during operation
4. Responsible for the noise occurring during the braking due to the formation of the hard contact patches.

In view of the above mentioned positive and negative effects of abrasives, optimized volume fraction is to be used in the aircraft brake pad application.

The following are the abrasive materials used in aircraft brake pads.

3.2.1 Silicon Carbide Powder

Silicon carbide (SiC) is a hard covalently bonded material predominantly produced by the carbothermal reduction of silica. Silicon carbide is abundantly available, cheap and stable up to 1800 ^{0}C.

Silicon carbide exists in at least 70 crystalline forms and mainly alpha silicon carbide (α-SiC) with a hexagonal crystal structure and beta modification (β-SiC) with cubic crystal structure are the most commonly encountered polymorphs.

Silicon carbide has low density, high strength, low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, excellent thermal shock resistance, and superior chemical inertness.

The typical characteristics of the SiC used in aircraft brake pad is shown in the table 3.4

Characteristics	**Value**
Thermal Conductivity	121 W/m K
Size	(-100+150)BS

SiC content	95% minimum
Density	3.21 g/cm^3
Color	Green
Melting Temperature	>1700^{0}C
Coefficient of Linear Expansion	5.5*10^{-6} /^{0}K
Specific Gravity	3.2
Tensile Strength	20GPa
Specific Heat at Room Temp	670-750 J/kg K
Antiseizure Property	Poor

Table 3.4: Characteristic of the SiC powder used in aircraft brake friction material formulation

3.2.2 Silica Powder

The chemical compound silicon dioxide, also known as silica, is an oxide of silicon with a chemical formula of SiO_2. Silica is the most abundant mineral in the Earth's crust.

Fused Silica powder which is used in the friction materials as abrasive is generally made from high purity crystalline silica sand. The crystalline silica is fused in very high temperature around 1730^{0}C, results in conversion of crystalline silica to fused silica. It has the lowest coefficient of thermal expansion among all fused minerals. It has high thermal shock resistance and low thermal conductivity.

The typical characteristics of the Silica used in aircraft brake pad is shown in the table 3.5

Characteristics	**Value**
Thermal Conductivity	1.4W/m K

SiO_2 content	90% minimum
Density	2.63 g/cm^3
Size	(-60+100)BS mesh
Melting Temperature	1650(±75) °C
Coefficient of Linear Expansion	0.4*10^{-6} /^{0}K
Crystal Structure	Tetrahedron
Tensile Strength	5-7 GPa
Specific Heat at Room Temp	740 J/kg K
Compressive Strength	3000 MPa

Table 3.5: Characteristic of the Silica powder used in aircraft brake

3.2.3 Zirconium Silicate Powder:

Zirconium silicate, also zirconium orthosilicate, ($ZrSiO_4$) is a chemical compound, a silicate of zirconium. It occurs in nature as the zircon, a silicate mineral.

The typical characteristics of the Zirconium Silicate used in aircraft brake pad friction material is shown in the table 3.6

Table 3.6: Characteristic of the Zirconium Silicate powder used in aircraft brake

Characteristics	**Value**
Thermal Conductivity	1.4W/m K
ZrO_2 /SiO_2 content	65%/35% minimum
Density	4.56 g/cm^3
Size	(-60+100)BS mesh
Melting Temperature	1540 °C
Coefficient of Linear Expansion	0.4*10^{-6} /^{0}K

Crystal Structure	Tetragonal
Tensile Strength	5-7 GPa
Specific Heat at Room Temp	740 J/kg K

3.2.4 Mullite Powder

Mullite is a synthetic alumino-silicate ceramic powder. Mullite powder with unique characteristics such as low thermal expansion coefficient, high creep resistance, melting point, thermal shock resistance and thermal stability under oxidizing conditions favors it to use it in friction material.

The typical characteristics of the Mullite powder used in aircraft brake pad friction material is shown in the table 3.7

Table 3.7: Characteristic of the Mullite powder used in aircraft brake

Characteristics	**Value**
Thermal Conductivity	2.0 W/m K
Al_2O_3/SiO_2 content	60-70/40-30% minimum
Density	2.63 g/cm^3
Size	(-60+100)BS mesh
Melting Temperature	1810- 1880°C
Coefficient of Linear Expansion	$4*10^{-6}$ /^{0}K
Tensile Strength	2-4 GPa
Specific Heat at Room Temp	0.175 cgs

3.3 Solid Lubricant and Stabilizer

These are added to stabilize the friction, wear at higher temperature and contribute to the formation of surface reaction layer on the frictional surface of the brake pad.

3.3.1 Barium Suphate:

Barium sulphate is a white crystalline powder with the chemical formula $BaSO_4$. It is stable at high temperatures. The expected deterioration of friction and wear properties in iron base friction materials is known to be effectively compensated by Barium Sulphate.

Barium Sulphate ($BaSO_4$) undergoes complete reduction by carbon of graphite during sintering according to the following equation

$$BaSO_4 + C = BaS + 4\,CO \qquad (3.1)$$

This reaction activates the sintering process of the iron base material making it stronger.

The typical characteristics of the Barium Sulphate powder used in aircraft brake pad friction material is shown in the table 3.8

Table 3.8: Characteristic of the Barium Sulphate powder used in aircraft brake

Characteristics	**Value**
Thermal Conductivity	18.4 W/m K
Crystal Structure	orthorhombic
$BaSO_4$ content	98.5% minimum
Density	4.50 g/cm^3
Size	(-250)BS mesh
Melting Temperature	1580 °C
Color	White
Grade	X-ray

3.3.2 Calcium Sulphate

Calcium sulphate is a white crystalline powder with the chemical formula $CaSO_4$.

The typical characteristics of the Calcium Sulphate powder used in aircraft brake pad friction material is shown in the table 3.9

Characteristics	**Value**
$CaSO_4$ content	98.5% minimum

Density	2.96 g/cm^3
Size	(-250)BS mesh
Melting Temperature	1460 °C
Structure	Orthorhombic
Color	White
Specific Heat	0.732324 J/g/°C
Grade	X-ray

Table 3.9: Characteristic of the Calcium Sulphate powder used in aircraft brake

3.3.3 Molybdenum di Sulphide

Molybdenum disulfide is the inorganic compound with the formula MoS_2. In its appearance and feel, molybdenum disulfide is similar to graphite. Hence, like graphite, it is widely used as a solid lubricant because of the weak van der Waals interactions between the sheets of sulfide atoms. MoS_2 has a low coefficient of friction, resulting in its lubricating properties. An outstanding characteristic of molybdenum-disulfide lubricant is its high heat resistance. Oxygen reacts with it only at temperatures above 400 ^{0}C. This lubricant retains its properties not only at high temperatures, but at low temperatures as well (as low as -70^{0}C).

The typical characteristics of the Molybdenum di sulphide powder used in aircraft brake pad is shown in the table 3.10

Table 3.10: Characteristic of the Molybdenum di sulphide powder used in aircraft brake

Characteristics	Value
Thermal Conductivity	18 W/m K
MoS_2content	95% minimum
Density	5.06 g/cm^3
Size	(-100)BS mesh

Melting Temperature	1185 °C
Coefficient of Linear Expansion	1-4 $*10^{-6}$ $/^{0}K$
Crystal Structure	Hexagonal
Compressive Strength	30 MPa
Specific Heat at Room Temp	1450 J/kg K
Colour	Black

3.3.4 Graphite Powder:

Graphite is structurally composed of planes of polycyclic carbon atoms that are hexagonal in orientation. The distance of carbon atoms between planes is longer and therefore the bonding is weaker.

Graphite has low binding forces parallel to the axis of its hexagonal layered lattice. For this reason, it forms lamellar plates with a high shear capacity. This high shear however is only maintained if a certain amount of water vapor and oxygen can be adsorbed from the surrounding atmosphere. The shear can be further improved and maintained even at higher temperatures if certain foreign atoms or molecules such as metal oxides are incorporated as well.The adsorption of water reduces the bonding energy between the hexagonal planes of the graphite to a lower level than the adhesion energy between a substrate and the graphite.

Graphite is characterized by two main groups: natural and synthetic. Synthetic graphite is a high temperature sintered product and is characterized by its high purity of carbon (99.5-99.9%). The primary grade synthetic graphite can approach the good lubricity of quality natural graphite.

Natural graphite is derived from mining. The quality of natural graphite varies as a result of the ore quality and post mining processing of the ore. The end product is graphite with a high content of carbon (ex: high grade graphite has 96-98%

carbon), sulfur, SiO_2 and Ash. The higher the carbon content and the degree of graphitization (more crystalline) the better the lubricity and resistance to oxidation.

The typical characteristics of the Graphite powder used in aircraft brake pad friction material is shown in the table 3.11

Table 3.11: Characteristic of the Graphite powder used in aircraft brake

Characteristics	**Value**
Thermal Conductivity	1.67-518.8 W/m K
Carbon content	94% minimum
Density	2.09-2.23 g/cm^3
Size	(-100+250)BS mesh
Melting Temperature	3527(±20) °C
Coefficient of Linear Expansion	0.1-19.4 *10^{-6} /^{0}K
Crystal Structure	Hexagonal
Compressive Strength	18-30 MPa
Specific Heat at Room Temp	8.517 J/mol K
Ash Content	4% max
Volatile Matter	2% max
Grade	Fine natural or synthetic

3.4 The Filler Material

Fillers are used to maintain the overall composition of the friction material and help to give the friction material the required coefficient of friction and wear properties. These materials are used, in amounts up to 15% to decrease the cost of the friction material.

The following are the filler materials used in the organic, copper and iron based friction materials.

3.4.1 Friction Dust

This is widely used filler material in organic based pads. It is generally based on a Phenolic monomer which has a very long hydrocarbon side chain which makes the polymer rubbery. The friction dust assists in the manufacture of the friction materials, and improves its friction and wears behavior.

3.4.2 Asbestos

Friction materials use asbestos as a reinforcement and friction modifier. Asbestos is particularly effective filler in that it can withstand high temperatures; it is very strong, has good thermal stability and high Length/diameter ratio. It can be continually subdivided down to molecular size and it is relatively cheap.

The high friction coefficient of asbestos powder is probably due to the fibers subdividing easily to give very clean surfaces and to the large area of contact inherent in a mass of easily deformable fibers. At high temperatures asbestos is dehydoxylated and above 810^{0}C it is transformed to forsterite and silica.

3.4.3 Mineral Particle

Another major types of filler used is mineral particles. In certain circumstances the μ of such fillers is approximately proportional to their Mohs hardness.

When mineral particles are added to the matrix the coefficient of friction (μ) of the resulting material is not simply related to the μ of particles and matrix and their relative proportions because of complex interaction between the two phases.

3.4.4 Metal Particle

These are often used in organic based brake pads. The metal makes its contribution to the coefficient of friction (μ) of the material and some metals scour the opposing surface preventing the buildup of resin or oxide films which may affect μ and which can act as thermal barrier.

Metal fillers are plastic during sliding and suggest that metal particles behave in the same way as the bulk materials.

3.4.5 Glass fiber (Chopped Strands):

Glass fiber is material made from extremely fine fibers of glass. Glass fibers are useful because of their high ratio of surface area to weight. These are often used in organic based brake pad to improve the matrix strength, coefficient of friction stability and mechanical property. These fibers are melts at 500^0C and shows poor wear resistance at higher temperature.

3.5 Wear resistant material

These are added in the organic based friction material to improve the wear resistance of the brake pad. The following are the list of wear resistant material used in the organic based brake pad.

3.5.1 Steel Wool

Steel wool or 'wire wool' is a bundle of strands of very fine soft steel filaments. Steel wool is made from low-carbon steel (low enough to be close to plain iron). It is not made by drawing "steel wool wire" through a tapered die, but rather by a process more like broaching where a heavy steel wire is pulled through a toothed die that removes a thin wire shaving.

When steel wool is heated, it increases in mass due to the burning iron combining with the oxygen. It is an excellent wear resistance additive besides being filler. It is used both in organic and metalloceramic friction materials.

CHAPTER: 4

DESIGN REQUIREMENT OF THE BRAKE PAD QUALIFICATION

4.1 INTRODUCTION:

Figure 4.1 represents a view of a typical disc type aircraft brake unit. The unit is designed as a multiple disc assembly consisting of a brake housing, pressure plate, torque tube, and disc stack comprising of a series of alternate stator and rotor discs assembled with brake pads and steel rotor segments, respectively.

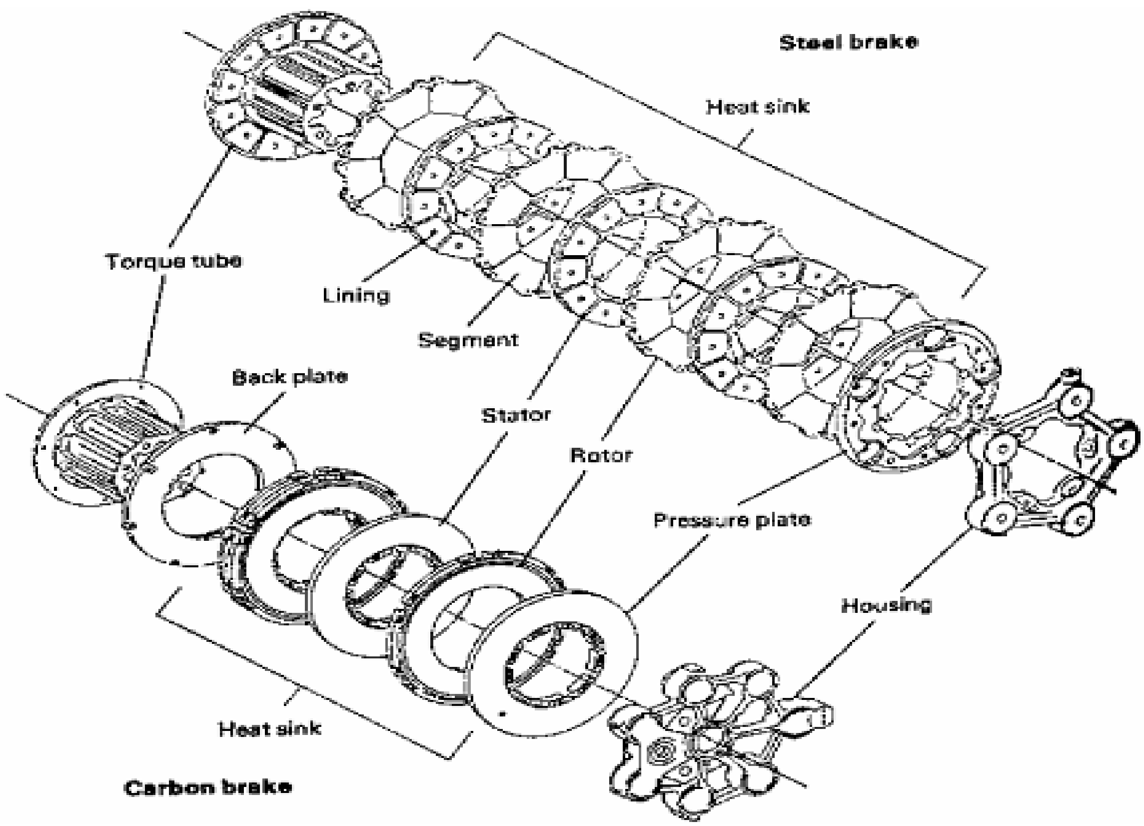


Fig 4.1 Brake unit assembly of Carbon and Steel Brake

The disc stack is also called the “heat sink” and is the most important part of the brake unit.

The brake functions by virtue of the conversion of the kinetic energy of the moving aircraft to heat energy and the absorption and subsequent dissipation of the same by the heat sink.

Heat generation arises from the rubbing of the surfaces of the brake pads on the rotor discs against those on the adjacent stator discs and is thus dependent on the frictional characteristics of these surfaces, specific heat of the heat sink mass and the rate of heat abstraction from the frictional surfaces.

Stator plates are keyed to the brake housing and torque tube, and rotor plates are keyed to the wheel drive blocks that rotate with the wheel to which they are attached.

An aircraft brake heat sink is designed using the following design performance parameters derived from the basic brake design specifications:-

- Heat Sink Loading (Kinetic energy per unit heat sink mass)
- Area Loading (Kinetic energy absorbed per unit swept area of the rubbing faces)
- Area Loading Rate (Area Loading per unit braking time)

4.2 DERIVATION OF FRICTION MATERIAL PROPERTIES FROM THE BRAKE SPECIFICAITON

All the above performance characteristics of the brake and the brake heat sink are determined by the brake design specification. The first phase of the development of an appropriate friction composition for the brake pads, therefore, starts with a detailed analysis of the brake design specification and deduction of physical and mechanical properties of the candidate friction material. Table 4.1 presents the typical brake design specification parameters that are required for the derivation of properties and development of an appropriate friction/brake pad material.

Table 4.1: Typical Aircraft Brake Design Specification Parameters

Sl.NO.	Basic brake design specification	Symbol(Units)
1.	Maximum Design Landing Weight of Aircraft at Sea Level	W_{DL}(Kgf)
2.	Maximum Brake Application Speed on Design Landing	V_{LBr} (m/sec)
3.	No. of Landing Brake s per Aircraft	N
4.	Maximum Take-off Weight of Aircraft	W_{TO}(Kgf)
5.	Maximum Decision Speed for Reject-Take-Off (R.T.O.)	V_D(M/sec)
6.	Mean Deceleration reqd. from Brake during Design Landing	D_1(-3m/sec^2)
7.	Minimum Deceleration reqd. from Brake during R.T.O.	d_{RTO} (1.83m/sec^2)
8.	Mean Service Life of Brake Linings in Number of Landings	L(m)
9.	Tyre Rolling Radius of Braking Wheel	R (m)
10.	Number of Brake Pistons	n

11.	Mean Diameter of Brake Pistons	D(cm)
12.	Pitch Circle Radius of Brake Pistons	r (m)
13.	Maximum Effective Brake Pistons	P_{eff} (kgf/cm^2)
14.	Total design heat sink mass of brake	M_{HS}(Kgf)
15.	Number of Frictional Rubbing surfaces per brake	B
16.	Total Frictional Swept Area per rubbing surface	a (cm^2)
17.	Threshold Brake Temperature Rise on Design Landing	T_{DL}(^0C)
18.	Maximum Allowable Brake Temp. Rise during Emergency R.T.O.	T_{RTO}(^0C)
19.	Nominal Friction Material Thickness per face of brake disc	F_{TH}(cm)

From the basic design specification data given in Table 4.1, a number of performance characteristics of the brake such as kinetic energy per brake, brake torque, stopping time, and stopping distance etc. could be derived which in turn form the acceptance requirements of the brake friction material being developed. From the basic data of table 4.1 and the derived brake performance characteristics, a number of physical and mechanical properties of the candidate friction material, such as coefficient of friction and wear, could be derived which govern the development of the friction material, table 4.2 presents the derived performance characteristics of an aircraft brake illustrating the relation between the basic design specifications and the derived characteristics.

Table 4.2 Derived Brake Performance Characteristics

Sl. No.	Derived Characteristics	Derived from	Relationship
1.	Kinetic energy (Design Landing(, $KE_{(DL)}$	W_{DL}, V_{LBr}, N	$KE_{(DL)}=1/2W_{DL} V_{LBr}^2/gN$
2.	Kinetic energy **(R.T.O.), KE** $_{(RTO)}$	W_{RTO}, V_D, N	$KE_{(RTO)}=1/2W_{RTO}VD^2/gN$
3.	Mean Stopping Time(Design Landing), $t_{(DL)}$	V_{LBr}, d_l	$t_{(DL)}= - V_{LBr} / d_l$
4.	Max, Stopping time allowed for RTO emergency braking , $t_{(RTO)}$	V_D, d_{RTO}	$t_{(RTO)} = -V_D /d_{RTO}$
5.	Mean braking distance (Design Landing) $S_{(DL)}$	V_{LBr}, d_l , $t_{(DL)}$	$S_{(DL)} =V_{LBr} t_{(DL)} + d_l t_{(DL)}^2/2$
6.	Max. braking distance allowed in RTO, $S_{(RTO)}$	V_D, d_{RTO}, $t_{(RTO)}$	$S_{(RTO)}=V_D t_{(RTO)}+d_{RTO} t_{(RTO)}^2/2$
7.	Mean Dynamic Brake Torque (Design Landing), $\tau_{(DL)}$	W_{DL}, d_l, N, R	$\tau_{(DL)} = W_{DL} d_l R/ gN$
8.	Heat Sink Loading , H_M	$KE_{(DL)}$, M_{HS}	$H_M = KE_{(DL)} / M_{HS}$
9.	Heat Sink Area Loading, H_A	$KE_{(DL)}$, a, b	$H_A = KE_{(DL)} / a b$
10.	Heat Sink Loading Rate		
	A) Mass Loading Rate , H_M	H_M , $t_{(DL)}$	$H_M = H_M / t_{(DL)}$
	B) Area Loading Rate, H_A	H_A, $t_{(DL)}$	$H_A = H_A / t_{(DL)}$

The basic physical and mechanical properties of the candidate friction material are derived from the analysis of the brake specification (table 4.1) and the derived performance characteristics (table 4.2). Table 4.3 presents some of the physical properties of the candidate friction material for a typical aircraft brake, the basic specification/characteristics and the friction material properties.

Table 4.3 Properties of the Candidate Friction material derived from the brake specification

SL. NO.	Property	Derived from	Relationship	Value of property derived for a typical transport aircraft
1.	Mean Coefficient of Friction, μ	$\tau_{(DL)}$, $\mathbf{P}_{eff}$, **D, n, b,r**	$\mu = \mathbf{4}\ \tau_{(DL)} / \pi \mathbf{D}^2\ nbr\ \mathbf{P}_{eff}$	0.29
2.	Mean Specific Heat of Friction Heat Pack, S_M	$\mathbf{KE}_{(DL)}$, $\mathbf{M}_{HS}$, $\mathbf{T}_{DL}$	$\mathbf{S}_M = \mathbf{KE}_{(DL)}/\mathbf{M}_{HS}\ \mathbf{T}DL$	0.59 J/gm/deg.C
3.	Maximum allowable Wear rate per braking stop, $\mathbf{W}_{TH}$	$\mathbf{F}_{TH}$, L_m	$W_{TH} = F_{TH}/L_m$	0.003 mm
4.	Minimum melting point of Friction material , T_M	T_{RTO}	$T_M \geq (\mathbf{T}_{RTO}+200^0C)$	1250^0 C

In a similar manner the other basic physical, mechanical properties of the candidate friction material such as thermal conductivity, specific gravity, shear strength, compressive strength, etc., could be easily derived from the brake specification.

4.3 DESIGN AND SELECTION OF FRICTION MATERIAL COMPOSITION

The composition of the prototype friction material is then designed, selected and formulated based on the properties derived. The first step in this process is the selection of the metallic matrix material which imparts the basic physical and mechanical properties such as friction, strength, specific heat, thermal conductivity and melting point to the friction material and normally accounts for 60 to 75% of the metallic matrix is restricted to either a copper base or an iron base or a judicious combination of the two bases. Minor additions of other metals such as Zinc, Tin, Nickel, Chromium, etc., as alloying elements, are sometimes necessary to enhance the mechanical properties of the metallic base.

Table 4.4 shows the relative characteristics of the Iron and copper matrix material.

Table 4.4. The relative characteristics of iron and copper based matrix materials

Sl.no.	Characteristics	Iron	Copper
1.	Specific Heat at Room Temp (Joules/gm/^{0}K)	0.59	0.42
2.	Thermal Conductivity at R.T. (J/M/sec/^{0}K)	59	346
3.	Coefficient of Linear Expansion ($^0K^1 . 10^6$)	14	18
4.	Heat Sink Loading Capacity (Joules/Kg)	450,000	280,000
5.	Tensile strength (MPa)	410	240
6	Melting Point (^{0}C)	1539	1083
7.	Antiseizure	Good	Poor
8.	Tolerance to ceramic/non-metallic additions	Poor	Good
9.	Softening Resistance at Elevated Temperature	Good	Poor
10.	Ease of Manufacture into friction Materials	Poor	Good

From an analysis of Table 4.4 and the desired properties of the candidate friction material, the matrix material could be easily selected. For example, for a typical transport aircraft brake, the derived properties of which are given in table 4.3, iron could be selected as the most suitable matrix material as most of the characteristics desired such as specific heat, heat sink loading, melting point, thermal conductivity, etc. However, in most cases to improve thermal conductivity with a negligible reduction of room temperature specific heat, about 5-10% of the iron is replaced by copper. Incorporation of a small quantity of copper in iron matrix also improves fabrication characteristics such as mixing, powder compressibility and sinterability and promotes strength and hardness of the resultant material due to precipitation hardening.

The next step in the design of composition is the selection of the other secondary ingredients such as friction additives, dispersed solid lubricants, stabilizers, etc. Table 4.5 illustrates the various ingredients commonly used in formulation of metalloceramic friction materials to fulfill the diverse functional characteristics required. The type and proportion of the secondary ingredients selected are based on the level of functional properties required in the resultant friction material.

Table 4.5 Friction Material Ingredients

SL.NO.	Frictional characteristics	Components/Ingredients
1.	Friction, strength, thermal conductivity and specific heat	Matrix: Copper or iron (with or without alloying elements, e.g. Sn, Zn, Ni, Cr, Mn etc.)
2.	Lubrication, seizure prevention, stability	Dispersed Lubricants: Graphite, MoS_2, Special high temp. Lubricants.

3.	Abrasion/Friction	Abrasive component: Silica, Mullite, Silicon Carbide etc.
4.	Friction stability, thermal stability, Softening resistance, Conformability	$BaSO_4$, $CaSO_4$, Mo, etc.
5.	Wear resistance	Spinels, steel wool, pearlite and Cementite phase in iron matrix.
6.	Fillers	Carbon, Minerals.

The abrasive component is the most important ingredient after the matrix as this gives rise to friction and also helps in preventing local welding and metal transfer of the metallic matrix material on to the mating part rubbing surface during braking. Out of the various abrasive ingredients, the oxides of silicon and aluminum are known to be suitable for low and medium energy friction materials whereas the carbide of silicon is most desirable for high energy possessing high heat sink loading values. For the transport aircraft brake, which has a friction material with a iron based matrix, SiC was chosen as the abrasive ingredient. SiC is also abundantly available in our country, is cheap and is stable till a temperature of 1800 ^{0}C and hence is the ideal abrasive ingredient for the friction material.

Dispersed dry lubricants are added to avoid gross seizure between the friction element and mating part. These lubricants provide smoothness of engagement during braking by forming a self regulating smooth film on the friction surface. These lubricants, by forming a film, also regulate friction and wear at all rubbing speeds and brake temperatures. Out of the various dispersed lubricants, natural graphite is best suited for the iron matrix as it also helps formation of the much desired pearlite phase in the iron matrix during sintering. Pearlite improves strength, friction coefficient, stability and wears resistance in iron base friction materials. Graphite, however, ceases to be a good lubricant at brake bulk temperatures above 600 ^{0}C and therefore a secondary high temperature lubricant is also required when temperatures more than 600 ^{0}C are encountered.

It has been found that high graphite contents (15 to 20%) are suitable for low temperature performance and where very high thermal conductance is assured, but in conditions of poor heat transfer such as in the present example, the addition of graphite should not exceed 6 to 8%. Secondary high temperature lubricant additions are normally kept very low, i.e., about 1 to 2%, as higher amounts added lead to excessive wear of the friction material.

An important requirement, which the friction material of a high energy aircraft brake must fulfill, is thermal stability which means that the basic strength, friction and wear rate of the material should not deteriorate appreciably with increasing rubbing speeds and brake temperatures. Sulphates of Barium, Calcium, Manganese or Iron are effective stabilizers. $BaSO_4$ is very commonly used in iron base friction materials. Additions are limited to 12% beyond which mechanical properties of the friction material decline.

The resultant composition of the iron base friction material for a typical high energy transport aircraft brake could be tentatively fixed as given in Table-4.6.

Table 4.6 Typical composition of the iron base friction material

Sl.No.	Ingredient	Weight Percent
1.	BaSO4	8 to 12%
2.	Graphite	6 to 8%
3.	Silicon carbide	7 to 10%

4.	High temp. Lubricant	1 to 2%
5.	Copper	5 to 7%
6.	Iron	Balance

It is thus observed that the friction material composition for any aircraft brake could be designed, formulated and derived from the brake specification data and such a composition derived would naturally satisfy all the properties and performance parameters dictated by the brake specification.

4.4. Design and Selection of Multi-layer Technology in Aircraft Brake pads:

The sintered metal-ceramic friction material developed does not by itself fulfill all the requirements of aircraft braking. There are other vital issues such as absorption of noise and vibrations generated during high speed aircraft braking, the steep thermal gradients to be neutralized, the proper fastening of the friction material to the carrier assembly etc. To meet all the above requirement, the friction element is designed as not only a multi-component friction material, but also a multi-layered composite.

Fig 4.2 shows the conceptual view of the multi-layers in a brake friction material.

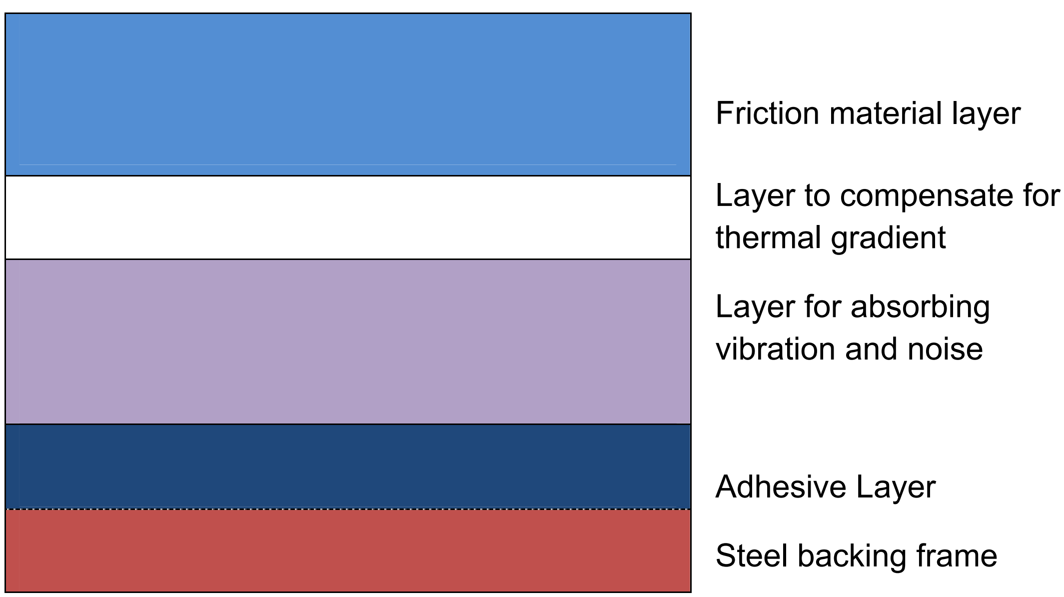


Fig 4.2 conceptual multi-layers in a brake friction material

In iron base friction elements a pure sponge iron powder layer of thickness 0.5 to 2.0 mm between the friction material and the nickel plated steel backing frame is incorporated as a special feature by making a multi-layer compact. The sponge iron acts as a cushion layer due to its sponginess. This characteristic allows the effective damping of vibrations/judder during braking. This layer also acts as a medium to further ensure good bonding between the friction material and the steel back plate through the intermediate nickel layer. A portion of lower melting copper/tin, which are the ingredients of the friction material, also percolate to this sponge iron layer during pressure sintering by capillary action and are believed to reduce the effect of thermal gradients.

The nickel coated layer of the back plate also contributes to neutralizing the thermal gradient due to a compositional gradient that exists across its thickness. The compositional gradient arises due to its alloying with some of the friction material ingredients on one side and with the back plate on the other side.

Fig 4.3 shows the microstructure image of a typical iron based aircraft brake pad showing various multi-layers

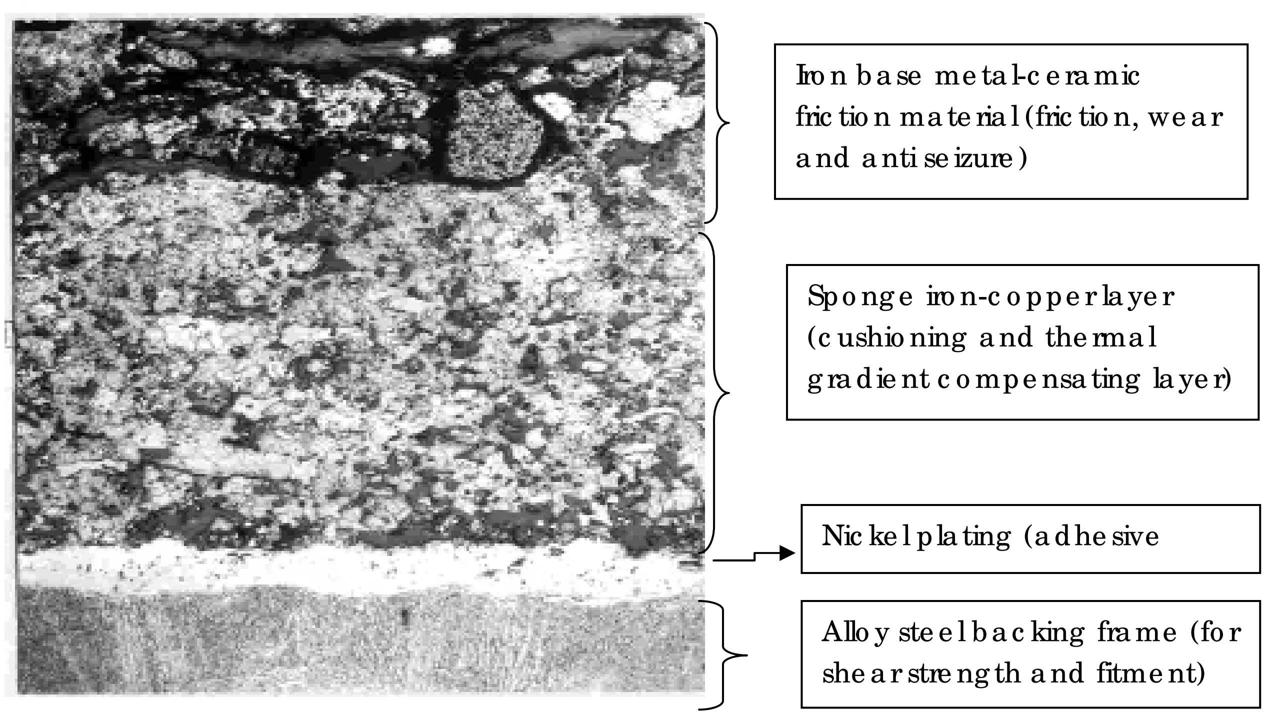


Fig 4.3: Sectional microstructure of a typical iron based aircraft brake pad showing various technological layers

In copper base friction materials, a cup type design and presence of metallic grid inserted by spot welding between the cup and the friction material ensures judder reduction, bonding and integrity of the material against thermal gradients.

CHAPTER: 5

POWDER CHARACTERISATION

5.1 Introduction:

Powder metallurgy method of brake pad manufacturing start with processing of powders. Hence it is necessary to understand the nature and characterization of the ingredient powders in order to develop a sound manufacturing method.

A particle is defined as the smallest unit of a powder that cannot be subdivided. Powder metallurgy deals with particles that are larger than smoke (0.01 to 1 μm), but smaller than sand (0.1 to 3 mm), and most of the common particles have diameters similar to that seen with human hair (25- 200 μm).

5.2 Particle Size and Shape:

Both particle size and particle shape exert considerable influence on the behavior of a powder during brake pad manufacturing. The properties of the powder compact and the final sintered part are directly related to the extent to which powder particles establish contact with their neighbors.

Metal powders suitable for processing in to brake pad material generally ranges from 0.1 to 200 μm in size.

The size of a particle is specified by linear dimension in spherical shaped powder as shown in fig 5.1. For plate or flake shaped particle two parameters i.e. diameter and width are needed to describe the size as shown in fig 5.1.

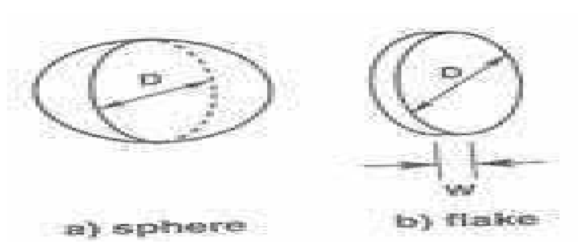


Fig 5.1: single and double parameter of sphere and flake powder particle

Fine powders provide many interparticle contacts during compactions. This promotes sintering but makes it difficult to achieve uniform compacted density. However coarse powders result in more uniform densification during compaction, but due to fewer interparticle contacts and more sluggish sintering behavior, large pores are retained after sintering.

The shapes of powder particles used in the brake pad applications vary greatly depending on the property required. The powder shape play a dominant role in establishing packing efficiency, flow ability, compressibility etc.

Fig 5.2 shows the some of the powder particle shapes used in the brake pad friction material manufacturing.

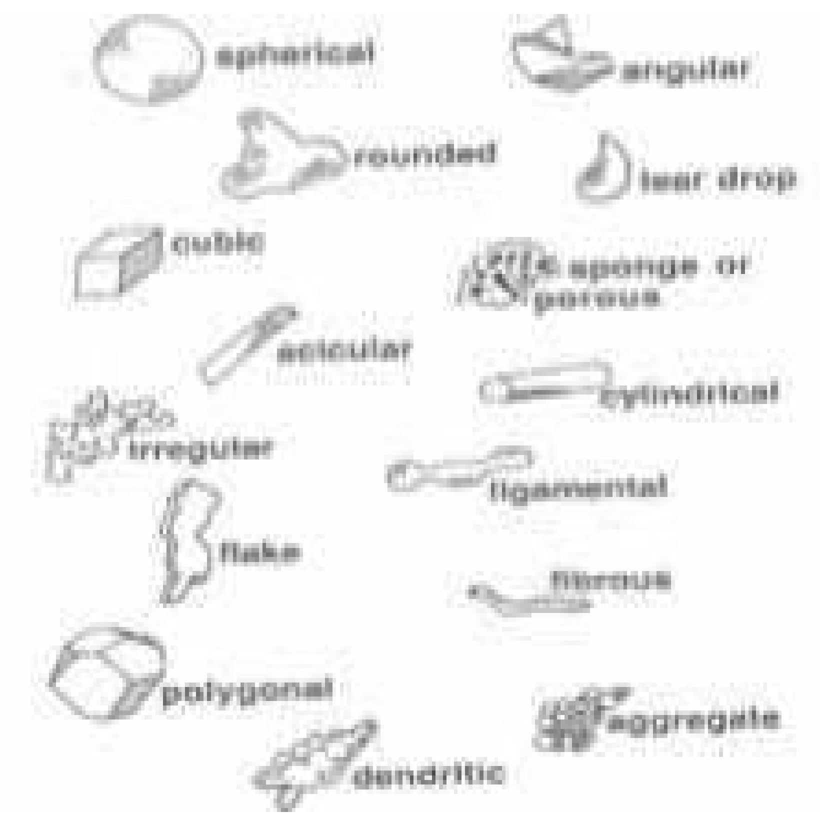


Fig 5.2: Different shaped powder

5.3 Powder Measurement Technique:

Most ferrous and non ferrous powders used in the brake pad friction material applications are measured for size by Sieve analysis and microscopic analysis.

5.3.1 Sieve Analysis:

Screening or sieve analysis is a common technique for rapidly analyzing particle size. This technique is usually applied only to particles larger than about 45 Micron meter.

This technique uses a square grid of evenly spaced wire called mesh. The mesh size is determined by the number of wires per unit length. The opening size varies inversely with the mesh size. Larger mesh sizes imply small opening sizes and vice versa.

Screen analyses begin with a stack of screen with decreasing mesh openings as shown in fig 5.3.

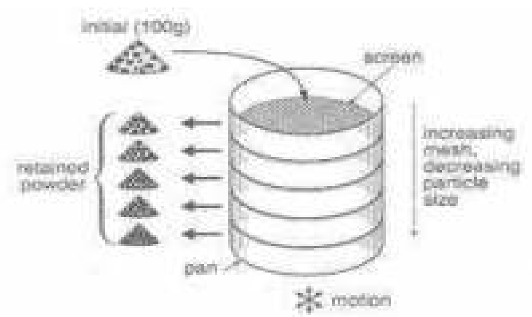


Fig 5.3 stacks of screens with decreasing opening

The smallest opening size sieve is placed at the bottom. The powder is loaded on to the top screen and the screen stack is agitated for 15 minutes. After vibration for 15 min, the screens are unstacked and the powder in each size interval is weighed. The powder passing through a mesh is designated as minus (-) sign, and that retained on a mesh is designated by a plus (+) sign.

5.3.2 Microscopic Analysis:

A widely applied technique for particle sizing uses the ability of the eye to rapidly size dispersed particles in a microscope. Microscopic methods have the advantages that they record not only particle size, but also particle shape, frequency distribution of the powder size and structure.

There are two types of microscopes used for microscopic analysis, they are optical microscope and Scanning Electron Microscope.

5.3.2.1 Optical Microscope:

The optical microscope, often referred to as the "light microscope", is a type of microscope which uses visible light and a system of lenses to magnify images of small samples.

In optical microscope the particles are measured and counted either on the focusing screen of the microscope or from image analyzer attached to the microscope.

Limitation of the optical microscope in terms of particle size measurement is that the depth of focus of this microscope is lesser then the scanning electron microscope hence it is not used for particle size lesser than 1 micron meter.

5.3.2.2 Scanning Electron Microscope

The scanning electron microscope is the most powerful method of examining powders optically. This method yields an illuminated image of the particle that is distinguished by high depth of focus and three-dimensional perspective.

5.4 Powder Fabrication:

The method selected for fabricating a powder depends on specific material properties required in the brake pad application. The three main fabrication technique used in the powder manufacturing used in friction material are electrolytic fabrication, chemical fabrication and atomization method.

CHAPTER: 6

MANUFACTURING OF BRAKE PAD COMPONENT

6.1 Manufacturing process for brake pads:

The manufacturing process for the copper and iron based brake pad components are shown in the fig 6.1 and fig 6.2 respectively

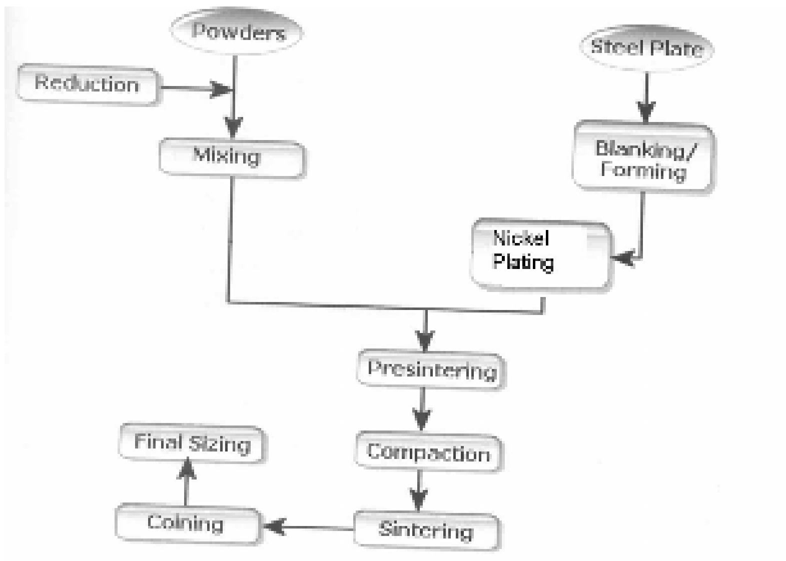


Fig 6.1 process chart for iron based brake pad

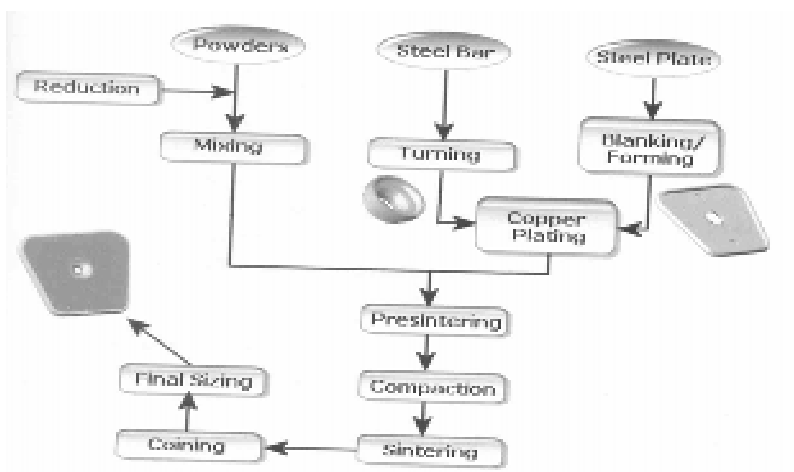


Fig 6.2 Process chart for Copper based brake pad

The steps involve selection of raw material, powder compaction, processing of back plate, pressure sintering, secondary operation etc.

6.2 Electroplating of brake pad back plate frames and formed cups:

The plating is given to back plate or cup of the brake pad material to aid diffusion bonding during sintering and to project the part against corrosion.

The plating process include following operations

a. Sand blasting
b. Vapour Degrease
c. Masking
d. Alkaline Cleaning
e. Acid Pickle
f. Plating
g. Post plating treatment (De embrittlement treatment)

In order to get the defect free plating, the part is checked visually for smoothness,porosity,nodules and blisters.

The typical lay out of a proces shop for plating of back plate/cup for aircraft brake pads is shown in fig 6.3.

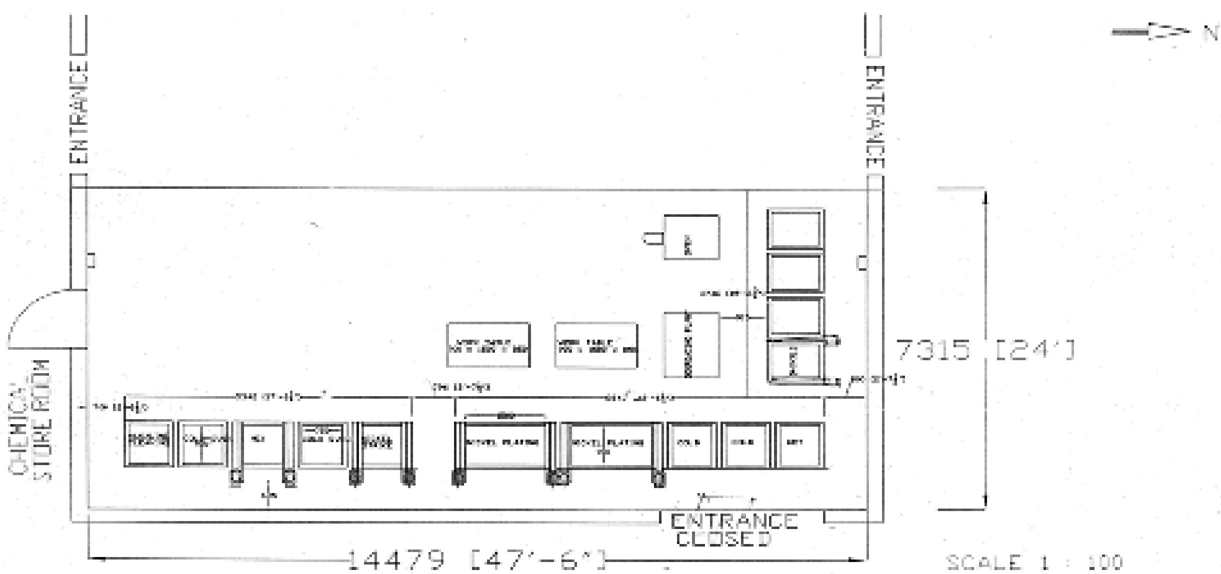


Fig 6.3: Typical layout of plating shop

6.3 Design and Selection of Dies and Tools required for manufacturing of brake pads

Design and Selection of tools has been done taking in to consideration the following aspects

a. Availability of Machines and their capacities
b. Accuracy requirements
c. The tool material is selected taking in to consideration the desired life of the tools based on its application
d. Economical aspects

The tools that are required in the manufacture of brake pads are

6.3.1 Blanking Tools

Steel sheets of different thicknesses have to be blanked with tolerance of 0.05 mm. For this purpose hardened high carbon steel blanking tool having proper guiding systems is selected. Fig 6.4 shows the typical blanking tool used in the manufacturing of brake pad component.

Fig 6.4: sectional and assembly view of the blanking tool

6.3.2 Forming Tools

The forming tool is mainly used for the cup type brake pad component manufacturing .The blanks got from blanking have to be formed in to a cup. The cup has two or three embossings on the back side. The press tool is made of hardened high carbon steel that first does the drawing operation and then the embossing. Fig 6.5 shows the typical forming or draw tool used in the manufacturing of brake pad component.

Fig 6.5: sectional and assembly view of the Forming tool

6.3.3 Powder Compaction Tools:

The tools required for compaction for the production of brake pads comprises, of a Top Punch, a Bottom Punch, Compaction Die and an upward ejection mechanism (for powder compacts) or a die shuttle mechanism for downward ejection (for cup type brake pad compacts).

The schematic of a typical compacts tooling for iron based brake pad is shown the Fig 6.6

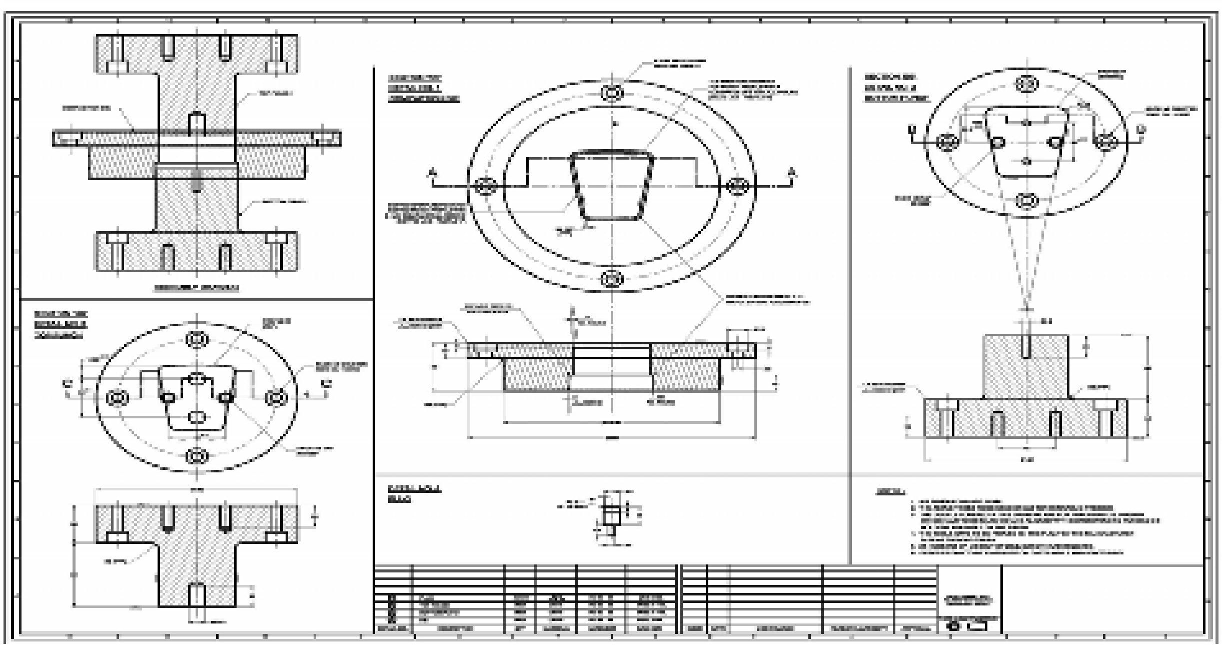


Fig 6.6 Tool drawing of the typical iron based pad

6.4 Laboratory testing of brake pads:

The brake pads manufactured require to be tested in al laboratory. A typical lab scale brake pad testing includes

6.4.1 Chemical Analysis:

The brake pad material is chemically analyzed for the presence of elements as per the approved respective test schedule. The back plate is analyzed for chemical composition of the steel. Facilities for inorganic analysis such as computerized spectrochemical analyzer, atomic absorption spectro photometer, Carbon-sulfur analyzer, carbon estimation apparatus and conventional wet chemical analysis facilities are typically required. For organic brake pad testing facilities include viscometer, scratch hardness tester and Shore 'D' hardness tester.

6.4.2 Metallurgy Analysis:

The brake pad friction material microstructure is analyzed for the presence and uniform distribution of all ingredients. The matrix is analyzed for the desired structures as per specification. The back plate is analyzed for desired heat treated microstructure and the integrity and bondness of bonding between the friction material and back plate across the plating is also certified. The plating thickness is also measured and certified.

The facility for the testing includes Scanning Electron Microscope, Hardness testers, and metallurgical optical microscopes with image analyzer facility, metallographic polishing, specimen preparation and mounting facility.

6.4.3 Friction and Wear Test: Lab scale Dynamometer for friction testing:

Two sectors selected out of every batch of metal-ceramic sectors is tested in the friction testing machine at Foundry & Forge Division for friction and wear properties.

Fig 6.7 shows the perspective view of the front & rear view of the friction test rig.

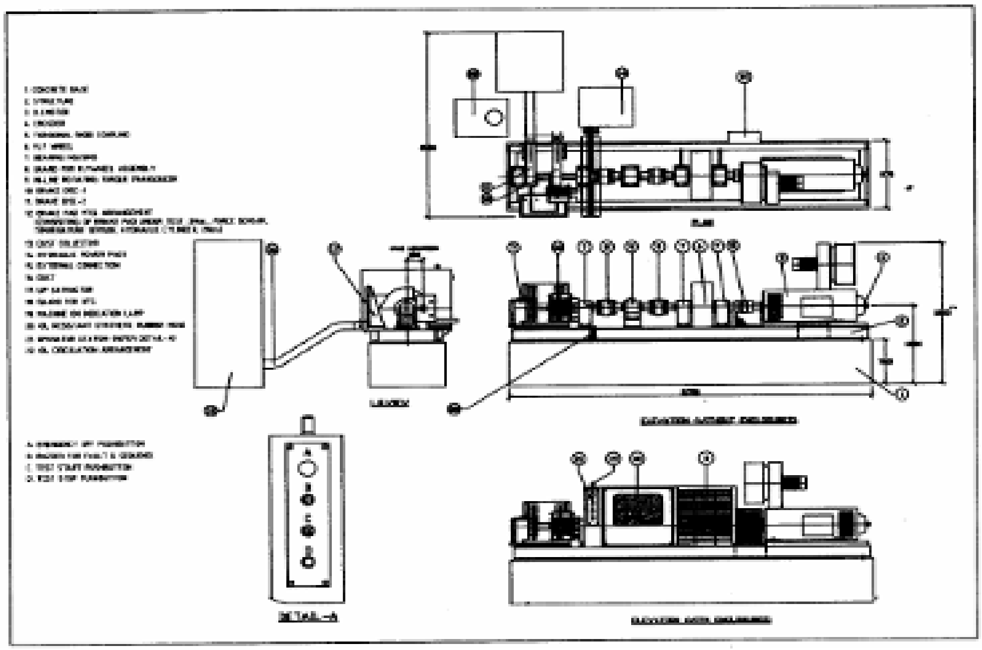


Fig 6.7 Perspective view of the front & rear view of the friction test rig.

Two sectors shall be riveted to the holder of the machine and these samples are to be tested under conditions derived from the brake design specification. The test shall be done on machined sectors. 50 braking stops shall be carried out and considered for measurements of friction and wear. The typical parameter for the iron based pad is shown the table 6.1.

Table 6.1: Friction test parameter of typical iron based pad

Kinetic Energy (Kgfm)	6298
Inertia of fly Wheel(kgm^2)	3.46
Speed of flywheel (rpm)	576
Brake Force(kgf)	163

During the test the following parameters are to be observed and recorded

a) Coefficient of friction (maxm, min, and average).

b) Wear by thickness loss and weight loss measurements after 50 stops

c) Run-down time (Seconds).

d) Run-down revolutions

e) Brake temperature rise (deg c)

f) The values of stop time, temperature rise etc., is recorded.

6.4.4 Bend Test:

6.4.1 One sample per sintering batch of the drawn randomly from the bottom of the stacks of sectors shall be subjected to bend test to asses the quality of the bond between back plate and friction lining. Bend test for assessing bond quality for metal-ceramic sectors as per BS.1639-1964.

6.4.2 The bend test fixture is used for testing.

6.4.3 The specimen shall be placed on the fixed rollers with the ceramic layer facing down. The pressing punch shall be placed centrally on the test piece. Pressure shall be applied on the pressing roll using a press to bend the sample to approximately 120^0

6.4.4 Observe broken ceramic layer. Friction layer could break away but steel surface shall not be exposed in the interface. Steel surface shall have a continuous layer of ceramic material sticking on to the steel.

6.4.5 Exposure of steel surface is indication of poor bonding and failure in the bend test.

6.5 Preservation and Packing of brake pad

The brake pads are preserved in non-corrosive environment with proper precautions to prevent corrosion during storage. They are be wrapped in chemically neutral, grease proof barrier material and delivered in suitable containers

For iron based brake pads, the brake pads are protected from atmospheric corrosion by applying a uniform coating of resin-based cellulose nitrate varnish mixed with aluminum paste or cellulose nitrate varnish mixed with Sudan red dye on all surfaces.

Every batch of metal-ceramic sectors is accompanied by a test certificate furnishing details of batch and test results on the samples, duly certified by the representative of Quality Control Department.

CHAPTER: 7

MIXING TECHNOLOGY

7.1 Introduction:

Mixing and blending are two common pre compaction steps used in the brake pad manufacture. Due to heterogeneous nature and different types of the powder used, a homogenous mix is a primary importance in getting the desired property in a brake pad manufacturing process.

Blending refers to the combination of different sized powders of the same chemistry to achieve control over the particle size distribution and remove powder segregation, where as mixing implies different powder chemistries to form new composition. The mixed powders are not as hard and do not work harden as rapidly during compaction process compared to prealloyed powder.

Small particles will agglomerate during mixing process because of a high surface area and the action of one of the weak forces. The common weak forces are vander Waals attraction, electrostatic charges, capillary liquid forces, cold welding at the particle contacts or magnetic forces.

The variables involved in blending or mixing powders include the material, particle sizes, mixer type, mixer size, relative powder volume in the mixer, speed of mixing, shear and time of mixing and humidity etc.

7.2 Mixing Equipment:

Metal powder mixing and blending is performed using following equipment

7.2.1 Pot mill/Ball mill

7.2.2 Double cone Blender

7.2.3 Sigma mixer

7.2.1 Pot Mill/Ball mill:

The fig 7.1 shows the ball mill/pot mill used for mixing of powder metal powders.

Fig 7.1: Pot mill/Ball mill

The drive assembly of pot mill consists of a pair of rollers with hard neoprene rubber with one roller driven through V pulley. The second rubberized roller should be easily removable so that it could be sent in any of four different positions allowing the space between the rollers are adjusted to accommodate different sized ball mills. Normally pot mill are used during development stage in small quantity of mix to establish mixing parameter. The mixing volume used in the pot mill container should be 1/3rd of the container volume. Table 7.1 shows the typical specification of the pot mill

Table 7.1: Specification of typical Pot mill/Ball mill

Specification	Dimension
Length of the roller	SUITABLE DIMENSIONS
Over all diameter of rollers	
Thickness of rubber lining	
Roller speed	
Induction Motor	
Stainless steel pots with wall thickness	
Stainless steel pot size	
Stainless ball size	

7.2.2. Double Cone Blender:

The fig 7.2 shows the sectional view of the double cone blender used for mixing of powders. The capacity of the blender is more compared to the pot mill/ball mill. It is mainly used during manufacturing stages.

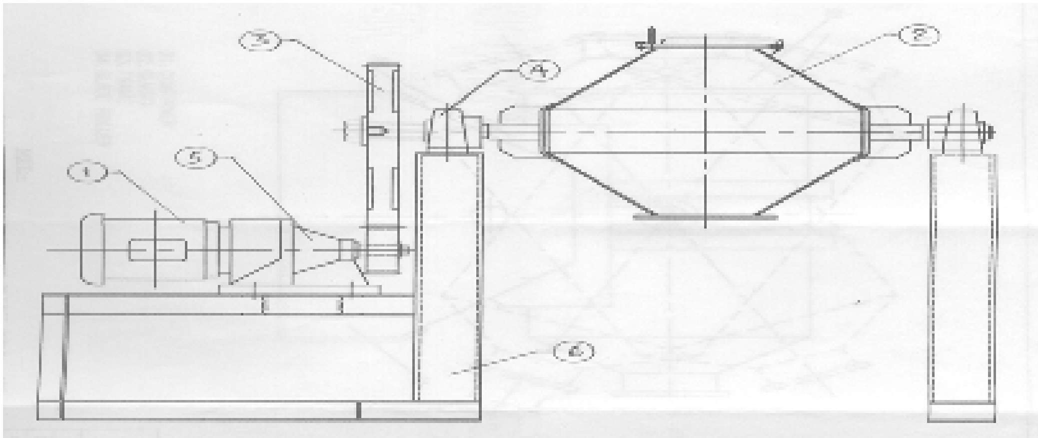


Fig 7.2 : Double cone Blender

The unit consists of break motor, vessel, gear Box, pillow block, Gear reducer and Channel frame. The specification of the double cone blender is shown in table 7.2

Table 7.2: Specification of typical double cone blender

Specification	Dimension
Gross capacity	SUITABLE DIMENSIONS
Working Capacity	
Drive Motor	
Blender Speed	
Blender material wall thickness	

7.2.3 Sigma Mixer:

Another type of mixer for high speed mixing facility .The unit consists of container, blades, cover, jacket, and tilting and sealing arrangement. The table 7.3 shows the specification of the typical sigma mixer.

Table 7.3: Specification of typical Sigma mixer

Specification	Dimension
Container size	SUITABLE DIMENSIONS
Working Capacity	
Driving arrangement	
Tilting arrangement	
Blades	
Blade speed	
Cover	

7.3 Mixing with Binders and Lubricants:

The binder is used to mold the powder and lubricants are mixed with powders to provide easier part ejection from compaction tooling and longer die life. Lubricants reduce the friction between the powders and die wall, and between the powder particles themselves. Lubricants decreases wear and tear of the tools and prevent tool seizure.

There are two ways of lubrication during pressing operation those are die wall and powder lubrication. Lubricant and binders are removed from the compacts during sintering operation.

Table 7.4 shows the most important lubricants used and their characteristics.

Table 7.4: Types of lubricant and their characteristics

Name	Formula	Melting point ^0C	Boiling or dissociation point ^0C
Zinc Stearate	$Zn(C_{18}H_{35}O_2)_2$	140	335
Calcium Stearate	$Ca((C_{18}H_{35}O_2)_2$	180	350
Stearic acid	$CH_3(CH_2)_{16}$ COOH	69.4	360
Molybdenum disulphide	MoS_2	1185	-

The addition of lubricant should not exceed 0.2 to 1 mass% of the powder mix. Larger quantities can cause disintegration of the green parts. In metalloceramic pad/Bimetallic brake pad dry lubricants are added to improve the die wear life.

7.4 Safety and Health consideration:

Powder handling requires safety precautions and cleanliness as some of the powder are health hazard to the working environment. The particle size and the specific gravity of the material largely determine the deposition site for an inhaled particle. Metal powders in a finely divided state are pyrophoric (burn in air) and potentially explosive.

The powder handing includes protective equipment like mask, gloves etc. good ventilation, controlled oxidation surface coating and minimization of spark. The Material safety data sheets (MSDS) are provided along with the powder, the same are to be read and safety points to be incorporated.

CHAPTER: 8

COMPACTION TECHNOLOGY

8.1 Stages of Compaction

Figure 8.1 shows the stages of compaction process in the ductile and brittle powder

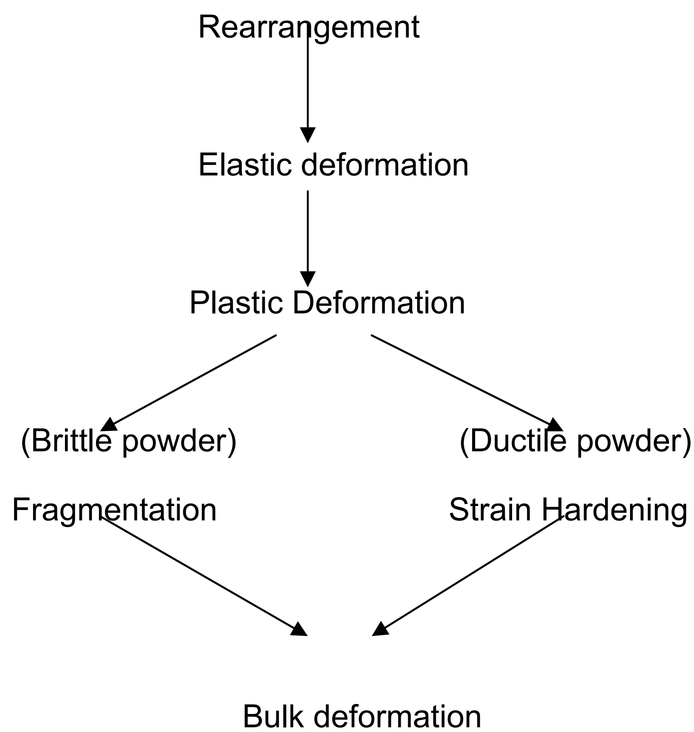


Figure 8.1.Compaction Stage

The compaction stages in the powder mix starts with particle rearrangements. As the compaction pressure increases, the relative volume of each particle undergoing plastic deformation increases. At low pressures, plastic flow is localized to particle contacts. As the pressure increases, homogeneous plastic flow spreads from the contacts and the entire particle become work hardened. The large pores are eliminated first and the particle coordination number increase to distribute the load.

The brittle materials, densification can occur by fragmentation. The compact surface area increases due to fragmentation. A small particle size hinders compaction because of the higher interparticle friction and higher particle work hardening rate.

The figure 8.2 shows the variation of compaction pressure with density of the powder compact.

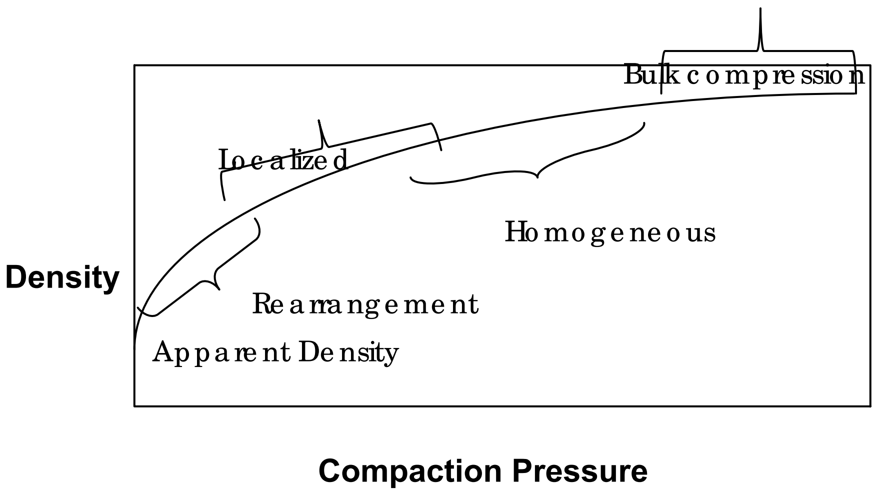


Fig 8.2 Variation of density vs compaction pressure

At the beginning of a compaction cycle, the powder mix has a density approximately equal to the apparent density. As pressure applied the rearrangement of the particle take place, by filling of large pores, giving a higher packing coordination. Further increasing pressure provides better packing by localized deformation followed by homogenous deformation and bulk compression, which leads to decreasing porosity with the formation of new particle contacts.

8.2 Compaction of brake pad material:

Compaction operation of metallo ceramic brake pad material is done in hydraulic presses. Compacting pressure varies from 15 to 35 tons/inch^2 is used based on the type of powder, the compacted density and other property required.

Uniaxial powder compaction method is predominantly used for production of brake pad material. In this process, the pressure applied along one axis using hard tooling of the type shown in Figure 8.3.

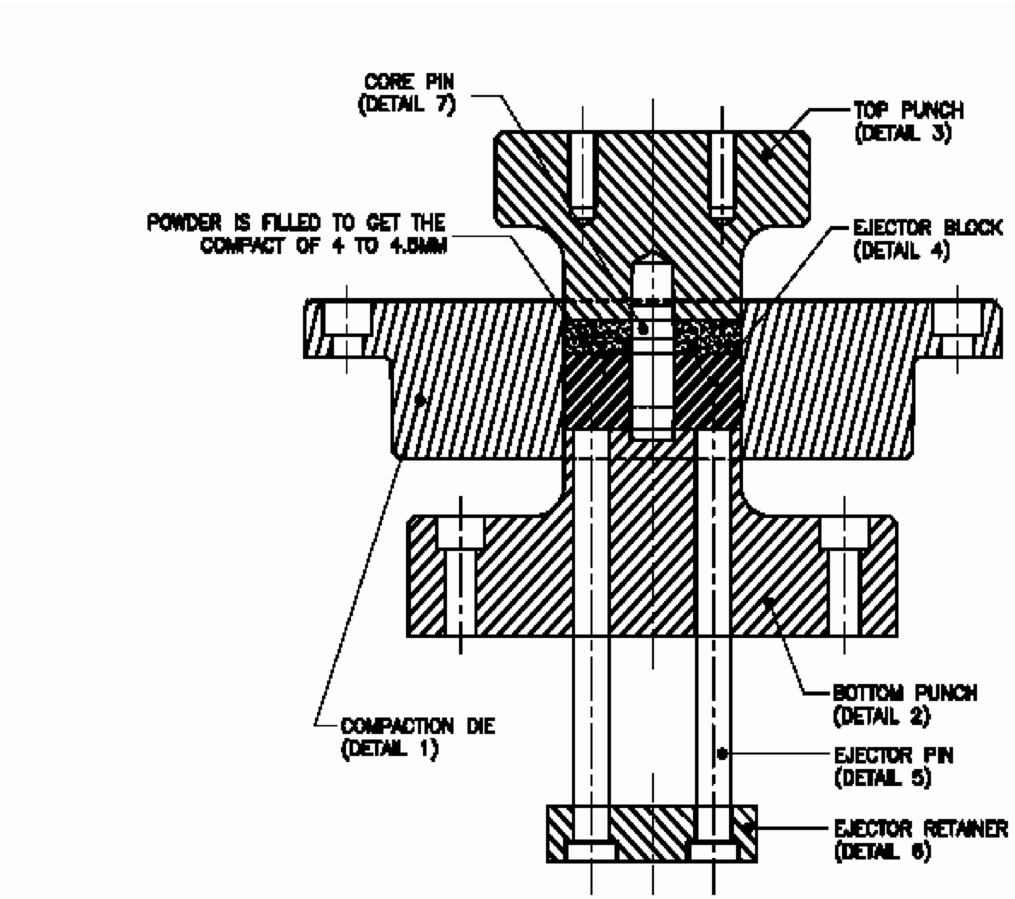


Fig 8.3 Uniaxial Powder compaction process

The compaction die provides the cavity into which the powder is pressed and gives lateral constraint to the powder. The top punch is retracted during powder filling. The powder is feed into the die from an external feed shoe. The fill position differs from the bottom punch position during pressurization to allow pressing in the center of the die. The position of the bottom punch can change during powder fill to aid uniform powder placement throughout the cavity. After filling, the bottom punch drops to the pressing position and the top punch is brought into the die. Both punches are loaded to generate stress within the powder mass. At the end of the compaction stroke, the powder experiences the maximum stress. Finally, the top punch is removed and the bottom punch is used to eject the compact. The cycle then repeats with a new fill of powder.

After compaction, the compact is removed from the die. The force exerted to push the compact out of the die is called the ejection force. The stored elastic energy in the compact causes it to press against the die wall, which causes considerable die wear. The die wear is minimized by application of lubricant in to the die cavity.

Now a days automatic process like HIP, CIP etc are available for better dimensional thickness compact during

8.3 Tooling Concerns

Proper design and specification of the compaction tools provides long life and proper functioning. The greater the number of parts to be formed on a given set of tooling, the more effort necessary to offset possible wear. Tool steels are approximate for shorter production runs, while cemented carbides are used for high volume production. The powder shrinkage and swelling due to sintering and elastic recovery on ejection must be incorporated into the tooling dimensions. The ability to form a final shape is a major attribute of P/M. Capitalization on that advantage required careful tool dimensioning to produce correct component dimensions.

The pressures used during compaction are limited by the tool shape and material. Furthermore, the press size, motions, part complexity, and required surface finish influence the tolling design.

CHAPTER: 9

SINTERING TECHNOLOGY

9.1 Sintering Fundamentals:

Sintering is a complex process where a variety of phenomena are encountered. In the ISO 3252, sintering was defined as "the thermal treatment of a powder or compact, at a temperature below the melting point of the main constituent for the purpose of increasing its strength".

9.1.1The driving force for sintering:

The driving force for mass transport in solid state sintering is primarily the minimization of the surface free energy of the powder system. A change in the surface area (dA_s) represents a change in free energy (dE) of the system as

$$dE = \gamma . dA_s \tag{9.1}$$

Where, γ is the surface tension. The variation in surface curvature that accompanies this reduction in surface area leads to a chemical potential change on three counts, namely, i) stress, ii) vapour pressure and iii) vacancy concentration.

9.2 Sintering Theory:

9.2.1 Sintering Stages:

Sintering operation are divided in to 3 stages based on the geometrical chages occuring during sintering process .

9.2.1.1. First stage or initial stage:

The particles, which are in contact with each other, form a very small neck. This small neck area increases continuously as sintering proceeds. The void spaces within the particle aggregates change into definite pore structures. In spite of initial neck growth, the particles in the original powder aggregate are still distinguishable.

9.2.1.2. Second or intermediate stage:

In this stage the particles can no longer be distinguished, the pore channels in the powder aggregate become cylindrical in shape and gradually get pinched off and closed. These pores are situated at the intersection of three or four grain boundaries. This is a stage of a very rapid densification.

9.2.1.3. Third or final stage:

The final stage begins when the pore phase gets eventually pinched off. The pores shrink continuously and tend to be spherical in shape. The migration of grain boundaries and grain growth take place. Majority of the pores are closed and isolated. At this stage, a definite grain structure also develops. The density of the sintered body reaches its maximum value at this stage.

9.3 Mixed Powder Sintering:

The mixed phase sintering phenomena relies on both physical and chemical factors. The physical factors involve the green powder structure, particle size, particle shape, Composition, homogeneity, and green density. Chemical interactions in mixed powders usually dominate during heating.

Four types of sintered structure are possible from the mixed powder these are

1. Homogenization when there is intersolubility between the mixed powders. Ex: stainless steel.
2. Enhanced sintering when the base powder is soluble in the additives, but not vice versa. EX: Refractory metals (W, Mo, Cr) with Ni additions.
3. Pore formation when the base powder has solubility for the additives, but not vice versa. Ex: Ti-Al, Al-Zn, Fe-Ti.
4. Composites when both base powder and additives are insoluble. Ex: Fe-Al_20_3.

9.4 Types of sintering process:

The fig 9.4 shows the map of key sintering process.

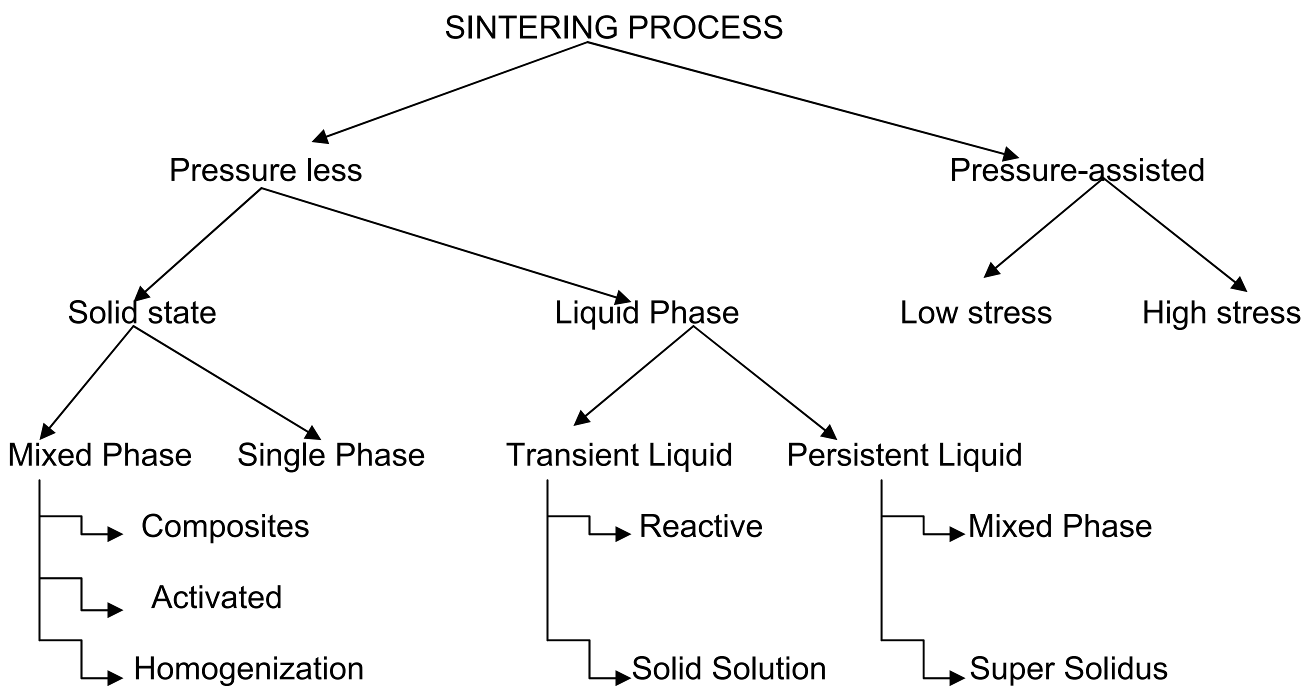


Fig 9.4 Map of key sintering process.

Sintering process is divided into pressure less and pressure assisted sintering process. In the pressure assisted process, pressure is usually from hot isostatic, forging and hot pressing process.

A pressure less sintering process is distinguished as a solid state and liquid phase sintering processes. solid state sintering processes are further categorized in to a single phase applicable to pure substances like Iron, Nickel, Copper etc and mixed phase include compact homogenization, activated sintering and composites. In the activated sintering process, the second solid phase contributes to rapid particle bonding.

Liquid phase sintering is categorized based on presents of liquid during the sintering process. The liquid may be present momentarily or may persist during much of the sintering cycle. Presence of the liquid in the sintering cycle accelerates mass transfer, densification, and microstructure coarsening. There are two main forms of liquid phase sintering, persistent liquid phases exists throughout the high temperature portion of the sintering cycle as in sintering of W-Ni-Fe alloys and transient liquid phase sintering where liquid that disappears during the sintering cycle, due to dissolution in to the solid solution or formation of a new phase as in the sintering of Cu-Sn and Cu-Zn alloys.

9.5 Sintering Atmosphere:

Sintering atmosphere influences sinter bonding and compact composition. The atmosphere is a key to ensure proper sintered properties.

The sintering atmosphere shall perform the following roles during sintering operations

1. Extracting the surface contaminants
2. Removal of organic materials used in forming operation to avoid undesired reactions with the powder.
3. Prevent air from entering the furnace
4. Reduce surface oxides on the powder particles
5. Control carbon on the surface and in the core of steel parts
6. Remove carbon in special applications
7. Provide controlled oxidation during cooling in special application.
8. Convey or remove heat efficiently and uniformly

9.5.1 Sintering atmosphere types:

There are seven types of atmosphere used in sintering process. It includes air, inert gas, Hydrogen, dissociated ammonia, nitrogen-based, natural gas- based and vacuum. In the brake pad sintering, mixed gases of hydrogen and nitrogen are mainly used as a sintering atmosphere .The hydrogen gas provide good oxide reducing character, high thermal conductivity and carbon control, while the nitrogen gas is used to minimize explosive dangers.

9.5.2 Impurity effects on sintering atmosphere

An impurity effect on sintering atmosphere is measured using the dew point. It tells the temperature at which water vapor will condense. It is a measure of the relative moisture content and the atmosphere oxidation-reduction potential.

9.5.3 Sintering Furnace

The sintering furnace provides time-temperature control of the sintering cycle while containing the atmosphere. P/M compacts are porous; therefore, a much greater surface area is exposed to the furnace atmosphere than with solid parts. Sintering temperatures are considerably higher than heat treating temperatures (1120 °C for iron and steel compared to 900 °C for carburizing and neutral hardening of steel).

Sintering furnaces are classified in to two types based on the productivity, these are

9.5.3.1. Batch furnace Ex: Bell furnace, oven, elevator furnace etc

9.5.3.2. Continuous furnace Ex: pusher furnace, Roller Hearth furnace etc

9.5.3.1. Batch Furnace:

The main advantage of batch furnace is flexibility. The pressure assisted sintering operation is carried out in these types of furnaces. The figure 9.5 shows the typical bell furnace used in the sintering of brake pad material.

Fig 9.5 : Bell furnance

Bell furnace is commonly used for pressure sintering of friction materials. They are equipped with work-pressing devices to apply heavy pressure during sintering operation.

9.5.3.2 Continuous Furnace:

A continuous furnace provides thermal treatments by controlling the position of the compact in a pre heated furnace. These are comes in several designs including the mesh-belt conveyor furnace, the ceramic-belt conveyor furnace, the roller-hearth furnace, the pusher furnace, the walking-beam furnace, and the continuous vacuum furnace. A typical continuous sintering furnace has four distinct areas, heat or burn-off area, the high heat or sintering area, the slow cool or transition area; and the final cooling area.

The first zone in a continuous furnace initiates compact heating, removes lubricants, binders and contaminants from the pores, and possibly starts gas reactions with the powder. The next two zones are the high-heat region, where the actual time, temperature and atmospheric conditions are maintained. Cooling takes place in the last zone, where the compact is subjected to a high gas flow. The figure 9.6 shows the pusher furnace used in the manufacturing of the copper based brake pad material.

Fig 9.6: Pusher furnace

CHAPTER: 10

AIRWORTHINESS CERIFICATE OF BRAKE PAD

10.1 AN-32 BRAKE PAD

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
मारतहल्ली कालोनी पोस्ट आफिस, बेंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं./Type Approval No.1206

मद/For Item : तीन तरह के ब्रेक पैड्स/" **Brake Pads -Three Types**

यह प्रमाणित किया जाता है कि **मेसर्स हिन्दुस्तान ऐरोनॉटिक्स लिमिटेड**, एफ एण्ड एफ प्रभाग, सेन्ट्रल मेटीरियल्स एण्ड प्रोसेसिंग लाबोरेटरी, विमानपुर पो.आ, बेंगलोर - 560017 द्वारा विकसित तथा उत्पादित **"तीन तरह के ब्रेक पैड्स"** रोटर ब्रेक पैड (केटी192ए-070 एफबीपी 600-1) स्टेटर ब्रेक पैड्स थिन (केटी192ए-060 एफबीपी 600-2/1) और स्टेटर ब्रेक पैड्स थिक (केटी192ए-060-1/एफबीपी 600-2/2) "एएन 32 वायुयान में काम आता है, विनिर्देश एफ पीएमएस 402 6 282 90 के अनुसार उत्पादन के लिए अनुमोदित किया जाता है । इसे आर.सी.एम.ए(एफ एण्ड एफ), बेंगलोर-17 के समन्वय से स्पेसिफिकेशन सं.सीआरई (ए/सी) एचएएल-बीसी/456/24 के अनुसार परीक्षित किया गया है । यह परिशिष्ट'ए' में संलग्न " टाइप रेकार्ड कम्पलायन्स स्टेटमेन्ट" की विवरण/परीक्षण संबंधी आवश्यकताओं को पूर्ण कर चुका है ।

*This is to certify that the "Brake Pads three types" Rotor Brake Pad (KT192A-070/FBP 600-1) Stator Brake pads Thin (KT192A-060/FBP 600-2/1) & Stator Brake Pad Thick (KT192A-060-1/FBP 600-2/2)", developed and manufactured by **M/s Hindustan Aeronautics Limited.**, F & F Division, Central Materials and Processes Laboratory, Vimanapura P.O, Bangalore 560 017, is hereby approved for production as per specification F/PMS/402-6/282/90 for use in AN-32 Aircraft. It has been tested, as per governing specification No. CRE (A/C)/HAL BC/456/24, in co-ordination with RCMA(F&F), Bangalore-17. It has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'.*

30/05/06

पृष्ठ/**Page 1 of 2**

2. इस वर्ग अनुमोदन को जारी करने के फलस्वरूप उत्पाद को प्रदत्त अनंतिम निकासी सुपरसीड होती है । उपरलिखित वर्ग अनुमोदन संख्या को सभी संगत आरेखन, संविदा तथा रिलीज़ नोट्स में प्रतिबिंबित किया जाना चाहिये ।

The Provisional Clearances accorded for this product are hereby superceded consequent to issuance of this Type Approval. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

2. यह वर्ग अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए, रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है ।

This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

3. यह वर्ग अनुमोदन **31 दिसंबर 2010** तक वैध है और इसके बाद में इसका नवीकरण करवाना होगा । विक्रेता को इस वर्ग अनुमोदन की अवधी समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए(एफ एण्ड एफ), द्वारा मेसर्स एचएएल(एफ एण्ड एफ), विमानपुरा पो.आ, बेंगलोर -17 से अनुरोध करना होगा ।

This Type Approval is valid up to **31st Dec 2010** *and will have to be renewed subsequently. The vendor shall request RCMA(F&F), C/o M/s HAL (F&F), Vimanapura P. O, Bangalore-17, for subsequent renewal, three months before the expiry of Type Approval.*

4. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या संलग्न टाइप रेकार्ड कम्पलायन्स स्टेटमेन्ट में कोई परिवर्तन करना हो तो सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बेंगलोर की पूर्व सहमति लेनी होगी।

Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record Compliance Statement enclosed are effected.

संलग्न/Encl : परिशिष्ट'ए'/Appendix'A'

सं/No. : सेमिलाक/CEMILAC/5070/टी.ए/TA-1206
दिनांक/Date : 25 मई 2006
फेक्स सं/Fax No: 080-25230856

(जे.के शर्मा/J.K.SHARMA)
मुख्य कार्यपालक(उड़नयोग्यता)
Chief Executive (Airworthiness)

10.2 AVRO BRAKE PAD

AVRO

GOVERNMENT OF INDIA

CIVIL AVIATION DEPARTMENT

TYPE CERTIFICATE

No. 7-12/88-RD

This Certificate, issued to
FOUNDRY AND FORGE DIVISION,
M/S HINDUSTAN AERONAUTICS LTD., BANGALORE
Certifies that the

STATOR BRAKE PAD OF MAIN WHEEL OF HS-748 AIRCRAFT

the technical data and operating limitations for which are contained in Technical Certificate No. TC-1 BP *dated* 14TH AUGUST, 1989 *is of proper design, material, specification, construction and performance for safe operation and meets the minimum standards, rules and regulations prescribed by the Director General of Civil Aviation.*

This Certificate is of indefinite duration unless cancelled, suspended or revoked.

Date 14TH AUGUST, 1989

(Y. P. BAWA)
Director R&D
for Director General of Civil Aviation.

10.3 BOEING BRAKE PAD

Boeing

Government of India

Directorate General of Civil Aviation

TYPE APPROVAL
(No. 7-12/90-RD)

This Approval, issued to

Hindustan Aeronautics Ltd.,
(Bangalore Complex)

certifies that the

BRAKE PAD FOR BOEING 737-200 AIRCRAFT
(Pt. No. HF 357-242 & HF 357-246)

indigenously developed and manufactured by Foundry & Forge Division of Hindustan Aeronautics Ltd. is of proper design, material, specification, construction and performance for safe operation and meets prescribed requirements of FAR 25.735.

The Type Approval is subject to the terms and conditions as stated in letter No. 7-12/90-RD dated 15.12.1997.

(H.S. KHOLA)
DIRECTOR GENERAL OF CIVIL AVIATION

Dated: January 20, 1998

66

10.4 CHETAH/CHETAK BRAKE PAD

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बैंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं./Type Approval No.1000

मद/For Item : ब्रेक लाइनिंग पार्ट सं.155पी.324डी.2020.202ए(ए 1-29524)
/Brake Lining Part No. 155P.324D.2020.202A
(A1-29524)

यह प्रमाणित किया जाता है कि मैसर्स एच.ए.एल फाउंड्री व फोर्ज प्रभाग, पोस्ट बाक्स सं.1791, बैंगलोर-17 द्वारा विकसित तथा उत्पादित, "ब्रेक लाइनिंग" पार्ट सं.155पी.324डी. 2020.202ए(ए1-29524), आरेखन सं. 155पी.324डी. 2020.202ए. इश्यू सी दिनांक 9/4/94 के अनुसार, चेतक हेलिकाप्टर मैन लैंडिंग व्हील में काम आता है उसे उत्पादन के लिए अनुमोदित किया जाता है। इसे आर.सी.एम.ए(एफ एण्ड एफ), डीआरडीओ, विमानपुरा पो.आ, बैंगलोर-17 की समन्वय से टाइप रेकॉर्ड सं. एफ/सीएल/8537/1429-अनुलग्नक-I और II दिनांक 5/11/2001 में उल्लेखित क्वालिफिकेशन और अक्सप्टेन्स टेस्ट शेड्यूल सं.एफटीएस 213 दिनांक शून्य के अनुसार परीक्षित किया गया है। यह परिशिष्ट 'ए' में संलग्न "टाइपरिकार्ड कंप्लायन्स स्टेटमेन्ट" में विवरित विवरण/परीक्षण संबंधी आवश्यकताओं को पूर्ण करता है।

This is to certify that the "Brake Lining" Part No. 155P.324D.2020.202A(A1-29524) developed and manufactured by M/s HAL Foundry & Forge division, Post Box No.1791, Bangalore-17, as per drawing No. 155P 324D 2020 202A Issue C, dated 9/4/94, is hereby approved for production for use in the Chetak Helicopter Main Landing Wheels. It has been tested, as per governing qualification and acceptance Test schedule No-FTS 213 dt. Nil referred in Type Record No.F/CL/8537/1429 dated 05/11/2001, in co-ordination with RCMA(F&F), DRDO, Vimanapura P.O, Bangalore-17. It has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'.

पृष्ठ/Page 1 of 2

2. उपरलिखित वर्ग अनुमोदन संख्या को सभी संगत आरेखन, संविदा तथा रिलीज़ नोट्स में प्रतिबिंबित किया जाना चाहिये

The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह वर्ग अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है ।

This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

4. यह वर्ग अनुमोदन 31 जून 2008 तक वैध है और इसके बाद में इसका नवीकरण करवाना होगा । विक्रेता को इस वर्ग अनुमोदन की अवधि समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए(एफ एण्ड.एफ) से अनुरोध करना होगा ।

This Type Approval is valid up to 30 June 2008 and will have to be renewed subsequently. The vendor shall request RCMA(F&F) for subsequent renewal, three months before the expiry of Type Approval.

5. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या टाइप रेकार्ड में कोई परिवर्तन करना हो तो सेना उडनयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बेंगलोर की पूर्व सहमति लेनी होगी ।

Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record are effected.

संलग्न/Encl : परिशिष्ट'ए'/Appendix'A'

सं/No. : सेमिलाक/CEMILAC/5070/टी.ए/TA-1000
दिनांक/Date : 30 मई 2002
फैक्स सं/Fax No: 080-5230856

30/5/03
(जे.के.शर्मा/J.K.SHARMA)
मुख्य कार्यपालक(उडनयोग्यता)/
Chief Executive (Airworthiness)

10.5 DORNIER AIRCRAFT

1 (2) DORNIER (2)

Valid up to 31-12-20

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
DEFENCE R&D ORGANISATION
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

Type Approval No: 845

FOR ITEM : Indigenous "BRAKE DISC"

Pt. No: HF 500 2062

This is to certify that the Indigenous **"Brake Disc"** *Pt No: HF 5002062 designed & developed by* **M/s HAL Foundry & Forge division,** *Bangalore-17, has been tested to Governing test schedule No.RTO (M)/REP/34 dt.15.3.1988, Dynamometer Test Schedule No.F/DGM/050/6/209/88 dt.16-12-88, and Flight Test Schedule No.CRE/76/7/TECH dt.24-8-90, in co-ordination with* **RCMA (Kanpur),** *CEMILAC, Kanpur – 208 008, & meets the requirements of specification / tests, as detailed in the type record enclosed as Appendix "A" for use in Dornier Aircraft in lieu of imported HF 5002062.*

2. *The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.*

3. *This approval is contingent upon the quality control aspects of bulk production being cleared by* **DGAQA,** *Ministry of Defence, Govt. of India.*

4. *This Type Approval is valid for a period of three years i.e., upto* **31ST December 2001** *and will have to be renewed* **subsequently.**

5. *Prior agreement of Centre for Military Airworthiness & Certification,***(CEMILAC)** *Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record enclosed are effected.*

6. *Any changes to manufacturing process will render the approval null & void.*

CONTROLLED COPY
WHEN IN RED
MASTER

Encl : Appendix "A"

No : CEMILAC/5070/TA-845
Date : 28th Oct 1998
Fax No : 080-5230856

(K NAGARAJ)
Chief Executive (Airworthiness)
Phone No (080) 5230680

10.6 DC 8 BRAKEPAD

Le Directeur Général

CERTIFICAT D'AGREMENT D'UN CENTRE DE CONCEPTION ET DE PRODUCTION

(DESIGN AND PRODUCTION APPROVAL CERTIFICATE)

N° AAC/DG/D.AIR/MK/[illegible]/2009

Conformément à l'article 05 de l'arrêté N° **409/CAB/MIN/TC/0075/2006** du 21/06/2006 portant **fixation** des **conditions** techniques **de** navigabilité des aéronefs civils opérant en **République Démocratique du Congo**, l'Autorité de l'Aviation **Civile de** la République Démocratique **du Congo atteste par le présent Certificat que**,

(Pursuant to the articles 05 of the Ministry of transport and communication decree **N°409/CAB/MIN/TC/0075/2006** *dated 21/06/2006, determining airworthiness Technical requirements of civil aircrafts operating in Democratic Republic of Congo, the* **Autorité de l'Aviation Civile de la République Démocratique du Congo** *hereby certified)*

HINDUSTAN AERONAUTICS LIMITED
FOUNDRY AND FORGE DIVISION
Post Bag N° 1791
Bangalore - 560017

A été dûment inspecté **du 07** au 08 Avril **2009**, en ce qui concerne son **aptitude à concevoir et à fabriquer les** plaquettes **de** frein à base de cuivre pour **usage sur les avions** DC-8. **Ces plaquettes seront produites exclusivement** pour le compte **de** l'AMO congolais **FIELD AIRMOTIVE basé à Rand Airport à Johannesbourg**.

(Was properly inspected from 07[th] to April 08[th] 2009 regarding his capability to develop and manufacture "Copper based Brakepads" part numbers HF 357233 and HF 357236 for use in DC-8 aircrafts. These pads will be produced exclusively on behalf of Congolese AMO "FIELD AIRMOTIVE" based in Rand Airport in Johannesburg.

Date d'agrement initial: *Date of initial approval*	**09 Octobre 2009** *October 09[th] 2009*	Kinshasa, le 09 OCT 2009
Date d'expiration : *Expiration date :*	**08 Octobre 2010** *October 08th 2010*	**Richard Kinangile Kasanza** [illegible]

10.7 HPT-32 AIRCRAFT

Reg. No. 01396
Date 29/05/04

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र

CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बैंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं.1348 /Type Approval No.1348

मद/FOR ITEM: एच पी टी-32 के "मोडिफाइड ऑर्गेनिक ब्रेक पैड्स"

"Modified Organic Brake pads" for HPT-32

यह प्रमाणित किया जाता है कि मैसर्स एचएएल एफ एन्ड एफ प्रभाग, सेन्ट्रल मटिरियल और प्रोसेस लेबोरेटरी, विमानपुरा पी ओ बैंगलोर - 560 017 द्वारा अभिकल्पित विकसित और उत्पादित "**मोडिफाइड ऑर्गेनिक ब्रेक पैड्स**" क्रमश: पार्ट सं एचएएल 88874-1 और एचएएल 88875-1 को एचपीटी-32 वायुयान में मुख्य पहिये के ब्रेक के लिए उपयोग हेतु आरेखण सं एफ डी 2502 इश्यू 'सी' दिनांक 24 जुलाई 2002 के अनुसार उत्पादन के लिए अनुमोदित किया जाता है। इसे आर सी एम ए (एफ एन्ड एफ) के समन्वय से टेस्ट शेड्यूल सं. 1) टी एस-026 इश्यू बी 2) टीटीएस/एएच 53290/पीएडी/001 इश्यू ए के अनुसार परीक्षित और एचपीटी-32/टीएस/बीआरएकेईएसवाईएस/01 इश्यू-1 के अनुसार विमान में मूल्यांकित किया गया है। यह डेवलपमेंट बैच पीएम 02, एयू 03, एएम 02, एयू 05 और पीएम 02 ओटी 05 परिशिष्ट'ए' में संलग्न "टाइप रिकार्ड कम्प्लायंस स्टेटमेंट" की विनिर्देश / परीक्षण संबंधी आवश्यकताओं को पूर्ण कर चुका है।

*This is to certify that the **"Modified Organic Brake pads"**, bearing the Part Nos: HAL 88874-1 & HAL 88875-1 respectively designed, developed and manufactured by **M/s HAL F&F Division, Central Material & Processes Laboratory**, Vimanapura P.O Bangalore-560017, is hereby approved for production as per drawing Nos. FD2502 Issue "C" dt.24/07/2002, for use on main wheel brake of HPT-32 aircraft. These items have been tested as per test schedule No.i). TS-026 Issue-"B" ii). TTS/AH 53290/PAD/001 Issue 'A' & evaluated on aircraft as per HPT-32/TS/BRAKESYS/01 Issue-1, in co-ordination with RCMA (F&F). The development batch PM 02 AU 03, AM 02 AU 05 & PM 02 OT 05 have met the requirements of the specification/tests as detailed in the type record compliance statement enclosed at Appendix 'A'.*

पृष्ठ/Page 01 of 02

2. [illegible]

Consequent issue of this (Type ApprovalNo.1348) to the modified Organic Brake Pads, the Type Approval No. 387 issued vide AERO/RD-132/106/4/1 dt.01st Sept 1990, issued to Organic brake pads part Nos:HAL/88874 & HAL/88875 for HPT-32 aircraft is stated to be withdrawn/Cancelled with immediate effect.

3. [illegible]

Similarly the Provisional Clearances accorded for this modified product are hereby superceded consequent to issuance of this Type Approval. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

4. [illegible]

This Type Approval is valid up to 30 June 2013 and will have to be renewed subsequently. The vendor shall request RCMA (F&F), C/o HAL F&F Division, Bangalore 560017 for subsequent renewal, three months before the expiry of Type Approval with all relevant documents including performance feedback.

5. [illegible]

Prior concurrence of Centre for Military Airworthiness & Certification, (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or changes if any, to Demonstrated Process & its declared performance indicated within the Type Record enclosed herewith are effected.

6. [illegible]

This approval is contingent upon strict adherence to the demonstrated process No90083 Issue –01 respectively as the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

[illegible]/Encl : [illegible]'A'/Appendix'A'

[illegible]/No: [illegible]/CEMILAC/5870/[illegible] 1348

[illegible]/Date : 11 Aug 2008

[illegible]/Fax No: 080-25230856

([illegible]/K.TAMILMANI)

[illegible]/Outstanding Scientist /Sc-'H'

[illegible]/

Chief Executive (Airworthiness)

10.8 HPT-32 LOCATING PAD

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
DEFENCE R&D ORGANISATION
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

Type Approval No:864

FOR ITEM : "LOCATING PAD" Pt. No: HAL-25627.

*This is to certify that the **Locating Pad** Pt No: HAL – 25627 developed & Manufactured by **M/s Hindustan Aeronautics Limited**. Foundry & Forge division, Bangalore-560 017, is hereby approved for production as per drawing No.FD-2956/5 issue-A dt.18.1.94 for use in HPT 32 Aircraft. It has been tested to Test schedule No.F/CL/8537/829, dt.17-01-1994, in co-ordination with RCMA (Lucknow),CEMILAC, Lucknow – 226 016. It meets the requirements of specification /tests, as detailed in type record enclosed at Appendix "A".*

2. *The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.*

3. *This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.*

4. *This Type Approval is valid upto 31st Dec 2002 and will have to be renewed subsequently.*

5. *Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC) Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record enclosed are effected.*

Encl : Appendix "A"

(J.K SHARMA)
offg. *Chief Executive (Airworthiness)*

No : CEMILAC/5070/TA-864
Date : 20th Nov 1999
Fax No : 080-5230856

10.9 ISLANDER AIRCRAFT

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
DEFENCE R&D ORGANISATION
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

TYPE APPROVAL NO : 847

FOR ITEM : **"BRAKE PADS OF ISLANDER AIRCRAFT"**
Pt. No: HF ISB 006-06200 & HF ISB 006-06500

This is to certify that the Indigenous "Brake Pads" of Islander Aircraft Pt No: HF ISB 006-06200 & HF ISB 006-06500 designed & developed by M/s HAL Foundry & Forge division, Bangalore-17, has been tested to Governing test schedule No.F/PMS/FBP110 Issue 1, dt.11-12-1996, and Test Schedule for Aircraft Trials. F/PMS/FBP 110/AT Issue 1 dt.02-06-1997 in co-ordination with RCMA (Foundry & Forge), CEMILAC, Bangalore – 560 017. It meets the requirements of specification /tests, as detailed in type record enclosed as Appendix "A" for use in the main wheel brakes of Islander Aircraft.

2. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

4. This Type Approval is valid for a period of three years i.e., upto 31ST December 2001 and will have to be renewed subsequently.

5. Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC) Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record enclosed are effected.

6. Any changes to manufacturing process will render the approval null & void.

Encl : Appendix "A"

No : CEMILAC/5070/TA-847
Date : 30th Nov 1998
Fax No : 080-5230856

(K NAGARAJ)
Chief Executive (Airworthiness)
Phone No (080) 5230680

10.10 JAGUAR INSULATOR PAD

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बैंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं.943 का विस्तार / Renewal of Type Approval No.943

विषय/Sub: "इन्सुलेटर पैड" पार्ट सं.एच ए एल 84538/
"INSULATOR PAD" PART No. HAL 84538

1. यह घोषित किया जाता है कि एच ए एल, लखनऊ प्रभाग के समन्वय से **मैसर्स हिन्दुस्तान एरोनॉटिक्स लिमिटेड,** फाउंड्री व फोर्ज प्रभाग, बैंगलोर-560017 द्वारा विकसित तथा उत्पादित **"इन्सुलेटर पैड" पार्ट सं.एच एच एल 84538** को पत्र सं.सेमिलाक/5070/एफ-90/टीए-943 दिनांक 31 जनवरी 2002 द्वारा वर्ग अनुमोदन सं.943 जारी किया गया था और वह 31 दिसम्बर 2004 तक वैध है।

*This is to state that the ""**Insulator Pad**" Part No.84538 developed and manufactured by **M/s Hindustan Aeronautics Limited,** Foundry & Forge Division, Bangalore 560017, has been issued with Type Approval No. 943 vide letter No.CEMILAC/5070/F-90/TA-943 dated 31st Jan 2002 and is valid up to 31st Dec 2004.*

2. यह प्रमाणित किया जाता है कि इस वर्ग अनुमोदन का नवीकरण किया जाता है तथा यह **31 दिसम्बर 2009** तक वैध है । विक्रेता, एचएएल (एफ एण्ड एफ), बैंगलोर को इस वर्ग अनुमोदन की अवधि समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए(लखनऊ), सेमिलाक, लखनऊ -226016, से अनुरोध करना होगा ।

*This is to certify that the Type Approval is hereby renewed and is valid up to **31 Dec 2009**. The vendor, HAL (F&P), Bangalore shall request **RCMA (Lucknow)**, Lucknow-226016, for subsequent renuwals, three months before the expiry of Type Approval.*

पृष्ठ/Page 01 of 02

3. यदि अनुमोदित उत्पादन प्रक्रिया/ उत्पादक में बदलाव हैं अथवा निष्पादन पर प्रतिकूल प्रतिपुष्टि, तो वर्ग अनुमोदन की वैधता का पुनरावलोकन किया जाएगा ।

Changes in the approved manufacturing process/manufacturer or adverse feedback on the performance, if any, the validity of the Type Approval would be reviewed.

सं/No. : सेमिलाक/CEMILAC/5070/टी.ए/TA- 943/IR
दिनांक/Date : 28 अक्तूबर 2005
फैक्स सं/Fax No: 080-25230856

(जे.के.शर्मा/J.K.SHARMA)
मुख्य कार्यपालक(उड़नयोग्यता)/
Chief Executive (Airworthiness)

टीए सं./TA No.943

सेवा में/To

1	मुख्य प्रबंधक मैसर्स एचएएल, लखनऊ, बाराबंकी प्रभाग लखनऊ - 226 016	1	**General Manager,** M/s HAL Lucknow Barabanki Division, Lucknow 226 016
2	क्षेत्रीय निदेशक द्वारा मैसर्स एचएएल, लखनऊ, बाराबंकी प्रभाग लखनऊ - 226 016	2	**The Regional Director,** C/o M/s HAL Lucknow Barabanki Division, Lucknow 226 016
3	मुख्य आवासिक परीक्षक(लखनऊ) मैसर्स एचएएल, लखनऊ बाराबंकी प्रभाग लखनऊ - 226 016	3	**Chief Resident Inspector** (Lucknow), C/o M/s HAL Lucknow Barabanki Division, Lucknow 226 016
4	**महा निदेशक,** डी.जी.ए.क्यू.ए. रक्षा मंत्रालय डीटीडीएण्डपी(एआईआर), एच ब्लाक, नई दिल्ली - 110 011	4	**Director General,** DGAQA, Ministry of Defence, DTD& P (AIR), H Block New Delhi -110011

10.11 JAGUAR BRAKE PAD

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बेंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं.1341/Type Approval No.1341

मद/For Item : " ब्रेक पैड"/ **Brake Pad**

यह प्रमाणित किया जाता है कि **मेसर्स एचएएल, एफ एण्ड एफ प्रभाग, बेंगलोर** - 560 017 द्वारा विकसित और उत्पादित **"ब्रेक पैड"** पार्ट सं. *151801000-113* (एचएफ - *85859/1*) को जगुआर विमान के मुख्य पहिये के ब्रेक में उपयोग हेतु आरेखन संख्या एफबीपी- 700, इश्यू - 03 दिनांक 23 मई 2001 के अनुसार उत्पादन के लिए अनुमोदित किया जाता है । इस उत्पाद को **आर.सी.एम.ए(एफ एण्ड एफ)** मेसर्स फाउंड्री एण्ड फोर्ज प्रभाग, बेंगलोर के समन्वय से तकनीकी विनिर्देश/ टेस्ट शेड्यूल सं. *151800000-154* इश्यू – 02 दिनांक *13 जुलाई 1993* के अनुसार परीक्षित किया गया है । यह उत्पाद परिशिष्ट"ए" में संलग्न "वर्गरिकार्ड कम्प्लाएंस स्टेटमेंट" में विवरित विनिर्देश/परीक्षण संबंधी आवश्यकताओं को पूर्ण कर चुका है ।

This is to certify that the ***"Brake Pad"*** *Part No. 151801000-113 (HF-85859/1) developed and manufactured by* ***M/s. HAL, Foundry & Forge Division****, Bangalore – 560 017, is hereby approved for production as per Drg Nos: FBP-700 Issue-03 dt 23/05/2001, for use in Main Wheel brake of Jaguar Aircraft. The product has been tested as per Technical Specification/Test Schedule No. 151800000-154 Issue -02 dt.13/07/1993, duly coordinated by* ***RCMA (F&F)****, M/s HAL F&F Division, Bangalore. The product has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'*.

पृष्ठ/Page 01 of 02

2. इस वर्ग अनुमोदन को जारी होने के फलस्वरूप उत्पाद को प्रदत्त अनंतिम निकासी भंग हो जाती है । उपरलिखित वर्ग अनुमोदन संख्या का उल्लेख सभी संगत आरेखन, संविदा तथा रिलीज नोट्स में किया जाना चाहिये ।

The Provisional Clearances accorded for this product are hereby superceded consequent to issuance of this Type Approval. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह वर्ग अनुमोदन, थोक उत्पादन के लिए निश्चित रूप से दर्शायी गई विधियों के अनुसरण और डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा जारी गुणवत्ता नियंत्रण के पहलुओं पर आधारित है ।

*This approval is contingent upon to demonstrated process and the quality control aspects of bulk production being cleared by **DGAQA**, Ministry of Defence, Govt. of India.*

4. यह वर्ग अनुमोदन निलंबित या रद्द न होने पर **30 जून 2013** तक वैध है और इसके बाद में इसका नवीकरण करवाना होगा । विक्रेता को इस वर्ग अनुमोदन की अवधि समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए निष्पादन प्रतिसूचना को सम्मिलित करते हुए सभी संगत दस्तावेजों के साथ **आर.सी.एम.ए(एफ एण्ड एफ - एफ ओ एल)**, द्वारा एचएएल एफ एण्ड एफ प्रभाग, बैंगलोर - 560 017 से अनुरोध करना होगा ।

This Type Approval is valid up to 30[th] June 2013 unless otherwise suspended, cancelled or revoked and will have to be renewed subsequently. The vendor shall request RCMA (F&F - FOL), C/o HAL F&F Division, Bangalore 560017 for subsequent renewal, three months before the expiry of Type Approval with all relevant documents including performance feedback.

5. अगर इस अनुमोदन को किसी अन्य अभिकरण को स्थानांतरण करना हो या संलग्न टाइप रेकार्ड में इंगित एसओपी के अनुसार निष्पादन में कोई परिवर्तन करना हो तो सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र **(सेमिलाक)**, बैंगलोर की पूर्व सहमति लेनी होगी।

Prior concurrence of Centre for Military Airworthiness & Certification, (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or changes if any Demonstrated Process/declared performance indicated within the Type Record enclosed herewith are effected.

संलग्न/Encl : परिशिष्ट'ए'/Appendix'A'

सं/No. : सेमिलाक/CEMILAC/5070/ टी.ए/TA- 1341
दिनांक/Date : 07 May 2008
फैक्स सं.Fax No: 080-25230856

(के.तमिलमणि/K.TAMILMANI)
उत्कृष्ट वैज्ञानिक / वै 'एच'/Outstanding Scientist/Sc-'H'
मुख्य कार्यपालक(उड़नयोग्यता)/
Chief Executive (Airworthiness)

10.12 KIRAN MKII AIRCRAFT

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
RESEARCH AND DEVELOPMENT ORGANISATION
DIRECTORATE OF AERONAUTICS

TYPE APPROVAL NO : 717

ISSUED TO	:	FOUNDRY AND FORGE DIVISION M/S HINDUSTAN AERONAUTICS LTD., P.B.NO.1791, BANGALORE-17
FOR	:	**INORGANIC BRAKE PADS (PART NO. HF-89028/2 FOR KIRAN MK II)**
CO-ORDINATED BY	:	RCMA(AIRCRAFT)

This is to certify that the above mentioned items designed and developed by M/s Hindustan Aeronautics Limited, Foundry and Forge Division, Bangalore-560 017 have been tested according to the type test schedule F/PMS/102-1/465/89 dt. 23.04.87 and F/PMS/102-1/566/87 dt. 21.11.87 outlined by the Directorate and referred in the type record and have been found suitable for aircraft use subject to limitations detailed in the type record placed at Appendix 'A'.

2. The approval Serial No.quoted above must be reflected in all relevant drawings,Contracts and release notes.

3. This approval is contingent upon the quality control aspects of bulk production being cleared by DTD&P(Air), Ministry of Defence, New Delhi.

4. Prior agreement of Directorate of Aeronautics will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record are effected.

5. Any changes to manufacturing process will render the approval null and void.

Encl : Appendix 'A'
No. : Aero/RD-132/106/3/717
Date : 20 Aug 1993

(K SRINIVASA)
Director of Aeronautics(R&D)

10.13 KMI INSULATOR BRAKE PAD

भारत सरकार, रक्षा मंत्रालय/

GOVERNMENT OF INDIA

MINISTRY OF DEFENCE

रक्षा अनुसंधान तथा विकास संगठन

DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र

CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बेंगलोर

MARATHAHALLI COLONY P.O.

BANGALORE - 560 037.

वर्ग अनुमोदन सं./Type Approval No.983

मद/For Item : इन्सुलेटर पैड पार्ट सं.एच.ए.एल-83149/

Insulator Pad Part No. HAL-83149

यह प्रमाणित किया जाता है कि मेसर्स एच.ए.एल फाउंड्री व फोर्ज प्रभाग, पोस्ट बाक्स सं.1791, बेंगलोर-17 द्वारा विकसित तथा उत्पादित, "इन्सुलेटर पैड पार्ट सं.एच.ए.एल-83149", आरेखन सं.एफडी-3975/58 इश्यू निल दिनांक 3/8/94 के अनुसार किरण एम.के-II वायुयान के व्हील एवं ब्रेक सिस्टम में ब्रेकिंग करते हो उत्पन्न ताप का अंतरण को कम करने में काम आता है उसे उत्पादन के लिए अनुमोदित किया जाता है। इसे आर.सी.एम.ए.(एफ एण्ड एफ), डीआरडीओ, विमानपुरा पी.ओ, बेंगलोर-17 के समन्वय से टेस्ट शेड्यूल/टेस्ट विनिर्देश सं.एफ/सीएल/8537/038-अनुलग्नक-I और II दिनांक 7/01/2002 के अनुसार परीक्षित किया गया है। यह परिशिष्ट 'ए' में संलग्न "टाईपरिकार्ड कम्पलायन्स स्टेटमेन्ट" में विवरित विवरण/परीक्षण संबंधी आवश्यकताओं को पूर्ण करता है।

This is to certify that the "Insulator Pad Part" No. HAL-83149 developed and manufactured by M/s HAL Foundry & Forge division, Post Box No.1791, Bangalore-17, as per drawing No. FD-3975/58 Issue Nil, dated 3/8/94, is hereby approved for production for use to reduce the transfer of heat generated during braking action of the wheels & Brakes system of Kiran Mk II aircraft. It has been tested, as per governing Test schedule / Specification No. F/CL/8537/038-Annexure-I,&II dated 7/01/2002, in co-ordination with RCMA(F&F), DRDO, Vimanapura P.O, Bangalore-17. It has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'.

पृष्ठ/Page 1 of 2

2. उपरलिखित वर्ग अनुमोदन संख्या को सभी संगत आरेखन, संविदा तथा रिलीज नोट्स में प्रतिबिंबित किया जाना चाहिये

The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह वर्ग अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है ।

This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

4. यह वर्ग अनुमोदन 31 दिसंबर 2007 तक वैध है और इसके बाद में इसका नवीकरण करवाना होगा । विक्रेता को इस वर्ग अनुमोदन की अवधी समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए(एफ एण्ड एफ) से अनुरोध करना होगा ।

This Type Approval is valid up to 31st Dec 2007 and will have to be renewed subsequently. The vendor shall request RCMA(F&F) for subsequent renewal, three months before the expiry of Type Approval.

5. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या टाइप रेकार्ड में कोई परिवर्तन करना हो तो सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बैंगलोर की पूर्व सहमति लेनी होगी ।

Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record are effected.

संलग्न/Encl : परिशिष्ट 'ए'/Appendix 'A'

सं/No : [illegible]
दिनांक/Date : 21 दिसम्बर 2002
फैक्स सं/Fax No: 080-5230856

(जे.के.शर्मा/J.K.SHARMA)
मुख्य कार्यपालक(उड़नयोग्यता)/
Chief Executive (Airworthiness)

10.14 MIG27 AIRCRAFT

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बैंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं./Type Approval No.1208

मद/For item : "चार तरह के ब्रेक पैड्स"/ Brake Pads -Four Types

यह प्रमाणित किया जाता है कि **मेसर्स एचएएल, एफ एण्ड एफ प्रभाग, बैंगलोर - 560 017 द्वारा** विकसित तथा उत्पादित निम्नलिखित पदार्थ यथा ए) "मेटालोसेरामिक सेक्टर्स" पार्ट सं. एचएफ-केटी-163-090सीबी बी) "बाई मेटालिक सेक्टर्स" i). पार्ट सं.एचएफ-केटी-163-070सीबी ii).एचएफ-केटी-163-110सीबी और iii).एचएफ-केटी-163-120 सीबी को मिग-27 वायुयान के मुख्य पहिये में उपयोग हेतु परिशिष्ट "ए" में दर्शाए गए आरेखन संख्या के अनुसार उत्पादन के लिए अनुमोदित किया जाता है । इसे आर.सी.एम.ए(एफ एण्ड एफ) प्रभाग, बैंगलोर के समन्वय से नियंत्रक टेस्ट शेड्यूल सं.एफ/पीएमएस/एफबीपी-800 इश्यू 01 दिनांक *31/12/1996* के अनुसार परीक्षित किया गया है । यह पदार्थ परिशिष्ट"ए" में संलग्न "टाईपरिकार्ड कम्प्लाएंस स्टेटमेंट" में विवरित विनिर्देश/परीक्षण संबंधी आवश्यकताओं को पूर्ण कर चुका है ।

*This is to certify that the following products namely: a). "Metalloceramic Sectors" Part No: HF KT 163-090CB, b). "Bi-Metallic Sectors " i). Part Nos. HF-KT-163-070CB, ii). HF-KT-163-110CB & iii). HF-KT-163-120CB developed and Manufactured by **M/s. HAL**, Foundry & Forge Division, Bangalore – 560 017, is hereby approved for production as per Drg Nos: Indicated at Appendix-"A", for use in Main Wheel of MiG-27 Aircraft. It has been tested as per governing Test Schedule No. F/PMS/FBP-800 Issue -1 dt.31/12/1996, duly coordinated by **RCMA (F&F)** Division, Bangalore. The product has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'.*

पृष्ठ/Page 01 of 02

2. इस वर्ग अनुमोदन को जारी करने के फलस्वरूप उत्पाद को प्रदत्त अनंतिम निकासी सुपरसीड होती है । उपरलिखित वर्ग अनुमोदन संख्या को सभी संगत आरेखन, संविदा तथा रिलीज़ नोट्स में प्रतिबिंबित किया जाना चाहिये ।

The Provisional Clearances accorded for this product are hereby superceded consequent to issuance of this Type Approval. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह वर्ग अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है ।

*This approval is contingent upon the quality control aspects of bulk production being cleared by **DGAQA**, Ministry of Defence, Govt. of India.*

4. यह वर्ग अनुमोदन **31 दिसंबर 2010** तक वैध है । विक्रेता को इस वर्ग अनुमोदन की अवधी समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए(एफ एण्ड एफ) से अनुरोध करना होगा ।

*This Type Approval is valid upto **31st Dec 2010**. The vendor shall request RCMA(F&F) for subsequent renewal, three months before the expiry of Type Approval.*

5. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या संलग्न टाइप रेकार्ड में कोई परिवर्तन करना हो तो सैना उड़नयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बैंगलोर की पूर्व सहमति लेनी होगी ।

Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record enclosed are effected.

संलग्न/Encl : परिशिष्ट'ए'/Appendix'A'

(जे.के.शर्मा/J.K.SHARMA)
मुख्य कार्यपालक(उड़नयोग्यता)/
Chief Executive (Airworthiness)

सं/No.: सेमिलाक/CEMILAC/5030/टी.ए/TA- 1208
दिनांक/Date : 10 जुलाई. 2006
फेक्स सं/Fax No: 080-25121024

10.15 MIG21 BIMETALLIC SECTOR

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION

सेना उड़नयोग्यता और प्रमाणीकरण केन्द्र

CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION

मारतहल्ली कालोनी पोस्ट आफिस, बैंगलोर
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037

वर्ग अनुमोदन सं. /Type Approval No.1216

मद/FOR ITEM: "मिग-21 के मैन व्हील और नोज व्हील के लिए ब्रेक पैड्स"/

Brake Pads for Main Wheel and Nose wheels of MiG-21

यह प्रमाणित किया जाता है कि **मैसर्स डी एम आर एल, हैदराबाद** द्वारा विकसित **एवं मैसर्स एचएएल, एफ एण्ड एफ प्रभाग, बेंगलोर - 560 017** द्वारा उत्पादित "**ब्रेक पैड्स**" पार्ट सं. क्रमशः मैन व्हील के लिए केटी89-91एम, केटी89-94एम, केटी92-82-01 और मिग-21 वायुयान के नोज व्हील(केटी102) के लिए केटी102-51, केटी-102-52 और केटी102-32 को आरेखन सं. एफएसएफ केटी89-91एम, एफएसएफ केटी89-94एम, एफएसएफ केटी92-82, एफएसएफ केटी102-51, एफएसएफ केटी102-52, और केटी102-32 बी621-01 के अनुसार मिग-21 वायुयान के मैन व्हील और नोज व्हील में उपयोग हेतु अनुमोदित किया जाता है। इसे आर.सी.एम.ए.(नासिक) के समन्वय से एफ एण्ड एफ टेस्ट शेड्यूल सं.टीएस/आईएनडी/40-05 के अनुसार परीक्षित किया गया है। यह पदार्थ परिशिष्ट"ए" में संलग्न "टाईप रिकार्ड कम्प्लाइंस स्टेटमेंट" में विवरित विनिर्देश/परीक्षण संबंधी आवश्यकताओं को पूर्ण कर चुका है।

*This is to certify that the "**Brake pads,** bearing the Part Nos. KT89-91M, KT89-94M, KT92-82-01 for Main wheel (KT-92B, KT-92D) and Part Nos. KT102-51, KT102-52 & KT102-32 for Nose Wheel(KT-102) for MiG-21 aircraft respectively developed by DMRL, Hyderabad & manufactured by **M/s HAL F&F Division, Bangalore-560017**, is hereby approved for production as per drawing Nos. FSF KT89-91M, FSF KT89-94M, FSF KT92-82, FSF KT102-51, FSF KT102-52 & FSF KT102-32 for use on Main Wheel and Nose Wheel of MiG-21aircraft. These items have been tested as per F&F test schedule No. TS/IND/40/05 in co-ordination with **RCMA (Nasik)**. The products have met the requirements of the specification/tests as detailed in the type record compliance statement enclosed at Appendix 'A'.*

पृष्ठ/Page 01 of 02

2. इस टाईप अनुमोदन को जारी करने के बाद उत्पाद को प्रदत्त अनंतिम निकासी रद्द हो जाती है। उपर्युल्लिखित टाईप अनुमोदन संख्या को सभी संगत आरेखण, संविदा तथा रिलीज नोट्स में प्रतिबिंबित किया जाना चाहिये।

The provisional clearances issued to the product are superceded consequent to the issuance of this type approval. The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह टाईप अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है तथा सभी उत्पादित बैचों के परीक्षण रिपोर्ट को अग्रेषित किया जाता है।

*This approval is contingent upon the quality control aspects of bulk production being cleared by **DGAQA**, Ministry of Defence, Govt. of India, and forwarding the test reports of all batches produced.*

4. यह टाईप अनुमोदन 30 जून 2011 तक वैध है और इसके बाद में इसका नवीकरण करवाना होगा। विक्रेता को इस टाईप अनुमोदन की अवधि समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए. (एफ एण्ड एफ), द्वारा एच ए एल(एफ एण्ड एफ) प्रभाग, विमानपुरा पी.ओ. बैंगलोर - 560 017 से अनुरोध करना होगा।

*This Type Approval is valid up to **30[th] June 2011** and will have to be renewed subsequently. The vendor shall request CEMILAC through **RCMA (F&F)**, C/o HAL (F&F) Division Vimanapura P.O Bangalore – 560 017 for subsequent renewal, three months before the expiry of Type Approval.*

5. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या संलग्न टाइप रेकार्ड अनुपालना स्टेटमेन्ट में कोई परिवर्तन करना हो तो सैन्य उड़नयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बैंगलोर की पूर्व सहमति लेनी होगी।

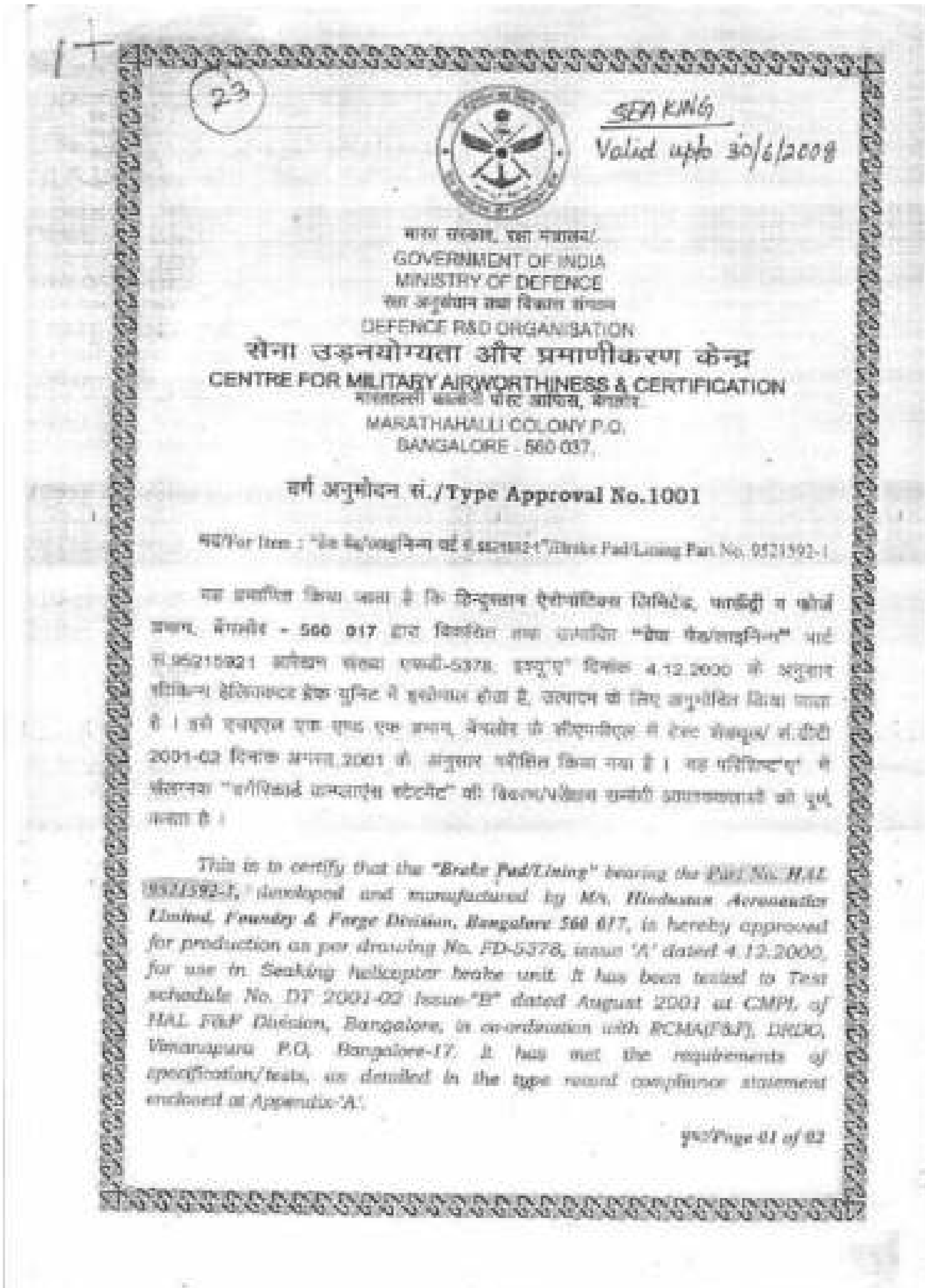
Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record Compliance Statement enclosed are effected.

संलग्न/Encl : परिशिष्ट'ए'/Appendix'A'

सं/No: सेमिलाक/[illegible] 1214
दिनांक/Date : 2.4. Aug 2006
दूरभाष/Tel: 080-25230856

(बी.एस.वेदप्रकाश) (B.S.VEDAPRAKASH)
स्थानापन्न मुख्य कार्यपालक(उड़नयोग्यता)/
Offg. Chief Executive (Airworthiness)

10.16 SEAKING AIRCRAFT



SEA KING
Valid upto 30/6/2008

भारत सरकार, रक्षा मंत्रालय/
GOVERNMENT OF INDIA
MINISTRY OF DEFENCE
रक्षा अनुसंधान तथा विकास संगठन
DEFENCE R&D ORGANISATION
सैना उड़नयोग्यता और प्रमाणीकरण केन्द्र
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
MARATHAHALLI COLONY P.O.
BANGALORE - 560 037.

वर्ग अनुमोदन सं./Type Approval No.1001

मद/For Item : [illegible] /Brake Pad/Lining Part No. 9521592-1

[illegible] ... 560 017 ... 4.12.2000 ... 2001-02 ... 2001 ...

*This is to certify that the "**Brake Pad/Lining**" bearing the Part No. HAL 9521592-1, developed and manufactured by **M/s. Hindustan Aeronautics Limited, Foundry & Forge Division, Bangalore 560 017**, is hereby approved for production as per drawing No. FD-5378, issue 'A' dated 4.12.2000, for use in Seaking helicopter brake unit. It has been tested to Test schedule No. DT 2001-02 Issue-"B" dated August 2001 at CMPL of HAL F&F Division, Bangalore, in co-ordination with RCMA(F&F), DRDO, Vimanapura P.O. Bangalore-17. It has met the requirements of specification/tests, as detailed in the type record compliance statement enclosed at Appendix-'A'.*

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2. उपरलिखित वर्ग अनुमोदन संख्या को सभी संगत आरेखन, संविदा तथा रिलीज नोट्स में प्रतिबिंबित किया जाना चाहिये

The Type Approval number quoted above must be reflected in all relevant drawings, contracts & release notes.

3. यह वर्ग अनुमोदन, थोक उत्पादन के लिए डी.जी.ए.क्यू.ए. रक्षा मंत्रालय, भारत सरकार द्वारा गुणवत्ता नियंत्रण पक्ष की निकासी पर आधारित है ।

This approval is contingent upon the quality control aspects of bulk production being cleared by DGAQA, Ministry of Defence, Govt. of India.

4. यह वर्ग अनुमोदन 30 जून 2008 तक वैध है । विक्रेता को इस वर्ग अनुमोदन की अवधि समाप्त होने के तीन महीने पहले ही अनुवर्ती नवीकरण के लिए आर.सी.एम.ए.(एफ एण्ड एल) से अनुरोध करना होगा ।

This Type Approval is valid upto 30th Jun 2008. The vendor shall request RCMA(F&F) for subsequent renewal, three months before the expiry of Type Approval.

5. अगर इस अनुमोदन को किसी अन्य अभिकरण में स्थानांतरण करना हो या संलग्न टाइप रेकार्ड में कोई परिवर्तन करना हो तो सैन्य उड़नयोग्यता और प्रमाणीकरण केन्द्र (सेमिलाक), बैंगलोर की पूर्व सहमति लेनी होगी ।

Prior agreement of Centre for Military Airworthiness & Certification (CEMILAC), Bangalore, will have to be obtained if this approval is to be transferred to any other agency or if changes within the Type Record enclosed are effected.

संलग्नक : परिशिष्ट 'ए'/Appendix 'A'

सं/No. : सेमिलाक/CEMILAC/[illegible]
दिनांक/Date : 25 June 2003
फैक्स नं/Fax No: 080-5230856

(जी.लोकनाथ/ G.LOKANATHA)
स्थानापन्न मुख्य कार्यपालक(उड़नयोग्यता)/
offg Chief Executive (Airworthiness)

CHAPTER: 11

STATUS OF TYPE APPROVAL/PROVISIONAL CLEARANCE

SL. NO	PROJECT	TA/PC REFERENCE* CEMILAC/RCMA*
1	BOEING	TA-7-12/90/RD(DGCA)
2	DORNIER	TA-5-13/90/RD(DGCA)
2A	DORNIER	TA-845
3	AVRO	TA-7-12/88/RD(DGCA)
3A	AVRO	CRE/067/13/TECH.
4	JAGUAR INSULATOR	TA NO-943
5	CHEETAH/CHETAK	TANO. 066
6	KIRAN MARK-II	TA NO -717
7	JAGUAR	TA NO-1341
8	ISLANDER	TA NO - 847
9	MIG-27	TA NO-1208
10	AN-32	TA NO-1206
11	HPT-32 (Locating Pad)	TA NO - 864
12	SEA HARRIER	DC-CRE(A/C)HAL-BC/245/24
13	ALH-NV	PC-RCMA (A)/14/Tech
14	MIG-27/29	PC-RCMA (F&F)/249/145
15	HPT-32 (Modified)	TA NO - 1348
16	SARAS	DGCA Capability register
17	ARJUN MBT	F/PMS/FBP 2600
18	HPT-32	TA NO-587
19	KIRAN INSULATOR	TA NO-983

20	**CHETAK/CHETAH**	**TA-1000**
21	**AVRO Rotor segment**	**PC-RCMA(KNP)/050/25/Tech**
23	**SEA KING**	**TA - 1001**
24	**MIG – 21 (BMS)**	**TA NO- 1216**
25	**MIG-21**	**TA NO- 1214**
26	**IJT/HJT**	**PC-RCMA (F&F)/247/145**
27	**KIRAN MARK-I**	**TA NO-1138**

*TA : Type Approval

*PC : Provisional Clearance

*CEMILAC: Centre for Military Airworthiness & Certification.

*RCMA : Regional Centre for Military Airworthiness.

CHAPTER: 12

JOINT SERVICES SPECIFICATIONS FOR AIRCRAFT BRAKEPAD

Numerous metallic and non- metallic materials are widely used in aviation industry. As Indian aviation industry began with production and overhaul of aircraft, engine and their associated systems under license agreement with collaborators, India was completely dependant on procurement of these articles, spares and systems from collaborators. In order to become a self – reliant, lot of emphasis has been laid down on indigenization. Now in India ab-initio projects like LCA, ALH, PTA etc. have also been successfully developed. A large number of varieties of materials have been indigenized equivalent to foreign specification through PSUs, DRDO Labs, and private firms all over the country.

In view of the above, CEMILAC has taken up task of the rationalization of various airborne stores through Aero Stores Standardization Sub Committee (Aero SSSC) under CCSSC, which in turn comprised eight working groups. Working Group of Aircraft Brake Pad is one among them. 7 Joint Services Specifications have been developed by this group over last five years. Table shows the JSS of different rubber compounds.

S. No.	JSS No.	DESCRIPTION	APPLICATIONS
1	JSS : 1630-01:2009	Metallic brake pad	Dornier and AN-32 Aircraft
2	JSS: 1630-03: 2009	Metallic brake pad	Cheetah/Chetak and Advanced Light Helicopter
3	JSS: 1630-05: 2009	Organic brake pad	Seaking Helicopter
4	JSS: 1630-06: 2009	Organic brake pad	Kiran MK I/IA
5	JSS: 1630-03: 2009	Organic brake pad	HPT -32
6	JSS: 1630-03: 2009	Metalloceramic Brake pad	Kiran Mk II
7	JSS: 1630-03: 2009	Metalloceramic brake pad	AVRO

Table12.1 Joint Services Specifications of Brake Pads

CHAPTER: 13

TYPES OF BRAKEPADS USED IN VARIOUS AIRCRAFT

13.1 AN-32 BRAKE PAD:

AN-32 ROTOR PAD   AN-32 STATOR PAD

Project	:	AN -32
Type	:	Iron Based
CEMILAC Type Approval No.	:	TA-1206

Characteristics

Max. Brake energy = 15 M Joules

Wear life = 250 Landings

13.2 JAGUAR BRAKE PAD:

JAGUAR BRAKE PAD JAGUAR INSULATOR PAD

Project	: JAGUAR
Type	: Iron Based and organic based
CEMILAC Approval No.	: TA-1341

Characteristics:

Max. Brake energy = 8 M Joules

Wear life = 250 Landings

13.3 BOEING BRAKE PAD:

BOEING BRAKE PAD

Project	:	Boeing 737-200
Type	:	Copper Based
CEMILAC Approval No.	:	TA-7-12/90-RD (DGCA)

Characteristics:

Max. Brake energy = 16 M Joules

Wear life = 600 Landings

13.4 CHETAK ORGANIC BRAKE PAD:

CHETAK ORGANIC BRAKE PAD

Project	:	Cheetah/Chetak
Part description	:	Clutch Brake Liner
Type	:	Organic Based
CEMILAC Approval No.	:	TA-066

Characteristics:

Max. Brake energy = 0.311 M Joules

Wear life = 150 Landings

13.5 <u>DC-8 BRAKE PAD:</u>

DC-8 BRAKE PAD

Project	: DC-8
Type	: Copper Based
CEMILAC Approval No.	: N409/CAB/MIN/TC/0075/2006
Characteristics:	

Max. Brake energy = 18 M Joules

Wear life = 250 Landings

13.6 <u>DORNIER BRAKE PAD:</u>

DORNIER BRAKE PAD

Project	: Dornier Do-228
Type	: Copper Based
CEMILAC Approval No.	: TA-845
Characteristics	:

Max. Brake energy = 2.6 M Joules

Wear life = 200 Landings

13.7 HJT-36 BRAKE PAD:

HJT-36 BRAKE PAD

Project	: HJT-36
Type	: Copper Based
Provisional Clearance No.	: PC-RCMA (F&F)/247/145

Characteristics

Max. Brake energy = 3.46 M Joules

Wear life = 100 Landing

13.8 HPT 32 BRAKE PAD

HPT 32 BRAKE PAD

HPT 32 LOCATING PAD

Project : HPT-32

Type : Organic Based

CEMILAC Approval No. : TA-1348

Characteristics:

Max. Brake energy = 0.6 M Joules

Wear life = 50 Landings

13.9 KIRAN MARKII BRAKE PAD:

KIRAN MKII PAD

Project : Kiran Mk-II

Type : Copper Based

CEMILAC Approval No. : TA-717

Characteristics

Max. Brake energy = 5.46 M Joules

Wear life = 250 Landings

13.10 <u>MIG 21 BRAKE PAD:</u>

MIG 21 MAIN BRAKE PAD   MIG 21 NOSE BRAKE PAD

Project	:	MiG-21
Type	:	Iron Based
CEMILAC Approval No.	:	TA-1214
Characteristics	:	

Max. Brake energy = 6 M Joules

Wear life = 200 Landings

13.11 MIG-21BIMETALLIC BRAKE PAD:

VARIOUS MIG 21BIMETALLIC BRAKE PADS

Project : MiG-21

Type : Bi-Metallic sectors

CEMILAC Approval No. : TA-1216

Characteristics:

Max. Brake energy = 6 M Joules

Wear life = 200 Landings

13.12 MIG 29 BRAKE PAD:

MIG 29 BRAKE PADS

Project	:	MiG-29
Type	:	Iron Based
CEMILAC Approval No.	:	PC-RCMA (F&F)/249/145

Characteristics

Max. Brake energy = 9 M Joules

Wear life = 250 Landing

13.13 MIG-27 BRAKE PAD:

VARIOUS MIG 27 BRAKE PADS

Project	:	MiG-27
Type	:	Iron Based
CEMILAC Approval No.	:	TA -1208

Characteristics

Max. Brake energy = 12 M Joules

Wear life = 250 Landings

13.14 <u>SARAS BRAKE PAD:</u>

SARAS BRAKE PADS

Project	:	Saras
Type	:	Copper Based
CEMILAC Approval No.	:	DGCA Capability register

Characteristics:

Max. Brake energy	=	6M Joules
Wear life	=	150 Landings

13.15 <u>SU-30 BRAKE PAD:</u>

SU-30 MKI BRAKE PADS

Project	:	Sukhoi-30 MKI
Type	:	Iron Based
CEMILAC Approval No.	:	TA- 1001
Characteristics	:	

Max. Brake energy = 15 M Joules

Wear life = 250 Landings

13.16 AVRO BRAKE PAD:

AVRO BRAKE PADS

Project	:	AVRO
Type	:	Copper Based
CEMILAC Approval No.	:	TA- 7-12/88/RD (DGCA)
Characteristics	:	

Max. Brake energy = 9.4 M Joules

Wear life = 500 Landings

13.17 ISLANDER BRAKE PAD:

ISLANDER BRAKE PADS

Project : Islander

Type : Organic Based

CEMILAC Approval No. : TA- 847

Characteristics:

Max. Brake energy = 0.4 M Joules

Wear life = 150 Landings

13.18 <u>Arjun Main Battle Tank PAD:</u>

ARJUN MBT BRAKE PADS

Project	:	ARJUN MBT
Type	:	Copper Based
CEMILAC Approval No.	:	F/PMS/FBP 2600
Characteristics	:	

Max. Brake energy = 6.5 M Joules

Wear life = 10,000 Kms

13.19 <u>KIRAN MKI BRAKE PAD:</u>

KIRAN MKI ORGANIC BRAKE PADS

Project : KIRAN MKI

Type : Organic Based

CEMILAC Approval No. : TA-1138

Characteristics

Max. Brake energy = 1.1 M Joules

Wear life = 100 Landings

13.20 <u>ALH-NV BRAKE PAD</u>:

ALH NV BRAKE PADS

Project : ALH-NV

Type : Copper Based

CEMILAC Approval No. : PC-RCMA (A)/14/Tech

Characteristics

Max. Brake energy = 13 M Joules

Wear life = 100Landings

HAL (BC)	PROVISIONAL TEST SCHEDULE AND TECHNICAL SPECIFICATION	T.S. No. F/PMS/FPM 5842 Issue: 02 Date of Issue: 11-12-2009 Page 1 of 13

TEST SCHEDULE AND TECHNICAL SPECIFICATION FOR EVALUATION AND ACCEPTANCE OF INDIGENOUS METAL-CERAMIC SECTOR,PART NUMBER HFKT89-81-1M,OF MIG-21 AIRCRAFT MAIN WHEEL BRAKE MADE AT FOUNDRY & FORGE DIVISION,HAL,BANGALORE

02	Part no is changed from KT-89-81-1M To HF KT89-81-1M for differentiate HAL-F&F pads from HAL-hyd pads	12/12/09	12/12/09	06/Jan/2010
01	Original	YAJNAPAL (ENGINEER)	V.N.ANIL KUMAR (CM-BRAKEPADS)	Dr. P. RAGOTHAMA RAO RD-RCMA(F&F)
Issue	Reason for issue Change	PREPARED & CHECKED BY	ISSUED BY	APPROVED BY
		FOUNDRY AND FORGE DIVISION, HAL (BC)		RCMA

SUBMITTED TO
RCMA-F&F
CEMILAC
BANGALORE
FOUNDRY AND FORGE DIVISION
HINDUSTAN AERONAUTICS LIMITED
BANGALORE COMPLEX
BANGALORE 560 017

PREAMBLE AND BACKGROUND

The metal-ceramic sector KT-89-81-1M of the main wheel brake KT92B of the MiG-21 aircraft was indigenously developed by M/s DMRL Hyderabad about 25 years back .The manufacturing of these sectors as per the DMRL process was taken up by M/s HAL Hyderabad. These sectors were qualified as per the test schedule no TS/IND/40/03 dated 25/9/90 and type approved by CRE (Hyderabad) vide AE
RO/RD-132/106/3 dated 06/04/94 and type approval no TA-664.

By 2004-2008 order for these sectors decreased considerably. During that time, HAL-Hyderabad took a decision to stop manufacturing activities of these brake sectors as the division was concentration on its core area i.e. electronics. In view of this, in order to meet the IAF's continued & renewed demand, HAL-Lucknow asked HAL F&F to manufacture these sectors in their Brakepad shop vide indent no. HAL-ADL/MIG/451/08 dated 04-06-2008 for qty of 10000 nos (copy enclosed).

This Type test schedule is prepared for testing and qualification of the above mentioned sector developed and manufactured at Foundry and Forge Division, HAL. In order to maintain consistency in the type testing and qualification parameters, the current test schedule has been prepared in line with the earlier test schedule TS/IND/40/03.Some minor changes and improvements like changing the MgO powder with Asbestos powder and use of Nickel Sulphamate bath for Nickel plating on the back plate instead of Nickel spraying are incorporated. These changes are based on updated knowledge and experience gained over the last 30 years in the development of various Iron based friction materials for a number of aircraft.

Applicable Documents

1. Test Schedule No TS/IND/40/03
2. Amendments
   a. Amendment to test schedule no TS/IND/40/3(copy enclosed)
   b. Renewal of Type approval CRE(HD)/762 dated:17/06/1995 and HAL/HD/Q/CPP/03 dated:05/05/2003(copy enclosed)
3. Russian Drawing No.KT89-81-M
4. HAL-Hyderabad Drawing Nos. BN 303504 & A 303505
5. Type approval NoTA-664(copy enclosed)
6. Standard & Specifications to be followed for various tests
   a) Back plate steels for the metal-ceramic sectors as per IS: 1570 (Part II), 1979 Gr. 20C8 (C20)
   b) Chemical composition of friction material as per FMK-11
   c) Bend test for assessing bond quality for metal-ceramic sectors as per BS.1639-1964.
   d) Chemical analysis of the various raw materials and that of the friction material of

PART-I

This part deals with the technical specification of various raw materials used for making the metal-ceramic sectors. The identification and marking of the sectors have also been stipulated. The suggested sources of various raw materials have also been indicated.

1.1 TECHNICAL SPECIFICATION OF RAW MATERIALS

1.1.1 Steel Strip for back plate

The steel material for the back plate of the metal-ceramic sector shall be in cold rolled and annealed condition and shall conform to the specification and technical requirements given bellow:-

a) **Specification** : **IS:1570(Part-II),1979 Gr.20C8(C-20)**

b) **Chemistry(%)** : **Carbon : 0.15-0.25%**
Manganese : 0.60-0.90%

c) **Condition of Supply : Cold rolled and annealed**

d) **Hardness** **229 BHN, max**

e) **Dimensions:**

Thickness **2.0(±0.1) mm**

Width **60(+1) mm**

Length **1500 to 3000 Meter**

Note:

1. A copy of IS: 1570 (Part-II), 1979 is enclosed.
2. Acceptance has to be verified for every consignment received during the manufacturing process.

1.1.2 Iron Powder:

Used as a basic ingredient of the friction material for the metal-ceramic sector, shall conform to the following technical specification:

Grade	:	Sponge or Electrolytic
Purity	:	99% minimum
Size distribution	:	95% (-100) BS Mesh
Hydrogen Loss	:	1% Maximum
Apparent Density	:	2.3-3.5 gms/cc

1.1.3 Copper Powder:

Used as an ingredient of the friction material for the metal-ceramic sector, shall Conform to the following technical specification

Grade	:	Electrolytic
Purity	:	99.0% minimum
Hydrogen (H_2) Loss	:	1% maximum
Size Distribution	:	90% (-250) BS Mesh
Apparent Density	:	1.3 to 2.4 gms/cc

1.1.4 Barium Sulphate Powder:

Used as an ingredient of the friction material for the metal-ceramic sector, shall conform to the following technical specification:

Purity ($BaSO_4$ Content)	:	98.0% minimum
Other inorganic	:	2% maximum
Particle Size	:	95%(-250) BS Mesh
Apparent Density	:	0.60gms/cc

1.1.5 Graphite Powder:

Used as an ingredient of the friction material for the metal-ceramic sector, shall conform to the following technical specification:

Grade	:	Fine natural flaky graphite powder
Carbon Content	:	94% minimum
Ash Content	:	4% maximum
Volatile matter	:	2% maximum
Size distribution	:	(-100) BS Mesh

1.1.6 Silica Sand Powder:

Used as an ingredient of the friction material for the metal-ceramic sector, shall conform to the following technical specification:

Purity as SiO_2 content : 90% minimum.
Loss on Ignition : 1% maximum.
Size (Sieve Analysis) : (-60+100) BS Mesh

1.1.7 Asbestos Powder:

Used as an ingredient of the friction material for the metal-ceramic sector, shall conform to the following technical specification:

Loss on drying : 1% Maximum.
Acid soluble (5% HCL) : 10% Maximum.
Size Distribution : (-40+150) BS Mesh

1.2. SOURCES OF SUPPLY OF RAW MATERIALS FOR METAL-CERAMIC SECTORS

1.2.1 Steel Strips

1. M/s Tube Investments of India Ltd.
   Post Box No.4, MTH Road Avadi,
   Chennai-600054

2. M/s Jainex Ltd.
   159/2,S.P.Road
   Bangalore-560002

3. M/s INDO ISPAT.
   76-D, Harish Chatterjee Street,
   Opp. Harish Park, Bhawani Pura,
   Kolkatta-700025

4. M/s Star Wire India Ltd
   21/4, Mathur Road,
   Ballabgarh
   Harayana-121004

5. M/s D.S. Enterprises
   No 29,5th Cross, Srirampuram,
   Bangalore-560021

NOTE:-The copy of Original Mill certificate/test certificate of the manufactured batch has to be supplied to HAL-F&F along with each consignment.

1.2.2 Iron Powder

1. M/s Hoganas India Ltd.
   Ganga Commerce,
   4 North Main Road,
   Koregaon Park,
   Pune-411001.

1.2.3 Copper Powder

1. M/s Metal Powder Co. Ltd.
   Maravankulam, Thirumangalam,
   Maravankulam- 625706.

2. M/s Metalloys,
   No.9, Martiers Dias Road,
   Margo, Goa- 403601.

3. M/s Kandoi Metal Powder.
   F-381& 382, Road,
   No.9, Vishwakarma industrial Area,
   Jaipur-302013.

1.2.4 Natural Graphite Powder

1. M/s JMM International INC.
   28, Moleod Street,
   Post Box No.16016
   Kolkata-700017.

2. M/s Sharda Enterprises.
   Piyu incorporation "PIYU" BGLW,
   Plot No.265-285 RSC-33,
   Mumbai-400091.

3. M/s Oxeeco Technologies.
   B-6/4, Industrial Development Area,
   Uppal, Hyderabad-560017.

4. M/s Graphite India.
   Speciality Division, Visveswarya,
   Industrial Area, White field Road,
   Bangalore-560048.

1.2.5 Silica Sand Powder

1. M/s Oswal Mineral
   No.6, 2nd Main Road,
   Ramacharapuram,
   Bangalore-560021.

2. M/s Universal fused quartz.
   MSR Industrial Estate
   Gokula Markets.
   Bangalore-560022.

3. M/s Karnataka Minerals& Refractor.
   No.68, Industrial Estate,
   Suburb, Yeshwanthpura.
   Bangalore-560022.

4. M/s Metal Powder Ltd
   Pudunagar Post.
   Thirumangalam,
   Madurai-560002.

5. M/s Sapthagiri Tech Mark system.
   744 12th main, 3rd Block.
   RajajiNagar.
   Bangalore-560037.

1.2.6 Barium Sulphate powder

1. M/s ACE Rasayan.
   18/8 5th main road, Jayadeva Hostel,
   P.O.No.9738, GandiNagar,
   Bangalore-560009.
2. M/s Eskay Forms.
   No.46, 2nd main,
   Vidyaranya Nagar, Magadi Road,
   Bangalore-560001.
3. M/s Ranbaxy Fine Chemicals Ltd.
   No.86, 3rd Cross new timber yard Layout,
   Mysore Road.
   Bangalore-560026.
4. M/s SD fine Chemicals.
   No.62, Laxman Rao Road,
   BVK Iyenger Road,
   Bangalore-560004
5. M/s UltraLab Products.
   No.433, 14th Cross, Lakkasandra.
   Bangalore-560068.

1.2.7 Asbestos Powder

1. M/s Union Asbestos & Allied Products.
   No.40, Strand Road, Shop No.51,
   Kolkata-700001.
2. M/s AMCON surface Tech.
   83/3, Saitpalya, Lingarajapuram
   Bangalore-560084.
3. M/s Divya Enterprises,
   No.143, Vivekananda Nagar BSKIII,
   ST Age, Bangalore-560085.
4. M/s Supreme Minerals.
   1584/2, B.M Road.
   Channapatna-571501.
5. M/s Shyam Industries
   No.42, Hongasandra Begur Road
   Bangalore-560002

1.3 IDENTIFICATION AND MARKING

All the metal-ceramic sectors shall be suitably identified at the back of the back Plate with batch/ mix number and place of manufacture and relevant part number

PART-II

This part of the test schedule lays down the various physical, metallurgical and mechanical tests to be carried out on individual sectors or on sample quantity of parts per batch. The sampling procedure for the various tests is also stipulated. This part also gives the various testing standards/ specifications to be followed for carrying out the tests.

2.1 Dimensions: Dimensions of the finish machined metal-ceramic sectors are to be checked with the drawing no. FPM- 5842, HFKT89-81-1M of HAL (F&F). An A4 size drawing of the brake pad is enclosed in annexure I.

2.2 Surface condition: The working friction material surface of all the finish-machined metal-ceramic sectors shall be inspected visually for uniform texture and absence of cracks, dents and peelings.

2.3 Hardness: Hardness test shall be carried out on 3 fully machined working surface of the metal-ceramic sectors per batch. Each batch of metal-ceramic sectors shall not exceed 200 nos. Hardness shall be measured on the friction material working surface on five points per sector distributed over the entire surface and on three points on the back plate using a Brinnel hardness tester with 10 Kg load (30 Kg for back plate) and 1 mm dia ball indenter. The hardness measured shall meet the requirement of minimum/maximum values given below:

Part No.	Minimum Hardness (BHN) of friction material	Maximum Hardness back plate (BHN)
HFKT89-81-1M	90*	229

NOTE:* Hardness on friction material shall not be less than 90 BHN at a minimum of 4 points and not less than 70 BHN at a maximum of one point. The hardness shall be measured at least 3mm away from the edges of the sector and the rivet holes. The distance between two indentations shall also be a minimum of 3 mm.

2.4 Microstructure:

A. Friction Material: The microstructure of the metal-ceramic sectors shall be examined on a cut and polished longitudinal section of the metal-ceramic sectors at 100X. Micro examination shall reveal uniform distribution of constituents such as silica particles and graphite in an iron-rich matrix. On etching, the matrix shall reveal a predominantly Pearlitic structure.

B. Interfacial Thickness: Below the friction lining there shall be evidence of sound interfacial bonding between the steel back plate and the friction material through an intermediate Nickel-plated layer. At the Nickel-steel interface there should not be any evidence of copper metal flow. Thickness of the Nickel-plated layer shall be within 0.05 to 0.20 mm.

C. Back Plate: The back plate structure shall reveal a ferrite and Pearlitic structure.

2.5 Chemical Composition:

The friction material of the metal-ceramic sectors shall be checked ~~by~~ classical analytical techniques. The removal of friction material shall be done carefully so as to avoid contamination from the steel back plate. A representative sample shall be made by coining and quartering a thorough mix of friction material taken from 3 brake sectors randomly selected per batch. Each batch of metal-ceramic sectors shall not exceed 200

2.6 Bend Test:

2.6.1 One sample per sintering batch(Each batch of metal-ceramic sectors shall not exceed 200 nos) of the drawn randomly from the bottom of the stacks of sectors shall be subjected to bend test to asses the quality of the bond between back plate and friction lining. Bend test for assessing bond quality for metal-ceramic sectors as per BS.1639-1964.

2.6.2 The bend test fixture shown in the Annexure-B shall be used for testing.

2.6.3 The specimen shall be placed on the fixed rollers with the ceramic layer facing down. The pressing punch shall be placed centrally on the test piece. Pressure shall be applied on the pressing roll using a press to bend the sample to approximately 120^0

2.6.4 Observe broken ceramic layer. Friction layer could break away but steel surface shall not be exposed in the interface. Steel surface shall have a continuous layer of ceramic material sticking on to the steel.

2.6.5 Exposure of steel surface is indication of poor bonding and failure in the bend test.

2.7 Friction Test:

Two sectors selected out of every batch of metal-ceramic sectors shall be tested in the friction testing machine at Foundry & Forge Division for friction and wear properties. Two sectors shall be riveted to the holder of the machine and these samples are to be tested under conditions given below. The test shall be done only on fully machined sectors. 50 braking stops shall be carried out and considered for measurements of friction and wear. The parameters given below in the table are to be maintained for the test.

Kinetic Energy(Kgfm)	16670*
Inertia of fly Wheel(kgm^2)	3.15
RPM of flywheel	984
Brake Force(kgf)	100

(* **The total energy of the KT 92B brake is 6 x 10^5 Kgfm was used in the brake dynamometer test in the previous T.S.No. TS/IND/40/03. The brake unit consists of 72 metal-ceramic sectors. Therefore the energy absorbed by 2 sectors is 16670 Kgfm**)

During the test the following parameters are to be observed and recorded

a) Coefficient of friction (maxm, min, and average).

b) Wear by thickness loss and weight loss measurements after 50 stops

c) Run-down time (Seconds).

d) Run-down revolutions

e) Brake temperature rise (deg c)

The values of stop time, temperature rise etc., shall be in the following range. (**These values have been fixed based on statistical analysis of the actual results of 3 sets of HAL-Hyderabad sectors vide Batch Nos: PM08HYD03 dated30/8/08, PM08HYD04 dated 30/8/08, PM08HYD05 dated 1/9/08 reports enclosed).**

1	Average Coeffient of friction	0.20-0.35
2	Run down Time(Second)	13-21 Seconds (Avg)
	Minimum	11 Seconds
	Maximum	24 Seconds
3	Average Run-down revolutions	125-140
4	Wear by thickness loss after 50 stops	2mm nominal
5	Wear by weight loss after 50 stops	30 gms
6	Brake Temperature(deg C)	150 Deg C Max

NOTE:

1. Maximum brake temperature rise may be measured only for development Batches and the first 10 production batches. Once the maximum temperature Values are stabilized in the above batches, temperature measurement on Further production batches may be discontinued.

2. The acceptance criteria may be reviewed after study of the first 100 production batches.

2.8 Sampling procedure: The metal-ceramic sectors shall be batch manufactured. A batch shall consist of not more than 200 metal-ceramic sectors sintered in the same cycle of pressure sintering operation. The various tests, on any batch of sectors, shall be carried out as per the following sampling plan:

a) Dimensions	100 %
b) Surface condition	100%
c) Chemical analysis	3 sectors per batch (Sectors used for bend test can be used for chemical analysis)
d) Hardness	3 sectors per batch
e) Microstructure	1 sector per batch
f) Bend test	1 sectors per batch
g) Friction test	2 sectors per batch

2.9 Further to these qualification the pads will be supplied to HAL-ADL, for further full-scale Dynamometer test and Aircraft trial test as per the Test schedule prepared by Design/ Indigenization department of HAL-ADL.

HAL F&F will involve in the full scale dynamometer test.

PART-III

3.0 PRESERVATION, PACKING AND DELIVERY

3.1 The brake pads shall be protected from atmospheric corrosion by applying an uniform coating of resin based cellulose nitrate varnish mixed with a Post office red dye for friction surface and Aluminum paste as per BS.388:1964 for all back plate surface.

3.2 Every batch of pads shall be accompanied by a test certificate furnishing details of the batch and test results on the batch duly certified by the representative of the Quality Control Department, Foundry and Forge Division, HAL the metal-ceramic/bimetallic sectors shall be carried out as per classical analytical techniques.

e) The apparent density of the metal powders shall be determined using a hall flow-meter apparatus as per ASTM B212 any other mutually acceptable standard test method.

f) Sieve analysis of metal powders shall be carried out as per ASTM B 214

g) Hydrogen loss test for copper and iron powders shall be carried out as per ASTM E 159-63T.

h) Batch consistency friction test is carried out in lab scale friction test rig on 2 pads on prorata energy credit requirements.

i) Full scale dynamometer test will be repeated at ARDC ground test dynamometer facility.

TEST SCHEDULE

FOR

DYNAMOMETER TESTING OF METAL-CERAMIC SECTOR PNO. HF-KT89-81-1M FOR USE IN MAIN WHEEL ASSY. PNO. KT-92B AND KT-92D OF MIG-21 AND MIG-21 BIS A/C

TEST SCHEDULE NO: TS/NDC/033/DC/W&B/KT-92D

ISSUE – A

Compiled by Indg. Cell	Checked by (Indg. Cell)	Concurred by (Design)	Approved by (RCMA)	Approval Date
S. E. [illegible]	[illegible]	[illegible]	[illegible]	24-12-2009

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TEST SCHEDULE NO.: *TS/IND/033/DC/WSB/K7-93D*

ISSUE NO- A

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8	1

Compiled by (Indg. Cell)	Checked by (Indg. Cell)	Concurred by (Design)	Approved by (RCMA)	Approval Date
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Revision / Issue Record

Document Name: Test Schedule

Document No.: TS/IND/033/DC/W&B/KT-92D

Revised Issue No.	Page No.	Para No.	Description of Amendment/ Change	Date	Revised By (HAL, Lucknow)	Approved By (RCMA, Lucknow)

Compiled by (Indg. Cell)	Checked by (Indg. Cell)	Concurred by (Design)	Approved by (RCMA)	Approval Date
				21-12-2009

1.0 INTRODUCTION:

The Metal Ceramic Sector P/no. KT89-81-1M had earlier been developed by HAL, Avionics Division, Hyderabad. Now Avionics Division Hyderabad has stopped the manufacture of the Powder Metallurgy (PM) based items due to closure of its PM shop. Therefore the supply of the Metal Ceramic Sector P/no. KT89-81-1M has also been stopped from Avionics Division, Hyderabad. As the sector is still required for production & ROH task as well for supply to Indian Air Force against RWSC, it has been taken up for development at F&F Division, Bangalore. As there is a change of manufacturing location, a separate Type Approval is required for the sector developed by F&F Division for use on Main Wheel Assy. P/no KT92B and KT92D of Mig-21 & Mig-21 Bis aircraft. The corresponding p/n for HAL(F&F) Ceramic Sector is HF-KT89-81-1M.

The Metal Ceramic Sector P/no. KT89-81-1M, are being used on Main Wheel Assy. P/no. KT-92B and KT-92D of MIG-21 and MIG-21 BIS a/c respectively. Main Wheel Assy. P/no. KT-92B and KT-92D are similar in design and consist mainly of the same components. However, a slight structural difference exists in the above two wheels e.g. the number of discs has been increased in KT-92D (Ref: Overhaul Manual No. MIG80/OH/2 F). The comparison of leading particulars are :

S. No	Requirements	KT-92B (Ref : GTY2B6-15)	KT-92D (Ref : KT-92D-OOOOTY)
1.	Static Load	2820 kg	3130 kg
2.	Inflation Pressure	8.0 [illegible] kg/cm²	9.5 [illegible] kg/cm²
3.	Kinetic Energy	600000 kg-m	685000 kg-m
4.	Brake operating Pressure	18.0 [illegible] kg/cm²	18.0 [illegible] kg/cm²

Since kinetic energy absorbed by wheel assembly KT-92D is higher than the kinetic energy absorbed by wheel assembly KT-92B and the brake operating pressures for both are same. Therefore, KT-92D wheel assembly which has higher energy absorption than KT-92B wheel assembly is selected for dynamic energy test.

2.0 OBJECTIVE:

This test schedule is drawn for Dynamic Test on Dynamometer Test Rig of the Metal Ceramic Sector P/no. HF-KT89-81-1M developed by HAL, Foundry & Forge (F&F) Division, Bangalore and

S. K. Patel (signature)	(signature)	(signature)	D. K. (signature)	21-12-2009
Compiled by (Indg. Cell)	Checked by (Indg. Cell)	Concurred by (Design)	Approved by (RCMA)	Approval Date

the sector developed by HAL, Avionics Division, Hyderabad. Based on the comparative analysis of the test results obtained, the sector developed by F&F Division will be cleared for use in Main Wheel Assy. P/no. KT92B and KT-92D of MiG-21 & MiG21 BIS A/c.

To carry out the test, one certified Main Wheel Assy. P/no. KT-92D with tyre and one ... Brake Assy. P/no. KT92D.020 shall be taken from Mechanical Factory, HAL Lucknow. Out of these two assy., one has to be fitted with the sectors developed by Avionics Division, Hyderabad and the other has to be fitted with the sectors developed by F&F Division, Bangalore and mark letter 'A' & 'B' respectively on both assemblies for comparison purpose and thereafter clearance / approval of sectors developed by F&F Division.

3.0 **PREPARATION OF UNITS:**

One Brake Assy. (Mark letter 'A') will be fitted with the sectors developed by Avionics Division, Hyderabad and other Brake will be fitted with the sectors developed by F&F Division, (Mark letter 'B') as per existing technology in Mechanical Factory, HAL, Lucknow.

Identify stator and rotor faces as per para 5.1.1 and take measurement as para 5.1.2 before Assembly and Acceptance Test.

The Part number, Issue number, Serial number and identification letter on both assemblies shall be recorded.

4.0 **VENUE OF TEST: HAL-ADL**

The unit marked 'A' & 'B' should be subjected to acceptance tests as per Test Sheet attached at Appendix-I derived from Overhaul Manual of KT 92D (Ref: Overhaul Manual No. MO30/OH/2 F).

5.0 **DYNAMIC TESTS:**

The units fitted with Metal Ceramic Sector of Avionics Division, Hyderabad & Metal Ceramic Sector of F&F Division, Bangalore should be subjected to Dynamometer test at Dynamometer Test Rigs situated at ARDC Bangalore.

5.1 Test Method:

5.1.1 Identify stator faces as S/11, S/12, S/21, S/22, S/31, and S/32 from torque plate side. Similarly, Identify rotor faces as R/11, R/12, R/21, R/22, R/31, R/32, R/41 and R/42 from torque plate side.

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[signature] 24/12/09 (S. K. Pandey) for ...	[signature]	[signature]	[signature]	21-12-2009

5.1.2 Measure weight and thickness of each disc. Thickness shall be measured at four places and the average shall be recorded. Thickness and weight of each disc shall be recorded with [illegible] sub-assembly. Visually examine the conditions of stators and rotors and record the actual condition.

5.1.3 Mount thermo-couples on the [illegible] of pressure stator.

5.1.4 Following dynamic stops are to be carried out:

Normal Energy Stop	(6.62 MJ)	:	50
RTO Energy Stop	(7.66 MJ)	:	01

5.1.5 During the course of 50 energy stops, one change of heat pack is permitted. The remainder of brake assembly parts must withstand this test sequence.

5.1.6 It is permitted to replace tyre if its physical condition deteriorates to such an extent that it cannot take further dynamometer stops. Record tyre change at such stage.

5.1.7 Following parameters shall be recorded for each stop:

a. Ambient Temperature.
b. Initial temperature of stators (not to exceed 50°C).
c. Brake application speed.
d. Brake application pressure Vs time
e. Run down revolutions/stop distance
f. Stop time
g. Torque Vs time plot, peak & average torque values
h. Average brake drag value
i. Kinetic Energy absorbed
j. Co-efficient of friction μ (calculated)

5.1.8 Brake must be cooled to 50°C before next brake application. It is allowed to force cool the brake once the peak temperature has been recorded.

5.1.9 Mount the wheel & brake unit on the 2.53 meter drum of the ARDC dynamometer with help of suitable fixture.

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5.2 Bedding In Stops:

5.2.1 With wheel A brake mounted as at para 5.1.6, carry out 3 bedding-in stops with following parameters:

	Drum RPM	Brake pressure
Bedding in stop #1	180	03 bars
Bedding in stop #2	360	05 bars
Bedding in stop #3	540	07 bars

If bedding-in is not satisfactory, few more stops at 540 rpm/07 bars shall be carried out.

5.2.2 Repeat measurements as per para 5.1.2

5.3 Normal Energy Stops:

5.3.1 Mount Wheel & Brake assy 'A' as per para 5.1.6. Carry out 10 energy stops as per following data:

Test Item	:	Brake Assy. Part No. [illegible]
Associated Wheel Part No.	:	KT020.010
Radial Load On Wheel	:	3120 kg
Inflation Pressure	:	8.50$^{+0.0}$ Kg/cm^2
Brake Operating Fluid	:	Air
Drum Diameter (M)	:	2.63
Kinetic Energy	:	6.82 MJ
Drum RPM	:	576
Brake Application Speed	:	275 Km/h
Brake Pressure (Bars)	:	*0.0 Bars
Stop Time (Secs)		28.0 sec
Stop Distance (M)		905 m
Av. Brake Drag (Kg)	:	600 kg

* The brake pressure can be trimmed to achieve the stop time. Test data as per para 5.1.7 shall be recorded for each stop. After completion of 10 stops, repeat measurements as per para 5.1.2.

5.3.2 With Para 5.3.1, carry out 10 energy stops on Wheels & Brakes Assy 'B'

5.3.3 With para 5.2.1 to 5.3.2 on sequence, carry out total five such sequences

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5.4 RTO ENERGY STOP

5.4.1 After completion of fifth block of normal energy stops on both Wheel & Brake assy., carry out 01 energy stop only on Wheel & Brake assy. marked "3" as per following data:

Test Item	:	Brake Assy. Part No. KT92D.020
Associated Wheel Part No.	:	KT92D.010
Radial Load On Wheel	:	3130 kg
Inflation Pressure	:	9.50$^{+0.5}$ Kg/cm^2
Brake Operating Fluid	:	Air
Drum Diameter (M)	:	2.53
Kinetic Energy	:	7.65 MJ
Drum RPM	:	836
Brake Application Speed	:	302.40 Km/h
Brake Pressure (Bars)	:	*18.34 Bars
Stop Time (Secs)	:	34.0 sec
Stop Distance (M)	:	1438.0 m
Av. Brake Drag (Kg)	:	605 kg

*The brake pressure can be trimmed to achieve the stop time.

5.4.2 After completion of the RTO stops, repeat measurements as per para 5.1.2.

6.0 ACCEPTANCE CRITERIA:

Performance of Sectors developed by F&F Division, Bangalore shall be compared with the sectors developed by Avionics Division Hyderabad on the basis of following observations and/or wear pattern or data recorded during testing:

1. Comparative study of sectors wear pattern
2. General brake performance parameters

A detailed report giving comparative statements between sectors developed by F&F Division, Bangalore and sectors developed by Avionics Division, to be compiled and submitted to RCMA, Lucknow.

Based on the above report, Metal Ceramic Sector Pno. HF KT93.01.1M developed by F&F Division, Bangalore shall be considered for clearance for use in Main Wheel Assy. Pno.KT92B and KT-92D of MIG-21 & MIG21 B-S A/c.

(signature) S.K. Tamse Sr. Manager (Indg)	(signature)	(signature)	(signature) C.B. Singh	21-12-2009
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Appendix I

TEST SHEET

1.	Name of Unit:
2.	Part No.
3.	S/N
4.	Identification Letter:
5.	Test Schedule No.:

Sl No.	Description	Requirement	Actual Reading
1.	Check brake seals for tightness by applying pressure of 20 $kg\,cm^{-2}$ and carry out 20 cycles by applying & releasing of pressure.	No leakage is allowed	
2.	With no pressure applied, check the brake clearance between the pressure disk and disk assembly.	Not less than 2.0 mm	
3	Check pressure required for clamping Check clearance between the middle zone of the sectors and pressure plate by feeler guage.	Does not exceed 5.0 kg/cm^2 Must not exceed 1.1 mm.	
4.	Check brake for air tightness by applying pressure of 25 kg/cm^2 for 10 minutes.	No leakage is allowed	

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REPORT No. :	TR/29/LDG/2711	Copy No. :

AIRCRAFT TAXI TRIALS CONDUCTED ON MAIN WHEEL BRAKE ASSEMBLY P/N KT163A OF MiG-27 A/C, FITTED WITH INDIGENOUSLY DEVELOPED BRAKE PAD SECTORS (P/N : HF KT163-070CB, HF KT163-090CB, HF KT163-110CB & HF KT163-120CB)

PREPARED BY	AURDC, HAL(NASIK)	P. PARAMESHWARAN MANAGER(D)	
CHECKED BY		S.V.MATE CH. MANAGER(D)	
COORDINATED BY	ASERDC, HAL(LD)	D.MUKHERJEE DY. MANAGER(D)	
	F&F, HAL(BC)	D.DUTTA CH. MANAGER(DEV)	
APPROVED BY	AURDC, HAL(NASIK)	M.S.HADGIR AGM(DESIGN)	
COORDINATED BY	DGAQA(NASIK)	Y.K. SHARMA SSO-I	
COORDINATED BY	RCMA(NASIK)	S.S. KALE SCIENTIST 'C'	

AIRCRAFT UPGRADE RESEARCH & DESIGN CENTRE
HINDUSTAN AERONAUTICS LIMITED
NASIK DIVISION
NASIK 422 207

TEST REPORT ON AIRCRAFT TAXI TRIALS CONDUCTED ON MAIN WHEEL BRAKE ASSEMBLY, P/N KT163A OF MiG-27 A/C, FITTED WITH INDIGENOUSLY DEVELOPED BRAKE PAD SECTORS (P/N : HF KT 163-070CB, HF KT163-090CB, HF KT 163-110CB AND HF KT163-120CB)

1.0 INTRODUCTION AND BACKGROUND

Brake pad sectors of the main wheel brake p/n KT163A of MiG-27 aircraft have been indigenously developed at the Foundry & Forge Division, HAL- Bangalore. The main wheel brake comprises of four different types of brake pad sectors, which have been indigenously developed, v.i.z..

Metalloceramic Sector	:- HF KT163-090CB
Bimetallic Sector	:- HF KT163-070CB
Bimetallic Sector	:- HF KT163-110CB
Bimetallic Sector	:- HF KT163-120CB

Prototype batches of all the above brake pad sectors were qualification tested for metallurgical properties and material characteristics in accordance with test schedule and technical specification no. F/PMS/FBP800 dated 31-12-98. These batches were then cleared by RCMA (F&F) for the next stage of qualification testing, v.i.z., simulated performance testing by static torque test and brake dynamometer tests. The prototype pads were assembled on main wheel brake units by HAL (Lucknow Division) and were then subjected to maximum static torque test at ASERDC, HAL(LD) and brake dynamometer tests at ARDC, HAL- Bangalore in accordance with test schedule no. TTS/KT163A/001 dated 4-2-1998 issued by ASERDC, HAL(LD). These tests were conducted and coordinated by ASERDC, HAL (LD) and ARDC, HAL (BC). A report on the static torque test and dynamometer tests has been prepared and issued by ASERDC, HAL (LD) vide HAL-LD/D/WB/MiG27/001 dated 15-4-99.

On successful completion of the above tests, RCMA (Accessories) accorded clearance to the indigenous pads to undergo the next stage of qualification testing, by aircraft taxi trials, vide letter no RTO (L)/411/1/Tech/188 dated 14-5-99. The test schedule TS/IND/LDG/2701 dated 19-5-99 for conduct of the aircraft taxi trials was prepared and issued by AURDC, HAL (Nasik Division) and approved by RCMA (Nasik). The test schedule is revised to issue 1 during the trials. The present aircraft taxi trials for qualification of the indigenous brake pads have been carried out in accordance with the revised test schedule .

2.0 AUTHORITY FOR CONDUCTING THE AIRCRAFT TAXI TRIALS

The following are the clearances accorded by the Airworthiness authorities for conduct of the aircraft trials on indigenous brake pads :-

i) RCMA (Accessories) letter no. RTO(L)/411/1/Tech/188 dated 14th May'99 according clearance for conducting aircraft taxi trials on KT163A main wheel brake assembly of MiG-27 aircraft fitted with indigenous brake pad sectors. Also letter no. RTO(L)/411/1/Tech dated 8th Oct'99 providing clarification/amendment of the above letter. (Both letters placed at appendix – IA).

ii) Batch clearance of the prototype indigenous brake pad sectors by RCMA (F&F) for aircraft trials vide RCMA (F&F) / 340 /1 dated 7-7-99 (placed at appendix – IB).

3.0 TRIAL AIRCRAFT AND TEST WHEEL BRAKE SPECIMENS

3.1 The trial aircraft allotted for the taxi trials by AHQ (vide telex message dated 4.10.99 copy enclosed at appendix - IC) was a HAL manufactured MiG-27 aircraft no. TS 584. Trials on this aircraft were carried out for SET-1 and SET-2 brake discs.

3.2 For the trial on Russian brake pads, the trial aircraft allotted was TS 527 vide authority letter enclosed at appendix IC . The Certificates of Flight Safety are enclosed at appendix ID .

3.3 The following main wheel brake assemblies fitted with indigenous and Russian origin brake pad sectors were used as test specimens :-

Sl. No.	Configuration of Assembly	Sl. No. of RH wheel brake assembly p/n KT163A -1	Sl. No. of LH wheel brake assembly p/n KT163A -2
a)	Fitted with SET-1 brake discs (mix of indigenous and Russian brake discs) as per test schedule TS/IND/LDG/2701	306315	707462
b)	Fitted with SET-2 brake discs (fully indigenous brake discs) as per AML-2 of test schedule TS/IND/ LDG/2701	-Do-	-Do-
c)	Fitted with fully Russian origin new brake discs as per issue 1 of test schedule TS/IND/LDG/2701	406845	-Do-

4.0 TEST SCHEDULE AND APPLICABLE DOCUMENTS

4.1 Test schedule no.TS/IND/LDG/2701 dated 19-5-99 issued by AURDC,HAL (Nasik). (Enclosed at appendix II A)
4.2 Amendment 1 to test schedule no TS/IND/LDG/2701 vides AML-1 dated 11-10-99. (Enclosed at appendix II B)
4.3 Amendment 2 to test schedule no TS/IND/LDG/2701 vides AML-2 dated 29-10-99. (Enclosed at appendix II C)
4.4 Test schedule no. TS/IND/LDG/2701 issue 1 dated 16.12.99. (Enclosed at appendix II D)
4.5 Extract of maintenance manual for main wheel and brake assembly p/n KT163A of MiG-27 aircraft. (Enclosed at appendix II E).

5.0 BRIEF DESCRIPTION AND COMMENTS ON THE TEST SCHEDULE AND ITS AMENDMENTS

5.1 The test schedule no TS/IND/LDG/2701 dated 19.5.99 originally issued, comprised of one low speed taxi stop at 50 Kmph (for the purpose of "bedding-in" of the brakes) followed by one high speed taxi stop at 150 Kmph with 2000 litres of fuel and then another stop at the same 150 Kmph speed with full internal fuel. These taxi stops were to be followed by a normal landing and brake application. Strip examination of the brake pads was called for after each stop at 150 Kmph and after the landing stop. The above trials were to be carried out on set-1 brake discs (i.e., both LH and RH main wheel brake units assembled with 50:50 mix of Russian origin and indigenous brake discs) and then repeated on set-2 brake discs (i.e., both LH and RH main wheel brake units assembled with fully indigenous brake discs).

5.2 The above test schedule was amended just prior to the commencement of the tests to include one additional low speed taxi stop at 50 Kmph for more effective "bedding-in" of the brakes prior to conducting the high speed taxi stops. Hence the schedule was amended to include two stops at 50 Kmph instead of one stop at 50 Kmph.
Further, on the advice of CTP (Nasik), temperature measurement of the brake after each taxi stop was also introduced.
The amendment to the test schedule with the above two changes was named AML-1 dated 11-10-99.

5.3 After completion of the tests for SET-1 brake discs, short of the landing trial, it was suggested by CTP (FW), Bangalore that a direct comparison of braking performance between the indigenous brake pads and the Russian origin brake pads is necessary instead of comparison with indigenous and mixed sets. It was suggested that at least three taxi stops should be carried out at 150 Kmph and with the same aircraft weight configuration (full internal fuel) on both brakes fitted with the indigenous

(SET-2) brake pads and then with fully Russian brake pads for obtaining repeatable comparative data on stopping time and stopping distance. Further it was felt that the landing trial is not necessary as the accelerate – stop tests at 150 Kmph with full internal fuel would adequately represent braking conditions of a normal landing.

The para 5.10 of the original test schedule, hence, was amended based on the above considerations and three stops, each at 150 Kmph with full internal fuel in the aircraft, were introduced for brakes fitted with fully indigenous pads (SET-2) and then for brakes fitted with fully Russian origin brake pads.

Further, stage inspection in between stops was removed since adequate confidence was available from results of the dynamometer tests already carried out on indigenous and Russian brake pads.

The second amendment to the test schedule with the above changes was named AML-2 dated 29-10-99.

As per AML-2 of the test schedule, the first taxi with fully indigenous brake discs were carried out at 150 Kmph speed with full internal fuel and after the taxi stop thermal indicators are found melted. On investigation, detail deliberation and study of the KT 163A maintenance manual , it was established that a low speed taxi trial meant for 'bedding-in' of the new brake discs is to be carried out prior to the first 150 Kmph taxi trial. As such, it was decided that one bedding-in stop at 50 Kmph speed with full internal fuel and two taxi stops at 150 Kmph speed with full internal fuel are required to be carried out for the taxi trials on fully russian brake discs.
The test schedule with the above changes was named issue 1 dated 16-12-99.

6.0 RESULTS AND OBSERVATIONS OF THE TRIALS

6.1 TAXI TRIALS ON SET-1 BRAKE DISCS IN ACCORDANCE WITH TEST SCHEDULE No. TS/IND/LDG/2701 DATED 19-5-99 AND ITS AMENDMENT No. AML-1 DATED 11-10-99

Two accelerate-stop taxi trials at 50 Kmph with 2000 litres of fuel as per AML-1 of the test schedule were carried out on aircraft fitted with SET-1 brake discs (mix of Russian and indigenous brake discs). This was followed by two accelerate –stop tests at 150 Kmph – the first one being with 2000 litres of fuel and the second one with full internal fuel. Strip examination of the brake discs was carried out after each trial at 150 Kmph.

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The results are given in the table-1 below :

TABLE-1 : RESULTS OF TAXI TRIALS ON SET-1 BRAKE DISCS

Sl. No	Test point & para of test schedule	Test date	Approx. Stop distance (feet)	Stop Time (secs)	Brake Temp. (°C)	Remarks
1	Para 5.5A of AML-1 First taxi stop at 50 Kmph, 2000 ltrs fuel	12-10-99	Normal	Normal	194 on RH brake	Bedding-in operation
2	Para 5.5B of AML-1 Second taxi stop at 50 Kmph, 2000 ltrs fuel	12-10-99	Normal	Normal	157 on RH brake	-Do-
3	Para 5.6 of TS/IND/LDG/2701. First taxi stop at 150 Kmph, 2000 ltrs fuel	13-10-99	Normal	Normal	247 on RH brake	
Stage Inspection : Brakes disassembled and strip examined. Physical condition of pads found satisfactory without any abnormalities. Brakes assembled back on aircraft for further trials.						
4	Para 5.8 of TS/IND/LDG/2701. Second taxi stop at 150 Kmph, full internal fuel	16-10-99	Normal	Normal	270 on RH brake	-
Stage Inspection : Brakes disassembled and strip examined. Physical condition of pads found satisfactory without any abnormalities.						

A brief interim report of the above trials was prepared and the same is appended at appendix III . The detailed report of the test pilot on the above four trials is enclosed at appendix V.

6.2 TAXI TRIALS ON SET-2 (FULLY INDIGENOUS) BRAKE DISCS IN ACCORDANCE WITH AMENDMENT No. AML-2 DATED 29-10-99 OF TEST SCHEDULE No. TS/IND/LDG/2701

Three accelerate-stop taxi trials at 150 Kmph with full internal fuel as per AML-2 of the test schedule were carried out on aircraft fitted with main wheel brake assemblies with SET-2 brake discs (fully indigenous brake pads). The results are given in the table-2 below:

TABLE-2 : RESULTS OF TAXI TRIALS ON SET-2 (INDIGENOUS) BRAKE DISCS

Sl. No	Test point & para of test schedule	Test date	Approx. Stop distance (feet)	Stop Time (secs)	Brake Temp. (°C)	Remarks
1	Para 5.10 of AML-2. First taxi stop at 150 Kmph, full internal fuel	4-11-99	1450 '	18"	315 on RH brake	Given below
Remarks : 3 thermal indicators on wheel rim on RH wheel and 1 indicator of LH wheel found fused on examination on 5-11-99. Probable causes attributed : (i) Bedding-in stop not carried out. (ii) Brake cooling after taxi stop insufficient. Inspection : Both brakes disassembled and strip examined for any overheating and physical condition of brake pads. No overheating signs were found and condition of pads found normal. RH wheel replaced with a fresh serviceable wheel, Sl. No. 406845. One fused thermal indicator on LH wheel replaced.						
2	Para of AML-2. Second taxi stop at 150 Kmph, full internal fuel	26-11-99	1400'	18"	219 RH 213 LH	Brake effectiveness and deceleration reported normal by test pilot for both the taxi stops. Further remarks given below
3	Para of AML-2. Third taxi stop at 150 Kmph, full internal fuel	26-11-99	1450'	19"	227 RH 230 LH	
Remarks : Condition of all thermal indicators and fusible plugs found satisfactory. Manual cooling of brakes with compressed air done for 15 minutes. Inspection : Both the LH and RH brakes disassembled and strip examined. Physical condition of pads found satisfactory without any abnormalities.						

The detailed report of the test pilot on the above three trials is enclosed at appendix V. Brief interim report covering the above three taxi trials and inspection findings is enclosed at appendix III .

6.3 TAXI TRIALS ON FULLY RUSSIAN BRAKE DISCS IN ACCORDANCE WITH ISSUE 1 DATED 16-12-99 OF TEST SCHEDULE No. TS/IND/LDG/2701

Two accelerate-stop taxi trials at 150 Kmph with full internal fuel as per issue 1 of the test schedule were carried out on aircraft fitted with main wheel brake assemblies with new Russian origin brake discs. These stops were preceded by a low speed taxi stop at 50 Kmph for "bedding-in" of the new brake discs.

The results are given in the table-2 below :

TABLE-3 : RESULTS OF TAXI TRIALS ON FULLY RUSSIAN BRAKE DISCS

Sl. No	Test point & para of test schedule	Test date	Approx. Stop distance (feet)	Stop Time (secs)	Brake Temp. (°C)	Remarks
1	Low speed taxi stop at 50 Kmph, 2000 ltrs fuel	15-12-99	-	-	317 RH 233 LH	Bedding-in operation
2	Para 5.12 of issue 1. First taxi stop at 150 Kmph, full internal fuel	16-12-99	1550'	19"	292 RH 275 LH	
3	Para 5.12 of issue 1. Second taxi stop at 150 Kmph, full internal fuel	16-12-99	1400'	18"	237 RH 262 LH	Thermal indicators found melted *
Stage Inspection : Brakes disassembled and strip examined. Physical condition of pads found satisfactory without any abnormalities.						

The detailed report of the test pilot on the above three trials is enclosed at appendix V .

7.0 DISCUSSIONS AND ANALYSIS OF RESULTS

7.1 TESTS ON SET –1 BRAKE DISCS

Results on tests carried out on SET-1 brake discs (both main wheel brakes fitted with a 50:50 mix of Russian and indigenous brake discs) are furnished in table-1. The brake effectiveness during these trials was reported to be normal by the test pilot, i.e., the effectiveness and brake feel were similar to an all Russian brake. On comparison of the stopping times and distances achieved during the stops at 150 Kmph with the similar data on all Russian original brakes (table-3), it is observed that the same are comparable. The maximum brake temperature figures also are found to be of the same order, i.e., 270-295 °C.
On strip examination of both LH and RH wheel brake assemblies, both the Russian and the indigenous brake discs of SET-1 showed uniform and similar wear pattern and surface appearance without any signs of overheating. The friction material of both the indigenous and the Russian brake pads showed no abnormal chipping or cracking.

From the above results it could be inferred that the indigenous brake pads are compatible in respect of material properties and performance with that of the Russian brake pads and use of a mix of Russian and indigenous brake pads during actual service shall not affect or alter the performance and serviceability of the main wheel brake.

7.2 TESTS ON SET-2 BRAKE DISCS

Tests on SET-2 brake discs (fully indigenous brake pads) fitted on both RH and LH main wheel brakes were carried out in accordance with amendment no. AML-2 of the original test schedule. This comprised of 3 taxi stops at 150 Kmph with full internal fuel in the aircraft. The results are given in table-2. During the first stop at 150 Kmph the temperature measured on the RH brake was 315°C which is about 50°C higher than the temperatures measured during a similar stop with SET-1 brake discs and all Russian brake discs (table-3). Further, it was detected on the following day after the completion of the trial that three thermal indicators on the wheel rim in case of RH wheel and one thermal indicator on the LH wheel had fused. This necessitated an analysis into the causes of this incident as well as taking corrective action for continuation of further trials.

On strip examination of the brake units after the above trial, the condition of the brake pads was found satisfactory and no signs of overheating were found. Subsequently, on investigation, detail deliberation and study of the KT163A maintenance manual, it was established that the probable causes of fusion of the thermal indicators are as follows :-

1) A low speed taxi trial meant for bedding – in of the brake discs (Set –2) was not carried out prior to the first 150 Kmph taxi trial.

2) Brake cooling fan being non – operational during taxi, manual cooling of the brakes using compressed air for a duration of 15 minutes minimum is essential which was probably not followed.

The causes for a higher brake temperature on RH brake, compared to the figures achieved on SET-1 brakes and all Russian brake discs, by about 50°C, are as follows :-

The first taxi was directly carried out at 150 Kmph with full internal fuel, without carrying out bedding-in operation at a lower speed as done in the case of SET-1 brake discs. This resulted in a longer duration of brake application thereby causing a higher temperature rise.

Further trials on the SET-2 brakes were continued after necessary corrective actions such as ensuring proper cooling of the brakes after each stop. Results of these tests are furnished in table-2. The brake effectiveness during these trials was reported to be normal by the test pilot, i.e., the effectiveness and brake feel were similar to an all Russian brake. On comparison of the stopping times and distances achieved during the stops at 150 Kmph with the similar data on all Russian original brakes (table-3), it is observed that the same are comparable. The maximum brake temperature figures also are found to be of the same order, i.e., 210-230°C.
On strip examination of both LH and RH wheel brake assemblies, the indigenous brake discs of SET-2 showed uniform wear pattern and surface appearance without any signs of overheating. The friction material of the indigenous brake pads on both LH and RH brakes showed no abnormal chipping or cracking.

7.3 TESTS ON FULLY RUSSIAN BRAKE DISCS

Results on tests carried out on main wheel brakes fitted with fully Russian origin brake pads are furnished in table-3. The brake effectiveness and feel during these trials was reported to be normal by the test pilot and comparable to that of the indigenous brake pads. On comparison of the stopping times and distances achieved during the stops at 150 Kmph with the similar data on indigenous brake pads (table-2), it is observed that the same are comparable. The maximum brake temperature figures also are found to be of the same order, i.e., 235-295 °C.

Table-4 furnishes a summary of comparative analysis of performance of all the above results obtained during the aircraft trials.

7.4 DISCUSSION WITH RCMA(ND),DGAQA(ND), HAL(ND) AND HAL(LD) SPECIALISTS :

A meeting was convened in the office of AGM (Design), HAL(ND) to discuss the results of taxi trials on 17-12-99 . The minutes of meeting is enclosed at IV .

TABLE-4

SUMMARY OF PERFORMANCE COMPARISON BETWEEN RUSSIAN & INDIGENOUS BRAKE PADS BASED ON TAXI TRIAL DATA

(A) TYPE OF BRAKE DISCS : SET-1 (MIXTURE OF RUSSIAN & INDIGENOUS BRAKE DISCS)
ALLOCATED A/C NO. : TS 584

SL NO	TRIAL EVENTS	BRAKE EFFECTIVENESS	CONDITION OF BRAKE PADS		REMARKS
			RUSSIAN	INDIGENOUS	
1.	02 stops at 50 kmph, 2000 ltrs of fuel	Satisfactory	--	--	Bedding-in
2.	01 stop at 150 Kmph,2000 ltrs of fuel	Satisfactory	Satisfactory	Satisfactory	Comparable
3.	01 stop at 150 Kmph,full internal fuel	Satisfactory	Satisfactory	Satisfactory	Comparable

(B) TYPE OF BRAKE DISCS : SET-2 (FULLY INDIGENOUS BRAKE PADS)
ALLOCATED A/C NO. : TS 584
(C)) TYPE OF BRAKE DISCS : FULLY RUSSIAN BRAKE PADS
ALLOCATED A/C NO. : TS 527

SL NO	TEST DATA AND OBSERVATIONS	02 TAXI STOPS AT 150 KMPH, FULL INTERNAL FUEL		REMARKS
		RUSSIAN	INDIGENOUS	
1.	BRAKE EFFECTIVENESS	Satisfactory	Satisfactory	Comparable
2.	AVERAGE STOP TIME (SECONDS)	18.5	18.5	Comparable
3.	AVERAGE STOP DISTANCE (FEET)	1475'	1425'	Comparable
4.	MAXIMUM BRAKE TEMP. RECORDED (°C)	292.4	230.0	Comparable
5.	CONDITION OF BRAKE PADS	Satisfactory	Satisfactory	Comparable

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8.0 CONCLUSIONS

(a) The indigenous brake pads are comparable in respect of material characteristics (wear pattern and surface condition of brake pad) and brake performance such as brake effectiveness , stop time , stop distance & maximum brake temperature achieved with that of the Russian brake pads.

(b) The Russian origin brake pads of main wheel brake assembly p/n KT 163A could be substituted by indigenous brake pads.

(c) Use of a mix of Russian and indigenous brake pads during actual service shall not affect or alter the performance and serviceability of the main wheel brake.

9.0 RECOMMENDATION :

The indigenous brake pads of main wheel brake assembly p/n KT 163A are recommended for service use.

PUBLICATIONS

1. D.Dutta and P.Raghothama Rao, "Engineering quality, airworthiness and reliability in friction material formulations for high-energy aircraft brake pads"; QUEST, Vol. 100, No.1, 1996, page E-1-E-14.
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Engineering quality, airworthiness and reliability in friction material formulations for high-energy aircraft brake pads

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ABSTRACT

High-energy aircraft brake pads comprise essentially of carefully engineered multicomponent metal-matrix composite materials called friction materials. Friction materials in aircraft brakes absorb the kinetic energy of motion, convert it to heat and dissipate the latter to the atmosphere. The paper describes in detail the vital aspects of indigenisation and airworthiness procedures adopted during design and development of a friction material for a given aircraft bringing out the fact how the quality and performance of the material is engineered right into the design and formulation of the friction material. The paper also presents a case study highlighting how a particular friction material composition developed for a given aircraft brake is unique to that aircraft and its use cannot be rationalised for the brakes of another aircraft.

INTRODUCTION

The kinetic energy of landing of a modern day aircraft is of the order of several million joules. A medium capacity civilian transport aircraft such as Boeing 737-200 for instance has a normal landing brake energy as high as 30 million joules and jet fighters have energies in the range of 5 to 20 million joules. This enormous quantum of energy, when absorbed by the brakes within a very short interval of 10-12 seconds after landing, imposes extremely severe and demanding requirements on the friction material of the brake pads. The friction material, hence has to be designed to not only impart friction and wear resistance properties, but also to ensure quite contradictory properties such as seizure prevention or dry lubrication and stability of the same over a wide range of temperature and thermal gradients. In addition, structural stability over the entire temperature range of operation is to be essentially ensured under quite complex states of stresses.

A friction material thus has to be designed to meet diverse and demanding property and functional requirements. No single engineering material can meet the entire spectrum of aircraft braking requirements and hence a friction material is one that is a 'man-made' material, synthesized after judicious selection and combination of a variety of metals, non-metals and exotic ceramic ingredients, which individually and in combination satisfy the entire range of aircraft braking requirements.

The rate of absorption of kinetic energy by the brake, the maximum temperature rise, the brake heat sink mass available and several other requirements vary from one aircraft to the other. Friction material compositions are designed to satisfy these requirements, are unique for each aircraft brake and cannot be rationalised. In other words a friction material for a particular aircraft is 'tailor-made'. The methodology of development of the unique friction material for a given aircraft brake, therefore, starts with an in-depth study of the brake design specification. A step by step approach is then followed for derivation of the physical and metallurgical properties of the candidate friction material from the brake specification. Thus the brake design parameters such as the brake energy and the allowable heat sink mass help one to decide on the density, specific heat and melting point of the friction material. The area energy loading, loading rate and brake torque requirements determine the coefficient of friction, thermal conductivity and stability properties of the material.

The friction material, so designed, is a complex multi component composite in which each ingredient has its unique role to play. Copper as a matrix, for instance, ensures basic strength and conductivity properties while also ensuring embeddability for hard ceramic ingredients

Graphite offers solid lubrication and resistance to seizure. Mullite particles are added to offer a stable friction coefficient and wear resistance. The proportion of each ingredient selected and added depends on the level of each property required.

Once developed, the friction material needs to undergo rigorous and repeated testing to prove reliability and reproducibility of its performance in actual service. For this, the friction material brake pads are mounted on actual aircraft brake and are subjected to real time brake dynamometer tests simulating the actual kinetic energies of aircraft braking under various conditions of operation such as normal landing, emergency landing, rejected take-off etc. The dynamometer tests are followed actual taxy trials on aircraft to assess pilot's feel of the newly developed brake friction material.

ANATOMY AND FUNCTION OF A TYPICAL AIRCRAFT DISC BRAKE

Figure 1 presents a view of a typical disc type aircraft brake unit. The unit is designed as a multiple disc assembly consisting of a brake housing, pressure plate, torque tube, thrust plate and disc stack comprising of a series of alternate stator and rotor discs assembled with brake pads and steel rotor segments, respectively.

The disc stack is also called the "heat sink" and is the most important part of the brake unit. The brake functions by virtue of the conversion of the kinetic energy of the moving aircraft to heat energy and the absorption and subsequent dissipation of the same by the heat sink. Heat generation arises from the rubbing of the surfaces of the brake pads on the rotor discs against those on the adjacent stator discs and is thus dependent on the frictional characteristics of these surfaces, specific heat of the heat sink mass and the rate of heat abstraction from the frictional surfaces.

An aircraft brake heat sink is designed using the following design performance parameters derived from the basic brake design specifications: -

- Heat Sink Loading (Kinetic energy absorbed per unit heat sink mass)
- Area Loading (Kinetic energy absorbed per unit swept area of the rubbing faces)
- Area Loading Rate (Area Loading per unit braking time)

DERIVATION OF FRICTION MATERIAL PROPERTIES FROM THE BRAKE SPECIFICATION

All the above performance characteristics of the brake and the brake heat sink are determined from and governed by the brake design specification. The first phase of the development of an appropriate friction material composition for the brake pads, therefore, starts with a detailed analysis of the brake design specification and deduction of physical and mechanical properties of the candidate friction material. Table-1 presents the typical brake design specification parameters that are required for the derivation of properties and development of an appropriate friction material.

TABLE – 1 TYPICAL AIRCRAFT BRAKE DESIGN SPECIFICATION PARAMETERS

Sl No.	Basic brake design specification	Symbol (Units)
1.	Maximum Design Landing Weight of Aircraft at Sea Level	W_{DL} (Kgf)
2.	Maximum Brake Application Speed on Design Landing	V_{BA} (m/sec)
3.	No. of Landing Brakes per Aircraft	N
4.	Maximum Take-off Weight of Aircraft	W_{TO} (Kgf)
5	Maximum Decision Speed for Reject-Take-Off (R.T.O.)	V_D (M/sec)
6.	Mean Deceleration reqd. from Brake during Design Landing	d_l (-3m/sec^2)
7.	Minimum Deceleration reqd. from Brake during R.T.O.	d_{RTO} (-1.65m/sec^2)

8.	Mean Service Life of Brake Linings in Number of Landings	L_L
9.	Tyre Rolling Radius of Braking Wheel	R (m)
10.	Number of Brake Pistons	n
11.	Mean Diameter of Brake Pistons	D (cm)
12.	Pitch Circle Radius of Brake Pistons	r (m)
13.	Maximum Effective Brake Pressure	P_{EM} (kgf/cm^2)
14.	Total design heat sink mass of brake	M_{HS} (Kgf)
15.	Number of Frictional Rubbing Surfaces per brake	b
16.	Total Frictional Swept Area per rubbing surface	a (cm^2)
17.	Threshold Brake Temperature Rise on Design Landing	T_{DL} (Deg. C)
18.	Maximum Allowable Brake Temp. Rise during Emergency R.T.O.	T_{RTO} (Deg C)
19.	Nominal Friction Material Thickness per face of brake disc	F_H (cm)

From the basic design specification data given in Table-1, a number of performance characteristics of the brake such as kinetic energy per brake, brake torque, stopping time, and stopping distance etc. could be derived which in turn form the acceptance requirements of the brake friction material being developed. From the basic data of table-1 and the derived brake performance characteristics, a number of physical and mechanical properties of the candidate friction material, such as coefficient of friction and wear, could be derived which govern the development of the friction material. Table-2 presents the derived performance characteristics of an aircraft brake illustrating the relation between the basic design specifications and the derived characteristics.

TABLE – 2 DERIVED BRAKE PERFORMANCE CHARACTERISTICS

Sl No.	Derived Characteristics	Derived from	Relationship

1.	Kinetic energy (Design Landing), KE_{DL}	W_{DL}, V_{DL}, N	$KE_{DL} = 1/2\, W_{DL} V_{DL}^2 / gN$
2.	Kinetic energy (R.T.O.), KE_{RTO}	W_{RTO}, V_0, N	$KE_{RTO} = 1/2 W_{RTO} V_0^2 / gN$
3.	Mean Stopping Time(Design Landing), t_{DL}	V_{DL}, d	$t_{DL} = - V_{DL} / d$
4.	Max. Stopping time allowed for RTO emergency braking, t_{RTO}	V_0, d_{RTO}	$t_{RTO} = - V_0 / d_{RTO}$
5	Mean braking distance (Design Landing), S_{DL}	V_{DL}, d, t_{DL}	$S_{DL} = V_{DL} t_{DL} + d\, t_{DL}^2 / 2$
6.	Max. braking distance allowed in RTO, S_{RTO}	V_0, d_{RTO}, t_{RTO}	$S_{RTO} = V_0 t_{RTO} + d_{RTO} t_{RTO}^2 / 2$
7.	Mean Dynamic Brake Torque (Design Landing), τ_{DL}	W_{DL}, d, N, R	$\tau_{DL} = W_{DL}\, d\, R / gN$
8.	Heat Sink Loading, H_M	KE_{DL}, M_{HS}	$H_M = KE_{DL} / M_{HS}$
9.	Heat Sink Area Loading, H_A	KE_{DL}, a, b	$H_A = KE_{DL} / a.b$
10.	Heat Sink Loading Rate		
	A) Mass Loading Rate, $\dot{H}_M$	H_M, t_{DL}	$\dot{H}_M = H_M / t_{DL}$
	B) Area Loading Rate, $\dot{H}_A$	H_A, t_{DL}	$\dot{H}_A = H_A / t_{DL}$

The basic physical and mechanical properties of the candidate friction material are derived from and analysis of the brake specification (table-1) and the derived performance characteristics (table-2). Table-3 presents some of the physical properties of the candidate friction material for a typical aircraft brake, the basic specification parameters from which the properties are derived, the relationship between the brake specification/characteristics and the friction material properties.

TABLE - 3 : PROPERTIES OF THE CANDIDATE FRICTION MATERIAL DERIVED FROM THE BRAKE SPECIFICATION

Sr. No.	Property	Derived from	Relationship	Value of property derived for a typical transport aircraft
1.	Mean Coefficient of Friction, $\bar{\mu}$	$T_{(DL)}$, P_{av}, D, n, b, r	$\bar{\mu} = 4T_{(DL)}/\pi D^2 n b r P_{av}$	0.29
2.	Mean Specific Heat of Friction Heat Pack, S_H	$KE_{(DL)}$, M_{HS}, T_{DL}	$S_H = KE_{(DL)}/M_{HS} T_{DL}$	0.59 J/gm/deg C
3.	Maximum allowable Wear rate per braking stop, W_{pr}	F_{TW}, L_N	$W_{pr} = F_{TW}/L_N$	0.003 mm
4	Minimum Melting point of Friction material, T_M	T_{HS}	$T_M \geq (T_{HS} + 200°C)$	1250°C

In a similar manner the other basic physical, mechanical and metallurgical properties of the candidate friction material such as thermal conductivity, specific gravity, shear strength, compressive strength, etc., could be easily derived from the brake specification.

DESIGN AND SELECTION OF FRICTION MATERIAL COMPOSITION

The composition of the prototype friction material is then designed, selected and formulated based on the properties derived. The first step in this process is the selection of the metallic matrix material which imparts the basic physical and mechanical properties such as friction, strength, specific heat, thermal conductivity and melting point to the friction material and normally accounts for 60 to 75% of the weight of the friction material. In case of metalloceramic friction materials, the choice of the metallic matrix is restricted to either a copper base or an iron base or a judicious combination of the two bases. Minor additions of other metals such as Zinc, Tin, Nickel, Chromium, etc., as alloying elements, are sometimes necessary to enhance the mechanical properties of the metallic base.

The relative characteristics of iron and copper based matrix materials are given below in Table -4

TABLE-4 SELECTION OF COPPER OR IRON AS MATRIX

Sl. No	Characteristics	Iron	Copper
1.	Specific Heat at Room Temp. (Joules/gm/°K)	0.56	0.42
2.	Thermal Conductivity at R.T. (J/M/Sec/°K)	59	345
3.	Coefficient of Linear Expansion (°K^{-1} .10^{-6})	14	18
4.	Heat Sink Loading Capacity (Joules/Kg)	450,000	280,000
5.	Tensile Strength (MPa)	410	240
6.	Melting Point (°C)	1539	1083
7.	Antiseizure	Good	Poor
8.	Tolerance to ceramic/non-metallic additions	Poor	Good
9.	Softening Resistance at Elevated Temperature	Good	Poor
10	Ease of Manufacture into Friction Materials	Poor	Good

From an analysis of Table – 4 and the desired properties of the candidate friction material, the matrix material could be easily selected. For example, for a typical transport aircraft brake, the desired properties of which are given in table 3, iron could be selected as the most suitable matrix material as most of the characteristics desired such as specific heat, heat sink loading, melting point, thermal conductivity, etc., are observed to be closely met by iron. However, in most cases to improve thermal conductivity with a negligible reduction of room temperature specific heat about 5-10% of the iron is replaced by copper. Incorporation of a small quantity of copper in iron matrix also improves fabrication characteristics such as mixing, powder compressibility and sinterability[12] and promotes strength and hardness of the resultant material due to precipitation hardening.[14]

The next step in the design of composition is the selection of the other secondary ingredients such as friction additives, dispersed solid lubricants, stabilisers, etc. Table – 5 illustrates the various ingredients commonly used in formulation of metal ceramic friction materials to fulfil the diverse functional characteristics required. The type and proportion of the secondary ingredients selected are based on the level of functional properties required in the resultant friction material.

TABLE – 5   FRICTION MATERIAL INGREDIENTS

Sl No.	Functional Characteristics	Components / Ingredients
1.	Friction, strength thermal conductivity and specific heat.	Matrix : Copper or Iron (with or without alloying elements, e.g., Sn, Zn, Ni, Cr, Mn etc.)
2.	Lubrication, seizure prevention, stability	Dispersed Lubricants : Graphite, Lead, MoS_2, Special high temp. lubricants.
3.	Abrasion / Friction	Abrasive Component : Silica, Mullite, Silicon Carbide, Alumina, Silicon Nitride, Boron Carbide, etc.
4.	Friction stability, thermal stability, Softening resistance, Conformability.	$BaSO_4$, $CaSO_4$, $MnSO_4$, Fe,F, B, Mo, W, etc.
5.	Wear resistance	Cast iron grits, spinels, steel wool, pearlite, and cementite phase in iron matrix
6.	Fillers	Carbon, Minerals

The abrasive component is the most important ingredient after the matrix as this gives rise to friction and also helps prevent local welding and metal transfer of the metallic matrix material on to the mating part rubbing surface during braking[7]. Out of the various abrasive ingredients, the oxides of silicon and aluminum are known to be suitable for low and medium energy friction materials whereas the carbides and nitrides of silicon are most desirable for high energy possessing high heat sink loading values[8]. For the transport aircraft brake, the heat sink loading and kinetic energy values are high (heat sink loading of more than 600 000 Joules/kg) and therefore the choice was between SiC and Si_3N_4 . Since SiC is more abundantly available in our country, is cheap and is stable till a temperature of 1800 °C, SiC could therefore be selected as the friction ingredient.

To avoid gross seizure between the friction element and mating part dispersed dry lubricants are added. These lubricants (5 to 25%) provide smoothness of engagement during braking by forming a self regulating smooth film on the friction surface. These lubricants, by forming a film, also regulate friction and wear at all rubbing speeds and brake temperatures. Out of the various dispersed lubricants, natural graphite is best suited for the iron matrix as it also helps formation of the much desired pearlite phase in the iron matrix during sintering. Pearlite improves strength, friction coefficient, stability and wear resistance in iron base friction materials[5]. Graphite, however, ceases to be a good lubricant at brake bulk temperatures above 600°C and therefore a secondary high temperature lubricant is also required when temperatures more than 600°C are encountered. In the present example of the transport aircraft, graphite could be chosen as the primary lubricant and a secondary high temperature lubricant is also required to be added.

It has been found that high graphite contents (15 to 20%) are suitable for low temperature performance and where very high thermal conductance is assured, but in conditions of poor heat transfer such as in the present example, the addition of graphite should not exceed 5 to 8%[7]. Secondary high temperature lubricant additions are normally kept very low, i.e., about 1 to 2%, as higher amounts added lead to excessive wear of the friction material.

An important requirement, which the friction material of a high energy aircraft brake must fulfil, is thermal stability which means that the basic strength, friction and wear rate of the material should not deteriorate appreciably with increasing rubbing speeds and brake temperatures. The expected deterioration of friction and wear properties in iron base friction materials is known to be effectively compensated by Barium Sulphate[7]. $BaSO_4$ undergoes complete reduction by carbon of graphite during sintering according to the following equation[7].

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

This reaction activates the sintering process of the iron base material making it stronger. The resistance to high temperature wear also increases with increase in $BaSO_4$ content[6]. However, $BaSO_4$ being a non-metallic ingredient is required to be limited within 12% as higher contents lead to rapid decline in mechanical properties, such as compressive and shear strength of the friction material[7]. In the present example of the transport aircraft brake, therefore, $BaSO_4$ upto 12% could be selected as the friction stabiliser.

The resultant composition of the iron base friction material for a typical high energy transport aircraft brake could be tentatively fixed as given in Table – 6.

TABLE – 6 COMPOSITION OF IRON BASE FRICTION MATERIAL TENTATIVELY SELECTED FOR A TYPICAL TRANSPORT AIRCRAFT BRAKE

Sl. No.	Ingredient	Weight Percent
1.	$BaSO_4$	8 to 12%
2.	Graphite	6 to 8%
3.	Silicon Carbide	7 to 10 %
4.	High temp. Lubricant	1 to 2%
5.	Copper	5 to 7%
6.	Iron	Balance

It is thus observed that the friction material composition for any aircraft brake could be designed, formulated and derived from the basic brake specification data and such a composition derived would naturally satisfy all the properties and performance parameters dictated by the brake specification. Thus such a friction material, when tested and qualified to meet the brake design requirements could be called an *engineered material*.

DEVELOPMENT AND ESTABLISHMENT OF POWDER METALLURGY(P/M) PROCESS FOR FABRICATION OF PROTOTYPE BRAKE PADS

After design and formulation of the friction material composition, the next activity in the development of prototype brake pads for an aircraft brake is development of an appropriate P/M process for fabrication of the friction material into brake pads / elements by controlled experimentation. The various steps involved in development of the optimum process are as follows:

A. Selection of Raw materials based on Composition

A number of designed experiments are carried out to optimise the characteristics and the specification of the raw material corresponding to each friction material ingredient. Prototype brake pad samples made from a few alternative raw materials of each ingredient are tested for basic properties such as friction, wear and specific heat. From the results of these experiments each raw material type and specification is fixed and optimised. Table – 7 presents the type and specifications of the various raw materials selected for the iron base friction material composition chosen for a typical transport aircraft brake as given in table – 6.

TABLE – 7 RAW MATERIAL SPECIFICATIONS SELECTED FOR IRON BASE FRICTION MATERIAL

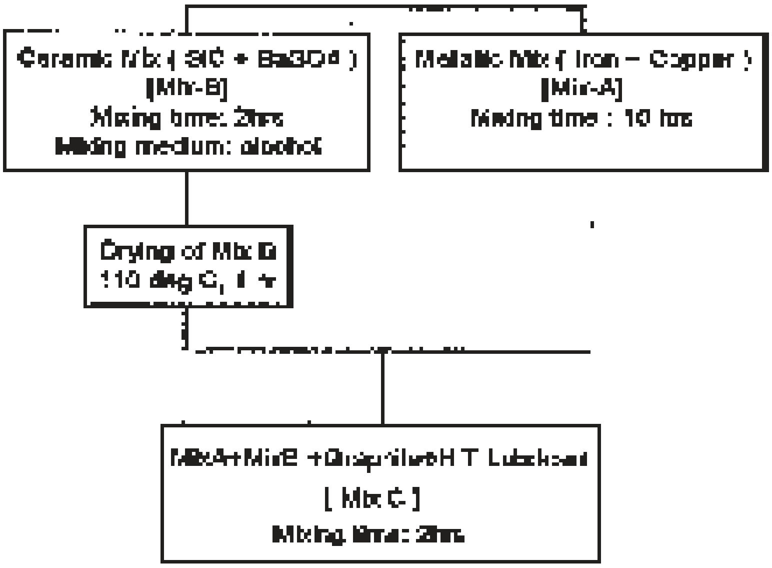
Sl. No.	Ingredient	Raw Material Specification
1.	Iron	Sponge iron powder of size 200 BS mesh, apparent density of 2.65 gms/cc and minimum purity of 98%.
2.	Copper	Electrolytic copper powder of size 300 BS mesh, apparent density of 2.4 gms/cc and purity of 99% minimum.
3.	Graphite	Natural flaky graphite of fixed carbon of 98% minimum and size 100 BS mesh.
4.	$BaSO_4$	98% pure, X-ray grade of size 400 BS mesh.
5.	High temperature Lubricant	97.5% pure, sintered and hot pressed, hexagonal crystal structure, size 100 BS mesh
6.	Silicon Carbide	Green fused SiC grains of size 80 BS mesh, polishing grade

B. Powder Mixing

Powder mixing experiments are carried out by varying sequence and method of mixing, mixing time and mixing medium. The aim of the experiments is to establish an optimum mixing procedure which would result in a friction material mix with the best bulk density and flow rate characteristics.

For the transport aircraft friction material formulation the following mixing procedure, established through experiments, would yield the best result:-

Mixing Sequence:



C. Powder Compaction

Compaction pressure for compacting the friction material into the desired shapes required in the final brake pad is chosen and optimised based on experiments which yield the most optimum green density value of the resultant compact. Higher pressures lead to marginal increase in the green density but may cause cracking of the compact due to high residual stresses. The compaction pressure for iron base friction materials is about 500 to 540 Mpa and for copper base friction materials it is in the range of 380 to 420 Mpa.

D. Processing of Back Plate Frame

A friction material is a composite with about 40% by volume of non-metallic ingredients and therefore possesses quite low strength, fatigue and impact properties compared to a bulk metal. In order to augment its strength properties to withstand the severe stress and temperature environment during operation and also to make it suitable for assembly into the brake rotor and stator plates by cold heading operations such as riveting, the friction material is either housed in a backing steel container or is diffusion bonded under pressure and temperature, during the sintering operation, on to a steel back plate frame of the same shape and contour as the friction material element. The selection of a suitable steel for use as a back plate material depends on the stresses, brake torque limit and the maximum temperature rise expected to be encountered during high energy aircraft braking.

For low and medium energy aircraft brakes in which maximum temperatures are within 600 deg. C, plain low carbon steel is considered a suitable back plate material. For high energy brakes, in which braking torque and stresses are high, expected temperature rise is beyond 750 deg. C , the choice of a back plate material is restricted to stabilised high strength low alloy steels of high hardenability and possessing good thermal fatigue properties. Steels normally used are AISI-4340, BS-S155, M-300 etc.

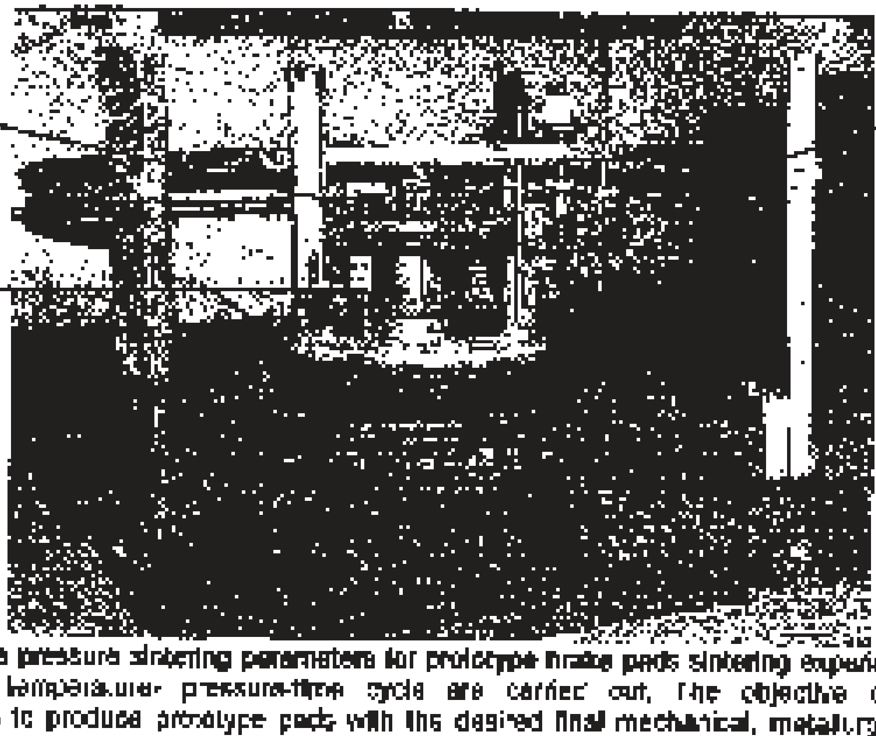
In the case of the iron base friction material chosen for the transport aircraft, since the brake energy and temperature rise figures are high, the back plate that is chosen is AISI-4340. After selecting and procuring the steel material in sheet or strip form, back plate segments are then fabricated by shearing operations using specially designed press tools.

The steel backing segments are then given a nickel or a copper plating, for iron base and copper base friction materials respectively, from cyanide/alkaline bath for aiding the subsequent diffusion bonding process with the composite friction material during the pressure sintering operation. After plating the plated back plates are given a diffusion anneal treatment to ensure proper bonding of the plated layer to the underlying steel plate.

E. PRESSURE SINTERING OF BRAKE PADS

Since the friction material brake pads are designed as a bimetallic, i.e., the friction material compact is diffusion bonded on to a steel back plate, in actual manufacturing practice the bonding of the friction material compact to the steel back plate has to be achieved simultaneously during sintering by application of external pressure on the back plate-friction material compact assembly. This is achieved by carrying out pressure sintering of the friction material.

The next and final step in fabrication of the prototype brake pads is therefore pressure sintering. To carry out pressure sintering a special type of sintering equipment, viz., a pressure sintering bell type furnace with a hydraulic charge pulling arrangement is used. The sintering charge, i.e., the friction material compact-plated back plate assemblies are stacked vertically, one above the other, to form a vertical stack comprising 15 to 20 such assemblies. Three such vertical stacks of pads are placed on the charge base of the bell furnace circumferentially and spaced at 120° from each other. The pressure application during sintering is achieved by placing a pressure plate on top of the three stacks and hydraulically pulling the pressure plate with the central "pull rod" coupled to a hydraulic jack located below the charge base. The hydraulic load can be varied and controlled externally. Figure 2 shows a pressure sintering arrangement.



To optimise the pressure sintering parameters for prototype brake pads sintering experiments to establish the temperature- pressure-time cycle are carried out. The objective of these experiments is to produce prototype pads with the desired final mechanical, metallurgical and physical properties as derived from the brake specification. Experiments carried out for the iron base friction material brake pad of the transport aircraft brake, for instance, resulted in the following optimum pressure sintering parameters that could yield prototype brake pads which met all the property requirements:

Sintering temperature :- 1025 °C
Sintering pressure :- 150Mpa
Sintering time :- 2 hours
Sintering atmosphere :- Dry Hydrogen

Figure – 3 shows the micro structure of a cut and polished cross section of the brake pad sintered under the above optimum conditions. The microstructure shows a predominantly fine pearlitic structure of the matrix iron phase in which SiC particles and graphite are observed to be uniformly dispersed. The irregular shaped light/ white areas are copper. Besides the ideal structure of the friction material, a sound interfacial diffusion bonding is also observed between the steel back plate and the friction material through an intermediate electrodeposited nickel layer of thickness of about 150 microns.

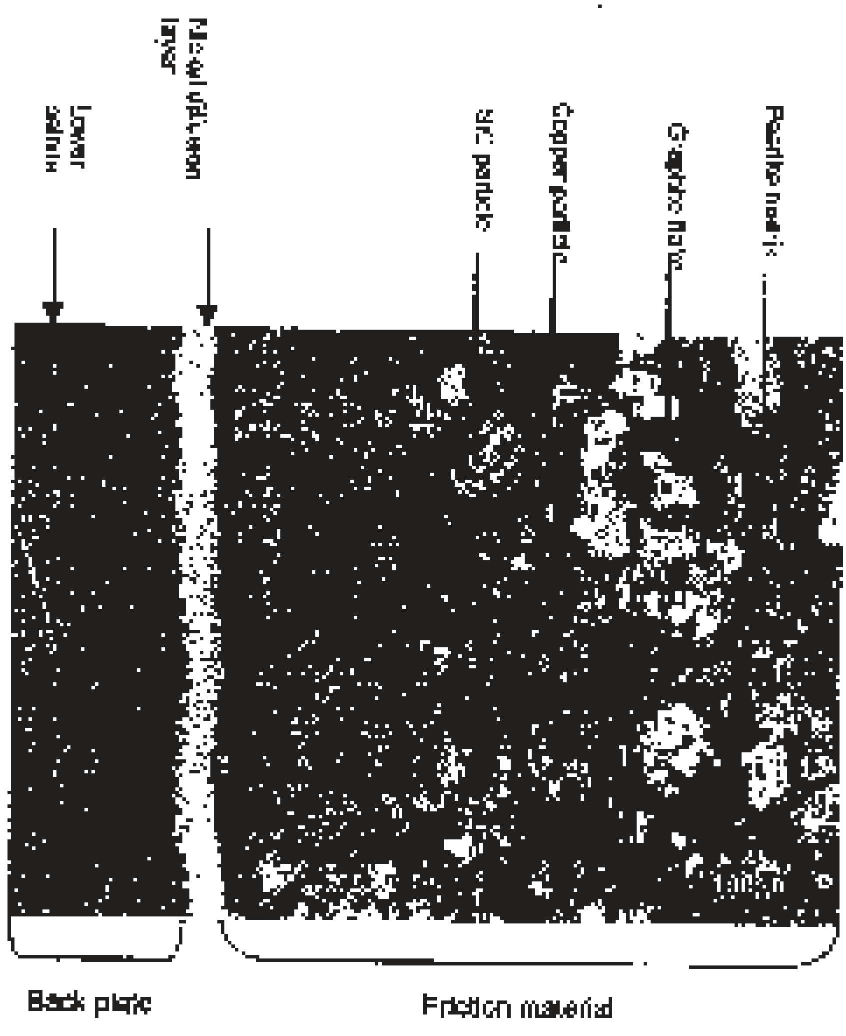


Figure – 3 Microstructure of a pressure sintered iron based brake pad

After establishment of the optimum manufacturing process by controlled experimentation as described above at each stage, i.e., raw material characterisation, mixing, compaction, back plate selection and preparation and finally pressure sintering, sufficient number of prototype brake pads are processed for undergoing airworthiness qualification tests.

QUALIFICATION AND AIRWORTHINESS TESTING OF PROTOTYPE BRAKE PADS

Although, as discussed in the previous sections that the quality and properties of the brake pads developed are established at the various stages of development right from the study of brake design specification requirements to the derivation of composition and optimum process, the prototype pads developed still need to undergo further qualification testing to prove their final airworthiness. This is essential since the friction material of the pads are complex multiphase composite materials, are required to withstand severe operating conditions and consistently guarantee a high level of reliable performance in service. The qualification testing stage during the development cycle of a brake pad therefore assumes critical importance.

The airworthiness requirement for brake materials meant for civil aircraft application are covered by FAR, part23 for normal utility and aerobatic aircraft; part 25 for transport aircraft; part 27 for normal rotorcraft and part 29 for transport rotorcraft. Airworthiness for all types of military aircraft is governed by MIL-W-5013 and Technical Standard Order-26 issued by Federal Aviation Administration, USA.

In accordance with the airworthiness requirements, highly elaborate test procedures are prescribed for friction brake pads for certifying them for normal use on aircraft brake. The entire testing procedure can be divided into three stages :

- Laboratory Qualification tests
- Brake Dynamometer tests
- Aircraft trials

a) Laboratory Qualification Testing

In this stage in-depth analysis and evaluation of the prototype brake pads is carried out repeatedly. The following tests to assess the metallurgical, physical and mechanical properties of the prototype pads are carried out in accordance with a laid down test schedule/specification and acceptance standard approved by the airworthiness authorities.

- Hardness test on friction material and back plate
- Density determination
- Chemical analysis
  - by classical wet analysis and/or
  - by special instrumental methods such as X-RD, EDAX Spectroscopy, etc.
- Microstructure characterisation
  - Optical microexamination for identification and distribution of major constituents in friction material and structure of back plate.
  - Bimetallic Bonding
  - Microhardness survey on selected constituents and phases
- Specific heat and thermal conductivity by calorimetry
- Coefficient of expansion by dilatometry
- Friction and wear test using a laboratory testing
- Phase identification studies by Scanning Electron Probe Micro Analysis (SEPMA) for identification, characterisation and chemistry distribution of various constituents and phases.

The iron base friction material brake pads developed for a transport aircraft when subjected to all the above tests gave the following results given in table 8 below

TABLE – 8 RESULTS OF LABORATORY QUALIFICATION TESTS ON PROTOTYPE BRAKE PADS DEVELOPED FOR A TYPICAL TRANSPORT AIRCRAFT

Sl. No.	Tests/Analysis Conducted	Results Obtained
1.	Hardness (Average)	
	a) Friction material	135 BHN
	b) Steel back plate	448 VPN
2.	Density of friction material (gms/cc)	6.11
3.	Chemical composition of friction material	SiC: 9%, C: 7.8%, BaS: 9.3%, Cu: 4.6%, [illegible]: 1.3%, Fe: Bal
4.	Microstructure(Fig-3)	
	i) Optical	a) SiC particle size : 100 to 180 microns b) Graphite : Flaky, 200 to 400 microns c) Matrix Fine Pearlite, Ferrite content:- 2 to 5% d) Copper : uniformly distributed in matrix
	ii) Bimetallic Bonding	Sound interfacial bonding between steel back plate and friction material through Ni. plated layer. Nickel layer thickness :- ~ 150 microns.
	iii) Back Plate	Fine lower bainite
	iv) Microhardness	a) Matrix : 315 to 335 VPN b) SiC : 1300 to 1540 VPN
5.	Specific heat at R.T. of brake pad	0.586 Joules/gm/°K
6	Friction Test (50 normal energy braking stops) on 2 prototype specimens	
	i) Avg. stopping time	9.2 seconds
	ii) Avg. coefficient of friction(dynamic)	0.292
	iii) Wear in 50 stops	
	a) by weight loss	2.5 gms (0.05 gms/stop)
	b) by thickness	0.14 mm (0.0028mm /stop)

By comparing the above results with the laid down property specifications, some of which are given in table-3, it is observed that the iron base friction material developed meets the requirement of the properties and the transport aircraft brake specification quite well. On this basis, the composition of the friction material selected, the raw material specifications, the back plate steel and the P/M process parameters are tentatively fixed and documented.

b) Brake Dynamometer Tests

The laboratory qualification tests on individual prototype samples of the newly developed brake pads are, however, not adequate to fully qualify the material for fitment on the transport aircraft brake directly for actual use in service. To qualify the pads for airworthiness, actual field performance is required to be tested thoroughly. This is fulfilled by conducting the *brake dynamometer tests* wherein the aircraft brake unit, assembled with the newly developed brake pads, is subjected to repeated cycles of real time brake performance tests on a brake dynamometer simulating the actual aircraft *"design (normal) landing"* and *"rejected take-off"* brake energy conditions.

The conditions simulated for the brake dynamometer tests of the iron based friction material brake pads of the transport aircraft were derived from the brake specification. These are given in table - 9 below :

TABLE – 9 CONDITIONS SIMULATED FOR BRAKE DYNAMOMETER TESTS FOR IRON BASE BRAKE PADS OF THE TRANSPORT AIRCRAFT

Sl. No.	Test parameters	Conditions simulated for test under	
		Design landing	R T O
1.	Brake Energy, $(I\omega^2/2)$	9.346×10^5 Kgfm	1.98×10^6 Kgfm
2.	Gyrating mass inertia, (I)	192 Kgfmsec^2	164 Kgfmsec^2
3.	Gyrating mass RPM, (N)	1080	1360
4.	Angular velocity of gyrating mass, $(\omega = 2\pi N/60)$	113 per second	142.4 per second
5.	Brake pressure	100 kgf/sq.cm	100 kgf/sq.cm
6	No. of stops	50	1

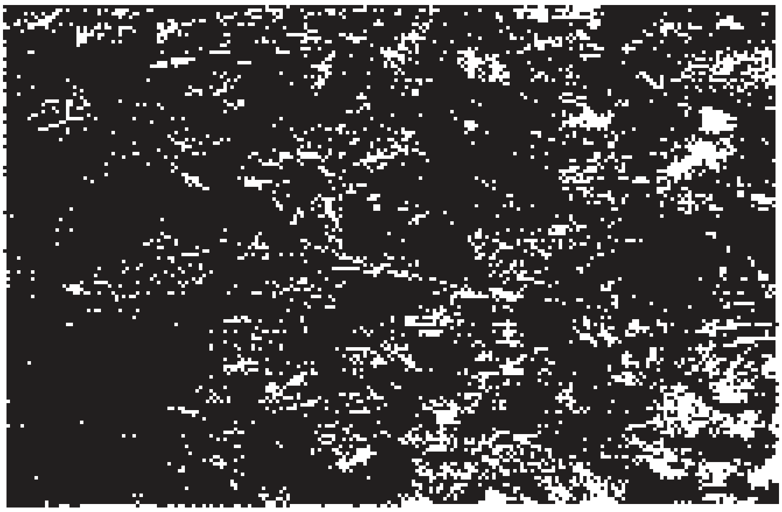
For brake energy calculations, determination of dynamometer test conditions and acceptance of the friction material brake pad, standard international specifications for testing of aircraft wheels and brakes are generally followed in addition to the brake specification. In the present case, since the transport aircraft is a military aircraft, MIL-W-5013K was followed for determination of dynamometer test conditions. Table –10 presents a typical result of the brake dynamometer tests conducted on the brake unit of the transport aircraft, comprising the iron base brake pads of the present example, for a design landing energy test.

TABLE – 10 OBSERVATIONS OF THE 10TH DESIGN LANDING TEST CARRIED OUT ON IRON BASE BRAKE PADS OF THE TRANSPORT AIRCRAFT BRAKE

Sl.	Parameter Evaluated/Recorded	Observations/Results

No.		
1.	Brake Energy absorbed	926530 Kgfm
2.	Stopping Time	17 seconds
3.	Peak Brake torque	1120 Kgfm
4.	Mean Brake torque	572 Kgfm
5.	No. of revolutions to stop (stopping distance)	163
6.	Mean coefficient of friction	0.288
7.	Maximum temperature rise on braking	502 deg. C

Figure 4 shows a brake disc of the transport aircraft, assembled with the iron base brake pads, after completion of 40% of the dynamometer tests.



High Energy Aircraft Friction Materials - yet another man-made wonder

Golden Jubilee Commemoration Lecture
(Tenth in the series)

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High Energy Aircraft Friction Materials - yet another man-made wonder

ABSTRACT

Several applications in aerospace demand extremes of performance that conventional materials could hardly meet. Engineers have developed 'man made' or 'engineered' materials that could be tailored to meet diverse and critical functional requirements in demanding situations. One such application is in the area of high energy aircraft braking, wherein complex 'man-made' friction material composites are engineered to meet extreme functional requirements of high kinetic energy dissipation.

My lecture will briefly touch upon the development, qualification and characterization of these wonder composites illustrating real-life applications in aircraft brakes. The achievements of the Hindustan Aeronautics Ltd in applied R&D and indigenous development of these exotic materials are described. Important success stories of the HAL, in this area, are highlighted.

INTRODUCTION

Aircraft Friction Materials Absorb Millions of Joules

The landing kinetic energy of modern day aircraft is several million joules. A medium civilian aircraft Boeing 737-200 has a landing energy of 30 million joules and Concorde 60 million joules. Jet fighters have energies in the range of 5 to 25 million joules; This enormous energy, when absorbed by the brakes within 10-12 seconds after landing, imposes severe thermal gradients of thousands of degrees centigrade per cm across the friction elements and brake bulk temperatures of 1000°C or more. The consequences of "fade" due to loss of friction at such temperatures could be dangerous and hence the friction material must retain its properties till 1000°C or more.

such as seizure prevention or dry lubrication and stability of the same over a wide range of temperature. In addition, structural stability over the entire temperature range of operation is to be essentially ensured under quite complex states of thermal stresses and gradients. The material should also have minimum wear over a wide temperature and load / speed range to ensure long service life in number of landings. In addition the friction material must also meet the following critical functional requirements of aircraft braking:

- Smoothness of engagement, i.e., low judder, vibration and noise
- No brake squeal
- Compatibility with mating part (low wear of mating part)

Characteristics Desired in an Aircraft Brake Friction Material

To satisfy the demanding and diverse functional requirements of aircraft braking, the friction material must possess the following properties :

- High and stable coefficient of dynamic friction and its stability over a wide range of speeds, loads and brake temperatures
- High and thermally stable wear rate for long life
- Adequate mechanical strength at room and elevated temperature
- High refractoriness (melting point)
- Good anti-seizure property with mating member material
- High specific heat and thermal conductivity
- Low coefficient of thermal expansion and tolerance to steep thermal gradients
- Compatibility and conformability with mating part to avoid judder
- Embedability property to hard ceramic particles or wear debris
- Tolerance to high ceramic and non metallic additions
- Ease of manufacture

Diverse Braking Properties Demand Engineered Materials

It is thus observed that there is a great diversity in the functional properties to be fulfilled to meet aircraft braking requirements. No single conventional engineering material or material design can meet the entire spectrum of aircraft braking requirements. A friction material is hence "engineered" and designed after judicious selection and combination of a variety of metals, non-metals and exotic ceramic ingredients, which individually and in combination satisfy the entire range of aircraft braking requirements.

The Engineered Friction Materials

The choice of materials which could qualify to meet such diverse requirements falls into a few "man-made" composite materials, v.i.z.,

- organic resin bonded composites
- sintered metal-ceramic composites
- carbon-carbon fibre composites

The organic resin / polymer composites are used for low energy, low speed aircraft and are being phased out due to asbestos usage regulations.

The carbon-carbon composites are the high end materials, recently developed to meet the highest energy dissipation and thermal requirements, but are very expensive. Usage is hence limited.

The sintered metal-ceramic composites synthesized by Powder Metallurgy (P/M) are the most abundantly used in aircraft braking and account for more than 60 % of the aircraft friction material market volume. Our successful R&D and indigenisation efforts in this country at HAL have been primarily in the area of sintered metal – ceramic friction materials by P/M.

SINTERED METAL-CERAMIC MULTI-COMPONENT COMPOSITES

The Challenges in Development

The sintered metal-ceramic friction composites consist of a variety of powdered metallic, non-metallic and ceramic ingredients that are combined to form a friction material by a specially developed P/M process. Each ingredient is chosen to meet a specific braking property.

The friction material composition for each aircraft brake is unique and so is the P/M process technology developed to synthesize the material. There is no published literature and there are only a few manufacturers world-over. There are only a handful of OEMs.

Since the material is a complex, multi-component metal matrix composite prone to heterogeneity, rigorous testing in accordance with stringent international airworthiness standards, v.i.z., FAR 25.735 / MIL-W-5013, is required.

These are the factors that make these materials exotic and the technology so dear and protected.

Further, the sintered metal-ceramic friction material developed does not by itself fulfil all the requirements of aircraft braking. There are other vital issues such as absorption of noise and vibrations generated during high speed aircraft braking, the steep thermal gradients to be neutralised, the proper fastening of the friction material to the carrier assembly etc. To meet all the above requirement, the friction element is designed as not only a multi-component friction material, but also a multi-layered composite.

This is illustrated in Figure-2 conceptually and in Figure-3 with the help of a schematic brake friction element. Figure-4 shows the metallurgical microstructure of an actual iron-based aircraft brake pad in which the technological layers are clearly observed.

Multi-layer Technology in Aircraft Brake Pads
Each layer is engineered for a specific function.

Figure 2: Conceptual multi-layers in a brake friction element

Engineered Functional Layers in a Schematic Friction Element

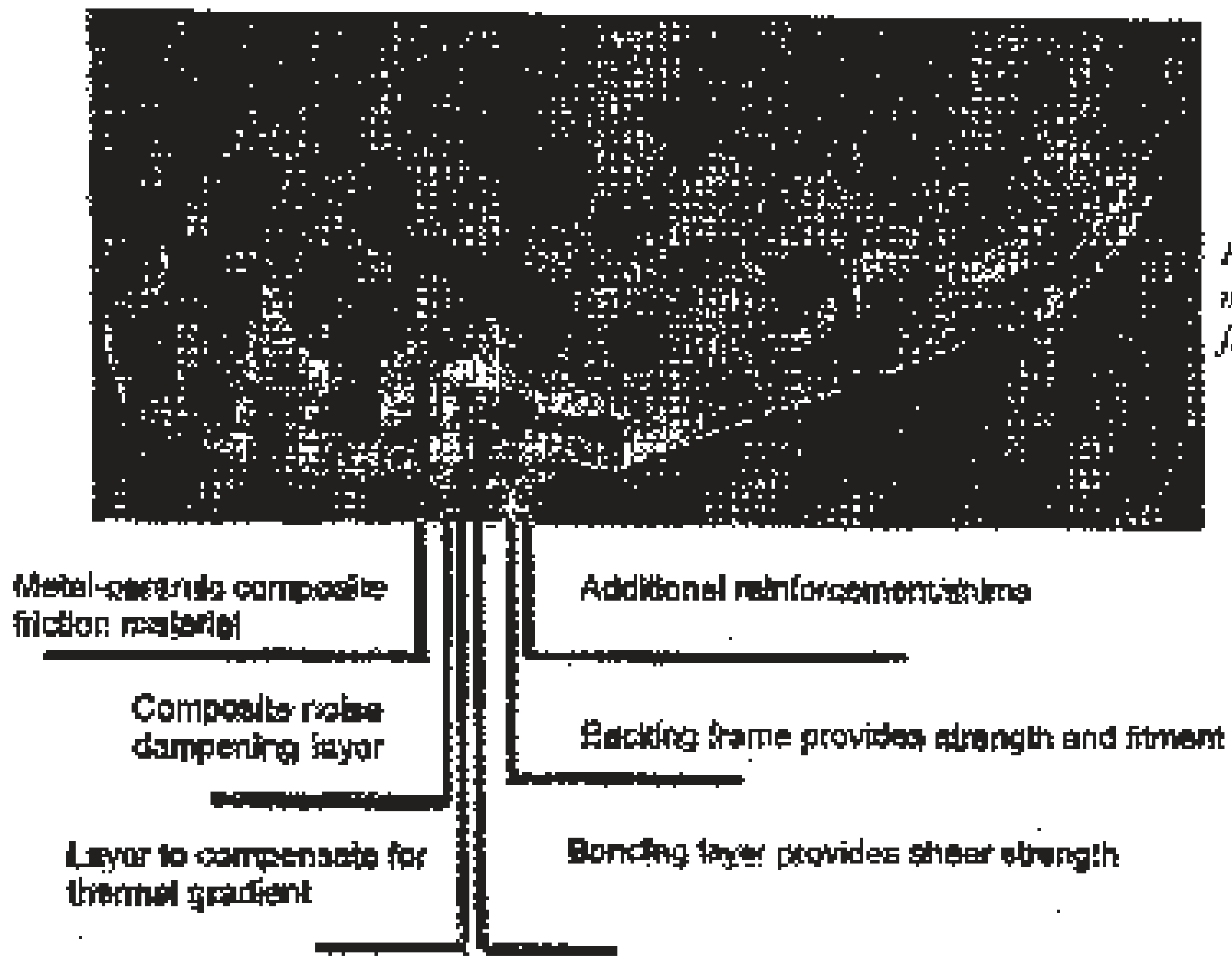

Figure 3 : Schematic multi-layers in a brake friction element

Engineered Functional Layers in Actual Friction Element

Figure 4 : Sectional microstructure of a typical iron-based brake pad showing the various technological layers.

METHODOLOGY OF DEVELOPMENT OF BRAKE FRICTION ELEMENTS

The rate of absorption of kinetic energy, the maximum temperature rise, the heat sink mass available and several other requirements vary from one aircraft to the other. Friction material composition designed to satisfy these requirements, is therefore unique for each aircraft and is 'tailor-made'.

The methodology of development of the friction material for a given aircraft brake, therefore, starts with an in-depth study of the brake design specification. A step by step approach is then followed for derivation of the physical and metallurgical properties of the candidate friction material from the brake specification, formulation design, controlled experiments to develop the technology and qualification by elaborate type and airworthiness tests.

The complete sequence of activities involved in the development of a friction element is illustrated in Figure-5.

Engineered Functional Layers in Actual Friction Element

Figure 4 : Sectional microstructure of a typical iron-based brake pad showing the various technological layers.

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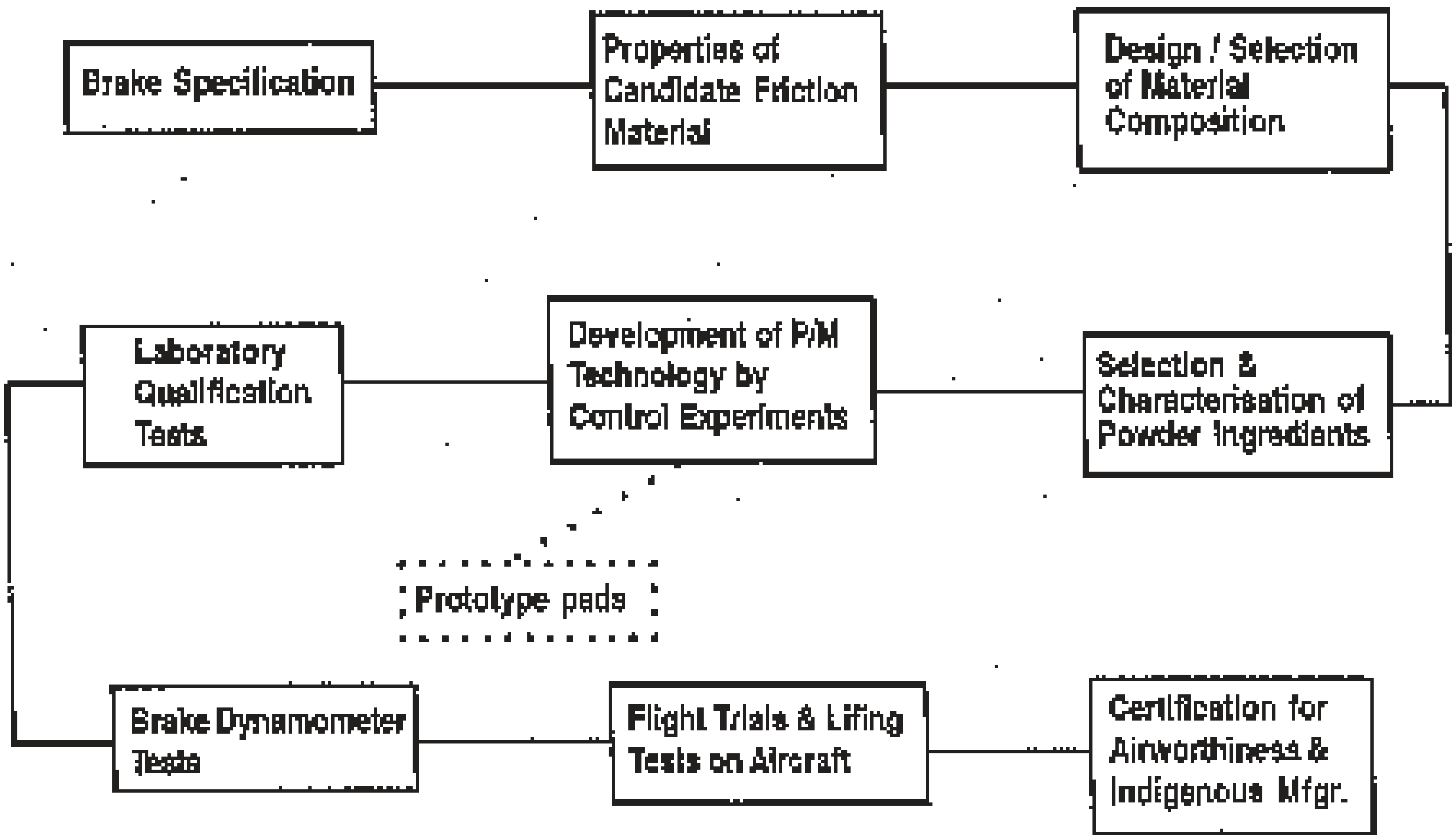


Figure 5: Sequence of activities in the development of an aircraft brake friction material

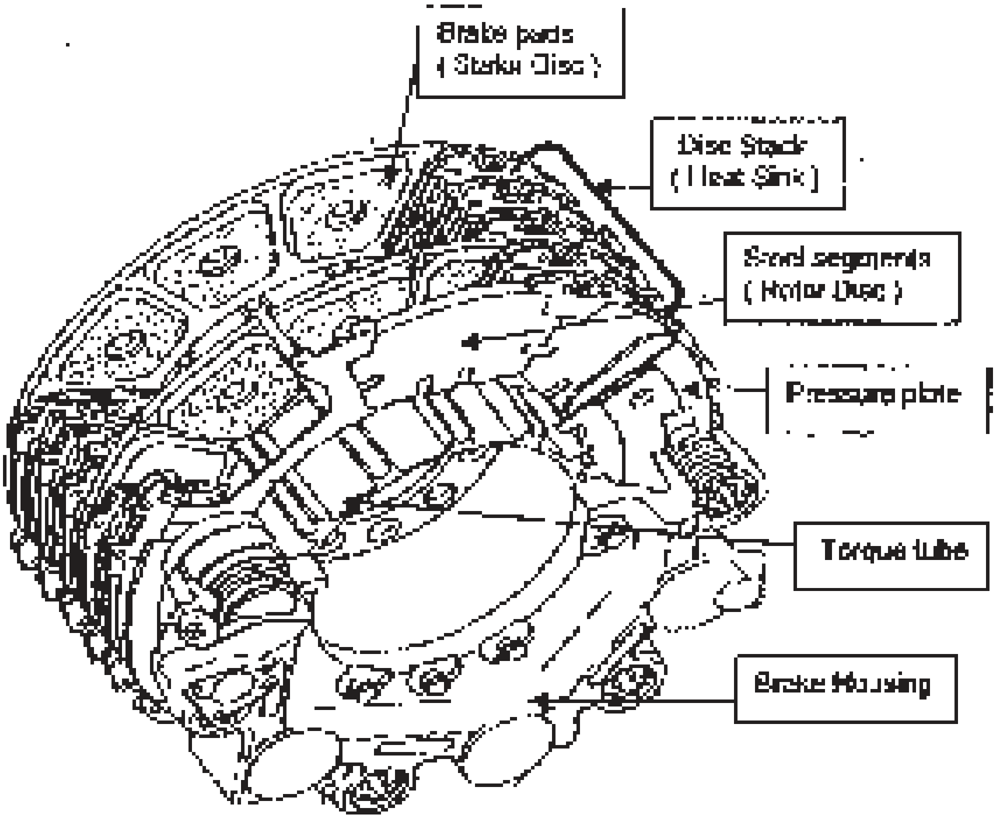


Figure-6 : Typical disc type aircraft brake unit

Step-1:Derivation of Brake Performance Parameters from Brake Design Specification

Design of a Typical Disc Type Aircraft Brake

Figure-6 presents a view of a typical disc type aircraft brake unit. The unit is designed as a multiple disc assembly consisting of a brake housing, pressure plate, torque tube, thrust plate and disc stack comprising of a series of alternate stator and rotor discs assembled with friction material brake pads and mating steel segments, respectively.

The disc stack is also called the "heat sink" and is the most important part of the brake unit. The brake functions by virtue of the conversion of the kinetic energy of the moving aircraft to heat energy and the absorption and subsequent dissipation of the same by the heat sink.

An aircraft brake heat sink is designed using the following design performance parameters derived from the basic brake design specifications: –

- **Heat Sink Loading** (Kinetic energy absorbed per unit heat sink mass)
- **Area Loading** (Kinetic energy absorbed per unit area of the rubbing faces)
- **Area Loading Rate** (Area Loading per unit braking time)

The above performance characteristics of the brake heat sink are determined from the basic brake design specification. The first phase of the development of an appropriate friction material therefore, starts with a detailed analysis of the brake design specification and deduction of brake performance characteristics from it.

Table-1 presents the typical brake design specification parameters that are required for the deduction of the brake performance characteristics. Table-2 furnishes the typical brake performance characteristics, from which basic brake design parameters are derived and how they are related.

TABLE-1 TYPICAL AIRCRAFT BRAKE DESIGN SPECIFICATION PARAMETERS

Sl No.	Basic brake design specification	Symbol (Units)
1.	Maximum Design Landing Weight of Aircraft at Sea Level	W_{dl} (Kgf)
2.	Maximum Brake Application Speed on Design Landing	V_{bl} (m/sec)
3.	No. of Landing Brakes per Aircraft	N
4.	Maximum Take-off Weight of Aircraft	W_{to} (Kgf)
5.	Maximum Decision Speed for Reject-Take-Off (R.T.O.)	V_1 (m/sec)
6.	Mean Deceleration reqd. from Brake during Design Landing	d_l (-3 m/sec^2)
7.	Minimum Deceleration reqd. from Brake during R.T.O.	d_{rto} (-1.83 m/sec^2)
8.	Mean Service Life of Brake Linings in Number of Landings	L_n
9.	Tyre Rolling Radius of Braking Wheel	R (m)
10.	Number of Brake Pistons	n
11.	Mean Diameter of Brake Pistons	D (cm)
12.	Pitch Circle Radius of Brake Pistons	r (m)

Sl No.	Basic brake design specification	Symbol (Units)
13.	Maximum Effective Brake Pressure	P_{ef} (Kg/cm²)
14.	Total design heat sink mass of brake	M_{hs} (Kg)
15.	Number of Frictional Rubbing Surfaces per brake	b
16.	Total Frictional Swept Area per rubbing surface	a (cm²)
17.	Threshold Brake Temperature Rise on Design Landing	T_{tr} (°C)
18.	Maximum Allowable Brake Temp. Rise during Emergency R.T.O.	T_{rto}(°C)
19.	Nominal Friction Material Thickness per face of brake disc	F_n (cm)

TABLE – 3 DERIVED BRAKE PERFORMANCE CHARACTERISTICS

Sl. No.	Derived Characteristics	Derived from	Relationship
1.	Kinetic energy (Design Landing), $KE_{(DL)}$	W_{DL}, V_{ta}, N	$KE_{(DL)} = ½ W_{DL} V_{ta}^2/gN$
2.	Kinetic energy (RTO), $KE_{(RTO)}$	W_{RTO}, V_o, N	$KE_{(RTO)} = ½ W_{RTO} V_o^2/gN$
3.	Mean stopping Time (Design Landing), $t_{(DL)}$	V_{ta}, d_t	$t_{(DL)} = -V_{ta}/d_t$
4.	Max. Stopping time allowed for RTO emergency braking, $t_{(RTO)}$	V_o, d_{RTO}	$t_{(RTO)} = -V_o/d_{RTO}$
5.	Mean braking distance (Design Landing), $S_{(DL)}$	$V_{ta}, d_t, t_{(DL)}$	$S_{(DL)} = V_{ta} t_{(DL)} + d_t t_{(DL)}^2/2$
6.	Max. braking distance allowed in RTO, $S_{(RTO)}$	$V_o, d_{RTO}, t_{(RTO)}$	$S_{(RTO)} = V_o t_{(RTO)} + d_{RTO} t_{(RTO)}^2/2$
7.	Mean Dynamic Brake Torque (Design Landing), $\tau_{(DL)}$	W_{DL}, d_t, N, R	$\tau_{(DL)} = W_{DL} d_t R/gN$
8.	Heat Sink Loading, H_M	$KE_{(DL)}, M_{HS}$	$H_M = KE_{(DL)}/M_{HS}$
9.	Heat Sink Area Loading, H_A	$KE_{(DL)}, a, b$	$H_A = KE_{(DL)}/(a\,b)$
10.	Heat Sink Loading Rate		
	A) Mass Loading Rate, H_M	$H_M, t_{(DL)}$	$H_M = H_M/t_{(DL)}$
	B) Area Loading Rate, H_A	$H_A, t_{(DL)}$	$H_A = H_A/t_{(DL)}$

Step-2: Derivation of Physical, Thermal and Metallurgical Properties of the Candidate Friction Material from Performance Parameters and Brake Design Specification.

From an analysis of the basic brake design data of Table-1 and the derived brake performance characteristics of Table-2, a number of physical and mechanical properties of the candidate friction material, such as coefficient of friction, wear, specific heat, melting temperature etc., could be derived, which govern the development of the friction material.

Table-3 presents some of the physical properties of the candidate friction material for a typical transport aircraft brake, the basic specification parameters from which the properties are derived, the relationship between the brake specification/characteristics and the friction material properties.

TABLE-3 PROPERTIES OF THE CANDIDATE FRICTION MATERIAL DERIVED FROM THE BRAKE SPECIFICATION

Sl. No.	Property	Derived from	Relationship	Value of property derived for a typical transport aircraft
1.	Mean Coefficient of Friction, $\bar{\mu}$	T_{DA}, P_{AC}, D, n, b, r	$\bar{\mu}=4T_{DA}/(nD^2b \times P_{AC})$	0.29
2.	Mean Specific Heat of Friction Heat Pack, S_M	KE_{DU}, M_{HS}, T_{BC}	$S_M=KE_{DU}/M_{HS}T_{BC}$	0.59 J/gm°C
3.	Maximum allowable Wear rate per braking stop, W_m	F_W, L_s	$W_m = F_W/L_s$	0.003 mm
4.	Minimum Melting point of Friction material, T_M	T_{BC}	$T_M \geq (T_{BC} + 200°C)$	1250°C

The typical transport aircraft friction material, properties for which are derived above will be taken as the candidate material in rest of the discussions as an example.

Step-3: Design & Selection of a Friction Material Composition

The composition of the prototype friction material is then designed based on the properties derived. The first step in this process is the selection of the metallic matrix material which imparts the basic physical, mechanical and thermal properties and accounts for 60 to 75% of the weight.

The choice of matrix is restricted to either a copper base or an iron base or a judicious combination of the two. Minor additions of other metals such as Zinc, Tin, Nickel, Chromium, etc., as alloying elements, are done to enhance the mechanical properties.

The relative characteristics of iron and copper based matrix materials are given below in Table-4.

TABLE-4 SELECTION OF IRON OR COPPER AS MATRIX

Characteristics	Iron	Copper
Specific Heat at Room Temp. (Joules/gm/°K)	0.59	0.42
Thermal Conductivity at R.T. (J/M/Sec/°K)	59	346
Coefficient of Linear Expansion ($°K^{-1}.10^{-6}$)	14	18
Heat Sink Loading Capacity (Joules/Kg)	450,000	280,000
Tensile Strength (MPa)	410	240
Melting Point (°C)	1539	1083
Antiseizure	Good	Poor
Tolerance to ceramic/non-metallic additions	Poor	Good
Softening Resistance at Elevated Temperature	Good	Poor
Ease of Manufacture into Friction Materials	Poor	Good

From an analysis of the properties of iron and copper and those desired in the candidate friction material, the matrix material could be easily selected. For the transport aircraft brake, taken as an example, iron could be selected as the most suitable matrix material as the properties desired such as specific heat, heat sink loading, melting point, etc., are observed to be closely met by iron.

The next step in the design of composition is the selection of the other secondary ingredients such as friction additives, dispersed solid lubricants, stabilisers, etc.

Table–5 illustrates the various ingredients commonly used in formulation of metal-ceramic friction materials to fulfil the diverse functional characteristics required. The type and proportion of the secondary ingredients selected are based on the level of functional properties required in the resultant friction material.

TABLE–5 FRICTION MATERIAL INGREDIENTS

Functional Characteristics	Components / Ingredients
Friction, strength, thermal conductivity and specific heat	Matrix: Copper or iron (with or without alloying elements, e.g., Sn, Zn, Ni, Cr, Mn etc.).
Lubrication, seizure prevention, stability	Dispersed Lubricants: Graphite, Lead, MoS_2, Special high temp. lubricants.
Abrasion / Friction	Abrasive Component: Silica, Mullite, Silicon Carbide, Alumina, Silicon Nitride, Boron Carbide, etc.
Friction stability, thermal stability, Softening resistance, Conformability	$BaSO_4$, $CaSO_4$, $MnSO_4$, Fe_3P, B, Mo, W. etc.
Wear resistance	Cast iron grits, spinels, steel wool, pearlite and cementite phase in iron matrix.
Fillers	Carbon, Minerals.

Selection of the Abrasive/Friction Ingredient

The abrasive component is the next most important ingredient as this gives rise to friction and also helps prevent local welding and metal transfer of the matrix material onto the mating part during braking.

Silica and mullite are suitable for low and medium energy friction materials whereas the carbides and nitrides of silicon are most desirable for high energy brakes of high heat sink loading.

For the transport aircraft brake, the heat sink loading and kinetic energy values are high (heat sink loading of more than 600,000 Joules/kg) and therefore the choice was between SiC and Si_3N_4. SiC was selected since it is more abundantly available, is cheap and is stable till a temperature of 1800°C.

Selection of the Dry Lubricant/Anti-seizure Additive

To avoid gross seizure between the friction element and mating part dispersed dry lubricants are added. These lubricants (5 to 25%) provide smoothness of engagement during braking by forming a self regulating smooth film on the friction surface.

High graphite contents (15 to 20%) are suitable for low brake temperatures and high thermal conductance, but in conditions of poor heat transfer, as in the present example, the addition of graphite should not exceed 6 to 8%. Graphite is not a good lubricant at temperatures above 600°C. Hence, a second high temperature lubricant is also required for high energy brakes. In the example of the transport aircraft, graphite could be chosen as the primary lubricant and a secondary lubricant is also required. Secondary lubricant additions are normally kept very low, i.e., about 1 to 2%, as higher amounts added lead to excessive wear of the friction material.

Selection of Friction and Wear Stabilisers/Modifiers

A critical requirement that a high energy friction material must fulfil, is thermal stability, i.e., the basic strength, friction and wear rate of the material should not deteriorate appreciably with increasing speed and brake temperature.

Sulphates of Barium, Calcium, Manganese or Iron are effective stabilisers. Boron, Molybdenum and Tungsten also are used.

$BaSO_4$ is very commonly used in iron base materials. Additions are limited to 12% beyond which mechanical properties of the friction material decline. In the present example of the transport aircraft brake, $BaSO_4$ upto 10 % could be selected as the friction stabiliser.

The resultant composition of the iron base friction material for a typical high energy transport aircraft brake could be tentatively fixed as given in Table–6.

TABLE-6 FRICTION MATERIAL FORMULATION FOR THE TRANSPORT AIRCRAFT BRAKE

Ingredient	Weight Percent
$BaSO_4$	8 to 12%
Graphite	6 to 8%
Silicon Carbide	7 to10%
High temp. Lubricant	1 to 2%
Copper	5 to 7%
Iron	Balance

Design and Selection of Other Functional Layers

In iron base friction elements a pure sponge iron powder layer of thickness 0.5 to 2.0 mm between the friction material and the nickel plated steel backing frame is incorporated as a special feature by making a multi-layer compact. The sponge iron layer acts as a cushion layer due to its sponginess. This characteristic allows the effective damping of vibrations/judder during braking.

This layer also acts as a medium to further ensure good bonding between the friction material and the steel back plate through the intermediate nickel layer. A portion of lower melting copper/tin, which are the ingredients of the friction material, also percolate to this sponge iron layer during pressure sintering by capillary action and are believed to reduce the effect of thermal gradients.

In copper base friction materials, a cup type design and presence of metallic grid inserted by spot welding between the cup and the friction material ensures judder reduction, bonding and integrity of the material against thermal gradients.

High energy braking could lead to a situation where the contacting surface of the friction material may be at a instantaneous temperature of 1000°C whereas the back plate may be closer to ambient temperature. This causes instantaneous thermal expansion on the friction material. At the same time the back plate resists this expansion resulting in the interfacial layers to be subjected to large shear stresses which could lead to catastrophic bond failure during service. The sponge iron layer due to a large volume of porosity neutralises the expansion gradient to a large extent due to the pores acting as "stress sinks".

The nickel coated layer of the back plate also contributes to neutralising the thermal gradient due to a compositional gradient that exists across its thickness. The compositional gradient arises due to its alloying with some of the friction material ingredients on one side and with the back plate on the other side.

Step 4: Development of P/M Process for Fabrication of Brake Pads

The next step is development of an appropriate P/M process for fabrication of the friction material into brake pads / elements by controlled experimentation. The various steps involved in development of the optimum process are as follows:

- Selection of raw materials based on composition
- Powder mixing
- Powder compaction
- Processing of back plate frame
- Pressure sintering of brake pads

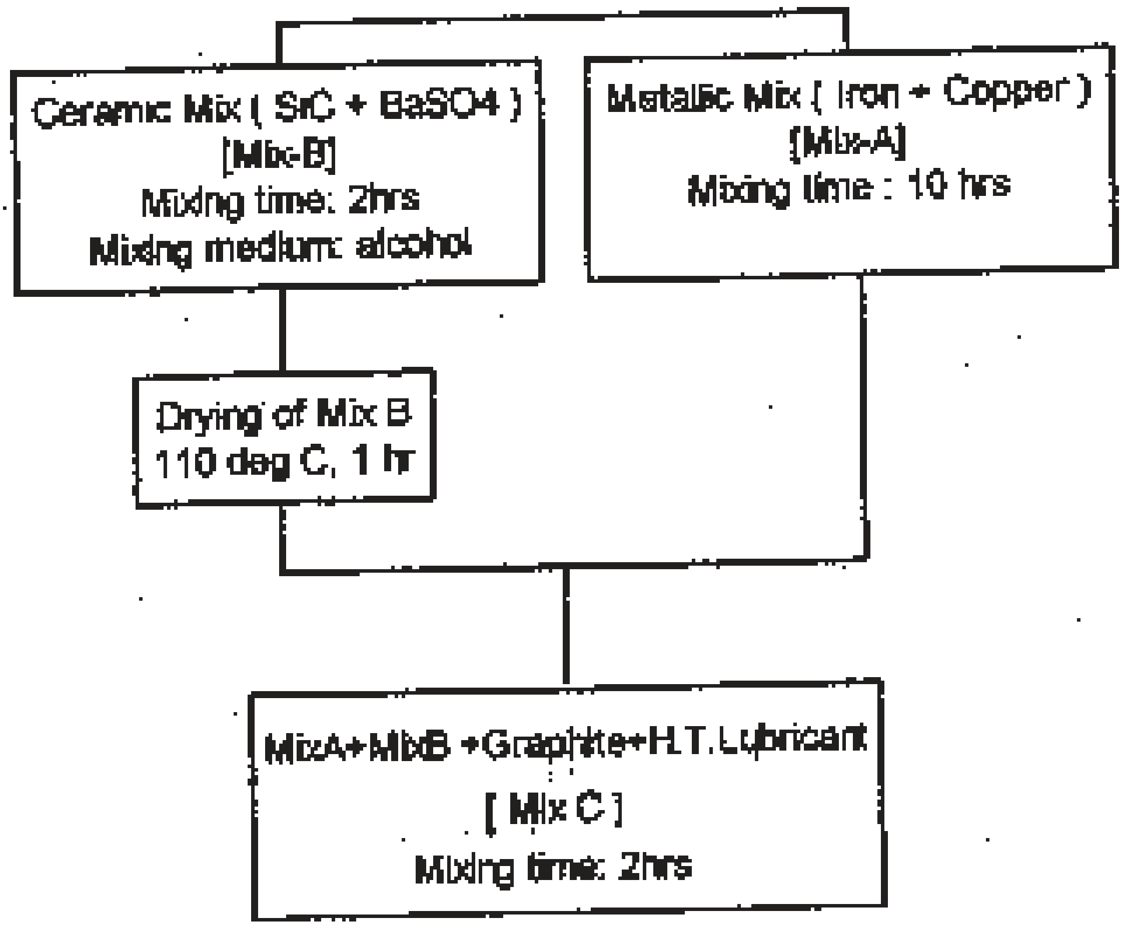
A) Selection and Optimisation of Raw Materials Based on Composition

Designed experiments are carried out to optimise the specification of the raw material corresponding to each friction material ingredient. Prototype brake pad samples made from a few alternative raw materials-of each ingredient are tested for basic properties such as friction and wear. From the results of these experiments each raw material type and specification is fixed and optimised.

A similar procedure was adopted for selecting and optimising the raw materials and their properties/specifications for the transport aircraft brake friction material in the present example.

B) Powder Mixing

Experiments are carried out by varying sequence and method of mixing, mixing time and mixing medium to establish an optimum mixing procedure which would result in the best bulk density and flow rate characteristics. For the military transport aircraft friction material formulation the following mixing procedure, established through experiments, yielded the best result:



C) Powder Compaction

Pressure for compacting the friction material into the desired shapes required in the final brake pad is chosen and optimised based on experiments which yield the most optimum green density value of the resultant compact. Higher pressures lead to marginal increase in the green density but may cause cracking of the compact due to high residual stresses.

Usually double or multi-layer compaction is carried out in which the first layer is the friction material layer and the others sponge powder layers.

The compaction pressure for iron-based friction materials is about 500 to 540 Mpa and for copper base friction materials it is in the range of 380 to 420 Mpa.

D) Processing of Back Plate Frame

A single or multi-layer friction material compact is a composite with about 40% by volume of non-metallic ingredients and possesses quite low strength. In order to withstand the severe service environment and also for assembly into the brake rotor and stator plates by riveting, the friction material is either housed in a backing steel container or is diffusion bonded, during pressure sintering operation, onto a steel back plate frame of the same shape and contour.

For medium energy aircraft brakes with maximum temperatures of 600°C, low carbon steel is considered a suitable back plate material. For high energy brakes, in which temperature rise is beyond 750°C, the choice of a back plate material is restricted to stabilised high strength low alloy steels of high hardenability and possessing good thermal fatigue properties.

Steels normally used are AISI-4340, BS-S155, M-300 etc. In present example for the iron-based brake friction material of the military transport aircraft, the back plate chosen is AISI-4340.

After selecting and procuring the steel material in sheet or strip form, back plate segments are then fabricated by shearing operations using press tools.

The steel backing segments are then given a nickel or a copper plating, for iron-based and copper-based friction materials respectively, from cyanide/alkaline bath for aiding the subsequent diffusion bonding process with the composite friction material during the pressure sintering operation.

After plating the back plates are given a diffusion anneal treatment to ensure proper metallurgical bonding of the plated layer to the underlying steel plate.

E) Pressure Sintering of Brake Pads

For pressure sintering a special type of sintering equipment, viz., a pressure sintering bell type furnace with a hydraulic charge pulling arrangement is used.

To optimise the pressure sintering parameters for prototype brake pads, sintering experiments to establish the temperature-pressure-time cycle are carried out. The objective is to produce prototypes with the desired mechanical, metallurgical and physical properties as derived from the brake specification.

Experiments carried out for the iron-based friction material of the military aircraft brake resulted in the following optimum pressure sintering parameters that could yield prototype brake pads which met all the property requirements:-

Sintering temperature	-	1025°C
Sintering pressure	-	150 Mpa
Sintering time	-	2 hours
Sintering atmosphere	-	Dry Hydrogen

The Resultant Prototype Friction Element

Figure- 7 shows the micro structure cross section of the brake pad sintered under the above optimum conditions. The microstructure shows a predominantly fine pearlitic structure of the matrix iron phase in which SiC particles and graphite are observed to be uniformly dispersed. The irregular shaped light/ white areas are copper. Besides

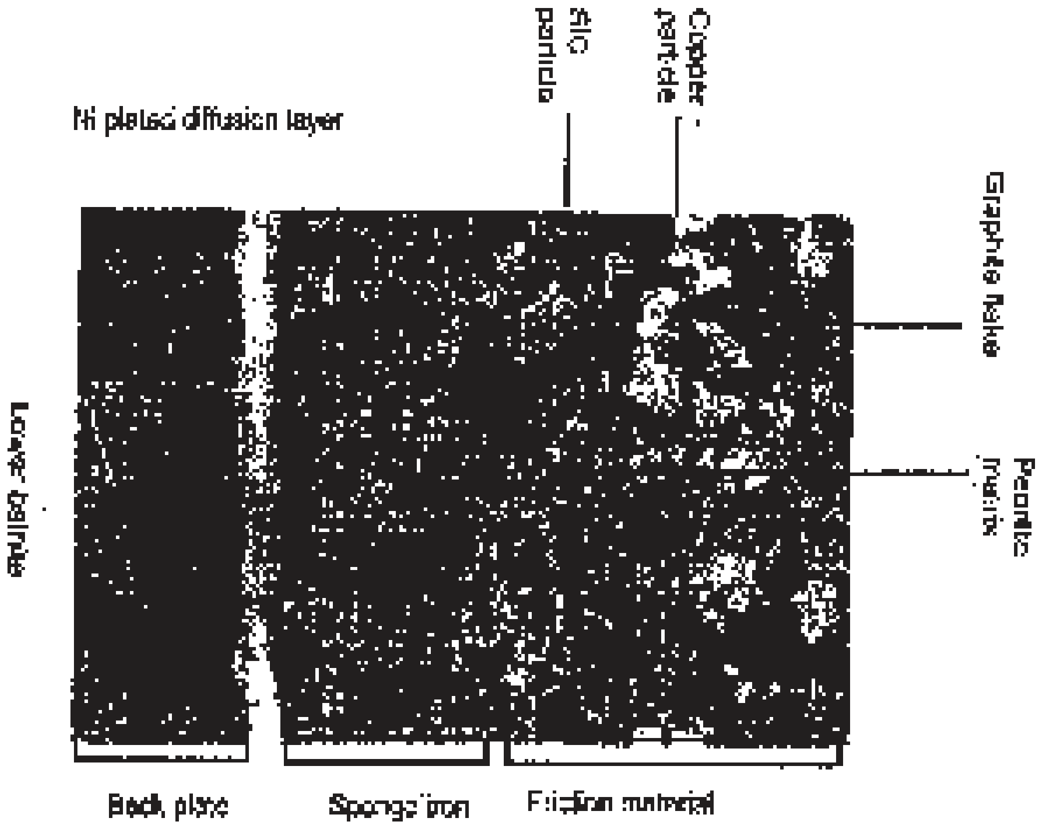


Figure - 7 : Microstructure of the pressure sintered iron-based brake pad of the military transport aircraft

the ideal structure of the friction material, a sound interfacial diffusion bonding is also observed between the steel back plate and the friction material through an intermediate electro-deposited nickel layer of thickness of about 150 microns.

Step 5 : Qualification and Airworthiness Testing of Prototype Brake Pads

After establishment of the optimum manufacturing process by controlled experimentation as described above, sufficient number of prototype brake pads are processed for undergoing airworthiness qualification tests.

The airworthiness requirement for brake materials meant for all types of military aircraft is governed by MIL-W-5013 and Technical Standard Order-26 issued by Federal Aviation Administration, USA.

In accordance with the airworthiness requirements, highly elaborate test procedures are prescribed for friction brake pads for certifying them for normal use on aircraft brake. The entire testing procedure can be divided into three stages:

* Laboratory Qualification tests
* Brake Dynamometer tests
* Aircraft trials

Laboratory Qualification Tests

In this stage in-depth analysis and evaluation of the prototype brake pads is carried out to assess the metallurgical and physical properties of the prototype pads in accordance with airworthiness schedules/ specification. The following are the tests:

- Hardness test on friction material and back plate
- Density determination
- Chemical analysis

  – by classical or instrumental methods such as XRD, EDAX, spectroscopy, etc.
- Microstructural characterisation:
  - Optical microexamination for identification and distribution of major constituents in friction material and structure of back plate.
  - Bimetallic Bonding
  - Microhardness survey on selected constituents and phases
- Specific heat and thermal conductivity by calorimetry
- Friction and wear test using a laboratory test rig
- Phase identification studies by Scanning Electron Probe Micro Analysis (SEPMA) for identification, and chemistry distribution of various constituents and phases.

Table-8 furnishes the results of Laboratory qualification tests carried out on the iron-based friction material prototypes developed for the military transport aircraft brake.

TABLE–8 RESULTS OF LABORATORY TESTS ON PROTOTYPE BRAKE PADS DEVELOPED FOR A TYPICAL TRANSPORT AIRCRAFT

Tests/Analysis Conducted	Results Obtained
Hardness (Average)	
a) Friction material b) Steel back plate	135 BHN 446 VPN
Density of friction material (gms/cc)	6.11
Chemical composition of friction material	SiC: 9%, C: 7.8%, BaS: 9.5%, Cu: 4.6%, HTL: 1.3%, Fe: Bal
Microstructure (Fig-7) i) Optical	a) SiC particle size: 100 to 180 microns b) Graphite: Flaky, 250 to 400 microns c) Matrix: Fine Pearlite, Ferrite content: 3 to 5% d) Copper: uniformly distributed in matrix
ii) Bimetallic Bonding	Sound interfacial bonding between steel back plate and friction material through Ni plated layer. Nickel layer thickness: ~150 microns.
iii) Back Plate	Fine lower bainite
iv) Microhardness	a) Matrix: 315 to 335 VPN b) SiC: 1300 to 1540 VPN
Specific heat at R.T.	0.598 Joules/gm°K
Friction Test (50 normal energy braking stops) on 2 prototype specimen	
i) Avg. stopping time	9.2 seconds
ii) Avg. coefficient of friction (dynamic)	0.292
iii) Wear in 50 stops	
a) by weight loss	2.5 gms (0.05 gms/stop)
b) by thickness	0.14 mm (0.0028 mm/stop)

By comparing the above results with the laid down property specifications, some of which are given in Table-3, it was observed that the iron-based friction material developed met the requirement of the properties and the transport aircraft brake specification quite well.

On this basis, the composition of the friction material selected, the raw material specifications, the back plate steel and the P/M process parameters are tentatively fixed and documented.

Brake Dynamometer Tests

The laboratory qualification tests on individual prototypes are not adequate to fully qualify the friction material for airworthiness. Actual field performance is required to be tested thoroughly. This is fulfilled by conducting the *brake dynamometer* tests wherein the aircraft brake unit, assembled with the newly developed brake pads, is subjected to repeated cycles of real time brake performance tests simulating the aircraft *"design (normal) landing"* and *"rejected take-off"* brake energy conditions.

For determination of dynamometer test conditions and brake energy, standard international specifications for testing of aircraft wheels and brakes are followed in addition to the brake specification. In the present case of the transport aircraft, MIL-W-5013K was followed and the conditions simulated are given in Table - 9

Table-10 presents a typical result of the brake dynamometer tests conducted on the brake unit of the transport aircraft, for a design landing energy test.

Aircraft Trials

Field / service trials are carried out on the prototype brake pads after successful completion of dynamometer tests using the aircraft as a test bed.

"Accelerate – stop", "landing" and "taxying and turning" tests are carried out under critical combinations of aircraft weight and speed

TABLE – 9 THE CONDITIONS SIMULATED FOR BRAKE DYNAMOMETER TESTS FOR IRON-BASED BRAKE PADS OF TRANSPORT AIRCRAFT

Test parameters	Conditions Simulated for test under	
	Design landing	R.T.O
Brake Energy, ($I\omega^2/2$)	9,346 x 10^5 Kgfm	1.66 x 10^6 Kgfm
Gyrating mass Inertia, (I)	152 Kgfmsec^2	164 Kgfmsec^2
Gyrating mass RPM, (N)	1060	1360
Angular Velocity of gyrating mass, ($\omega = 2\pi N / 60$)	111 per second	142.4 per second
Brake pressure	100 Kgf/sq.cm.	100 Kgf/sq.cm
No. of stops	50	1

TABLE–10 OBSERVATIONS OF THE 10th DESIGN LANDING TEST CARRIED OUT ON IRON-BASED BRAKE PADS OF THE TRANSPORT AIRCRAFT BRAKE

Parameter Evaluated/Recorded	Observations/Results
Brake Energy Absorbed	929890 Kgfm
Stopping Time	17 seconds
Peak Brake torque	1120 Kgfm
Mean Brake torque	572 Kgfm
No. of revolutions to stop (stopping distance)	160
Mean coefficient of friction	0.288
Maximum temperature rise on braking	502° C

INDIGENOUS DEVELOPMENT OF SINTERED FRICTION MATERIALS FOR AIRCRAFT BRAKES

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INTRODUCTION

Friction materials used as brake pads and discs in high energy aircraft brakes are carefully engineered man-made composite materials. These materials are designed and developed to withstand extremely severe and diverse operating conditions and are rigorously tested and certified to guarantee a high level of performance and reliability in service.

There are basically three categories of man-made composite materials used as friction materials of which the sintered metalloceramic composites are the most common and are abundantly used in aircraft brakes. These composites are fabricated by the modern technology of powder metallurgy (P/M).

Development of a sintered friction material for a given aircraft brake involves design and formulation of an appropriate friction material composition, development of a special technology for fabrication of the material into the required brake element shape and finally proving the properties, performance and reliability of the friction material against stringent airworthiness specifications through elaborate and repeated tests. The above R&D exercise is a well planned, step-by-step, scientific approach and involves usage of sophisticated analytical and research tools and techniques and also calls for a high degree of technical skill and perseverance.

In the last twenty years, significant work has been done in the Country in the field of sintered friction materials. Pioneering work in this field has been done by the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, in the early 70's which led to the successful development of the iron-base MiG.21 aircraft brake pads which are now under routine production at the Hindustan Aeronautics Limited (HAL). Following this pioneering effort of DMRL, responsibility for further R&D in friction materials and development of brake pads for various other aircraft was taken up by HAL. HAL has over the last five years successfully developed and tested sintered friction materials for various aircraft. HAL has now developed a full-fledged infrastructure and expertise for applied R&D and production of aircraft brake friction materials.

Indigenous development and production of friction material in our Country has resulted in considerable savings in foreign exchange.

PROPERTIES, DESIRED CHARACTERISTICS AND TYPES OF FRICTION MATERIALS

The primary function of a brake friction material in any vehicle, in motion, is to absorb the kinetic energy of motion and convert it to heat energy by doing frictional work. The type of vehicle, the initial kinetic energy level and the allowable stopping distance are the most vital factors which decide the extent and rate of frictional work to be done by a friction material during braking. Thus the friction material should be suitably engineered and designed to meet the specific needs of a particular vehicle.

The prime requisite of a good friction material is a suitably high dynamic co-efficient of friction and stability of this property over a wide range of temperatures and brake application speeds. In addition to this, the friction material should possess a host of other stable and consistent physical and mechanical properties to guarantee reliable long-term performance under the extremely severe and complex operating conditions encountered during the service life of a brake. The kinetic energy, which the friction material of a modern day heavy transport or high speed jet aircraft must absorb, for instance, could be of the order of several millions of joules. This enormous quantum of energy when absorbed by the friction material over a short interval of 10 to 15 seconds, after landing, imposes extremely severe thermal conditions on the friction material. The thermal gradient in a modern disc type aircraft brake, for instance, can reach several hundred degrees centigrade per centimetre and the surface temperature on the friction material element can reach well over $1000^{0}C$. The consequences of "fade" due to loss of friction at such high temperatures, and drastic reduction of mechanical properties would be highly dangerous. The friction material therefore in addition to providing the frictional work of decelerating and stopping the aircraft, must also retain its physical and mechanical properties upto $1000^{0}C$ or more.

All the above severe operating conditions impose extremely demanding and diverse requirements on the brake friction material. No conventional engineering material processed by conventional fabrication methods, can satisfy the diverse requirements and therefore the choice of a suitable friction material is restricted to a few types of carefully engineered manmade composite materials which can meet the following property requirements in addition to a stable co-efficient of friction:-

- high specific heat and thermal conductivity.
- high melting point.
- low co-efficient of thermal expansion.
- elevated temperature strength and structural stability.
- good thermal shock and thermal fatigue resistance.
- good anti-seizure property.
- compatibility of friction material with mating part (steel or cast iron) to provide smoothness of engagement.
- low wear rate and stability of wear rate with rise in brake temperature and rubbing speed.

Most of the above properties are achieved in a tailor-made friction material composite by judicious selection and combination of various types of metal/non-metal, organic, ceramic and certain exotic synthetic material ingredients each of which can satisfy either individually or in combination almost the entire spectrum of braking requirements.

Depending on the level of kinetic energy to be absorbed and the limit of temperature generated on the friction material surface, modern friction materials can be categorised into the following three classes:-

- Resin, Asbestos or Rubber based Organic composites with organic fillers;
- Metal-base inorganic sintered metalloceramic composites;
- Carbon-carbon fibre composites.

Organic resin based composites were the earliest friction materials developed and used extensively in the 1920's and 1930's. Used under various trade names as "Ferodo", "Ratinax", "Ray best", etc., these composites are still used for light to moderate duty braking applications where kinetic energy absorption requirements and brake temperatures and speeds are on the lower side of the spectrum. They find extensive application in braking mechanisms of motor cars, buses, two wheelers, moving machinery parts and light weight-low speed aircraft. These composites possess a working surface limit temperature of about 600°C and suffer from poor thermal conductivity and specific heat.

Metal base metalloceramic friction materials are much stronger and more heat resistant and were developed in response to energy inputs and temperatures which exceeded the capabilities of organic composites. World War II, with its demands for large quantities of heavy duty friction materials in military vehicles and aircraft, contributed much to the growth of metalloceramic friction material industry. Today sintered metalloceramic composites are the most abundantly used friction materials and account for about 30 percent of the total friction materials industry and almost 75 percent of the aircraft brakes are made out of these materials.

Carbon-Carbon composites are the latest entry into the field of friction materials and have been developed mainly to cater to the severest operating conditions encountered in modern day supersonic jet fighters and very large and heavy commercial jet liners. The working limit temperature of steel-based metalloceramic friction materials is 1100^{0} C whereas Carbon composites, which have a density approximately a quarter of that of steel and a specific heat double that of steel, can comfortably operate at brake temperatures of over 1400^{0}C while effecting a substantial reduction in aircraft brake weight.

P/M METALLOCERAMIC FRICTION MATERIALS

Of the various types of braking applications, the most severe operating conditions are encountered by the friction material elements used on aircraft brakes as the highest braking speeds and the hottest environment are encountered by aircraft brakes. Since a majority of the aircraft brakes are made out of metalloceramic friction materials, from the industry's stand point this class of materials assumes utmost significance. This class of friction materials are made by the modern route of Powder Metallurgy (P/M) and can be further classified into two categories depending on the metallic matrix used i.e., these materials are either Copper-based or Iron-based compositions.

Iron-based compositions are generally preferred in moderate-to-severe duty aircraft brake applications and can withstand peak brake temperature in excess of 1100^{0}C. The Copper-based compositions are preferred for light to moderate duty brake applications, possess good thermal conductivity for efficient heat dissipation and can withstand peak temperatures upto 800^{0}C.

Typical processing techniques for P/M friction materials include powder compaction, pressure sintering in protective atmosphere furnaces at high temperatures for long times, sometimes followed by re-pressing. Fine and reactive metal powders and other non-metallic additions are preferred. The friction elements are usually brazed, welded, riveted or are most often directly diffusion bonded to the supporting steel members.

The P/M friction materials are multiphase composites and contain typically between 4 to 8 ingredients, which leads to innumerable combinations and effects that can satisfy the diverse functional requirements of aircraft braking. Design and selection of P/M friction material compositions is based on four or five functional characteristics which are summarised below in Table-1.

TABLE-1 – FRICTION MATERIAL INGREDIENTS

Functional Characteristics	Components
1) Friction, strength and thermal conductivity	Matrix/binder: Copper or Iron base(with or without alloying additions such as Sn, Zn, Ni, Cr, Mn, etc)
2) Lubrication (seizure prevention, stability)	Dispersed lubricants: graphite, lead, molybdenum disulphide, Boron nitride, etc.
3) Abrasion/friction	Abrasive (frictional) components: Silica, mullite, alumina, silicon carbide, silicon nitride, boron carbide, etc.
4) Wear Resistance	Cementite, cast iron grits, spinels, steel wool, etc.
5) Friction stability, thermal stability, softening resistance, conformability	BaS, CaS, MoS, Fe_3P, B, Mo, W.
5) Fillers	Carbon, Minerals.

The matrix which is usually an Iron-base or Copper-base material accounts for 50 to 90% of the total weight (more than 40% of volume). About 5 to 15% consists of a low melting point metal such as tin or zinc which alloys with the matrix through liquid phase sintering. This provides strength, friction and thermal conductance.

To avoid gross seizure between the friction element and the mating part, certain dry lubricants are added. While these lubricants (5 to 25%) prevent gross seizure, they do not prevent local welding and metal transfer. To minimise this, upto 20% of an abrasive (often called the frictional component) is added. Since these abrasive additions also produce wear, the amount added depends on how much wear can be tolerated in a specific application.

An important requirement is thermal stability, which means that the basic strength, friction and wear rate should not appreciably deteriorate with increasing brake temperature upto the limit temperature. Special additions such as Sulphides of Barium and Calcium are introduced into the composition to promote stability of friction and wear at elevated temperatures. Refractory metals such as Tungsten and Molybdenum are added to promote elevated temperature strength.

The wear resistance components account for upto 10%, essentially for dry applications. Some of these components such as spinels and mixed metal oxide solutions may be formed during sintering.

Finally fillers are added, in amounts upto 16%, to decrease cost.

The co-efficient of friction is dependent not only on speed, brake pressure and temperature, but also on composition and the characteristics of the powder ingredients used. In view of this complexity, optimum compositions are still derived empirically to suit given requirements.

The P/M friction material elements are designed in a wide variety of sizes, shapes and configurations depending on design of the brake system. Thus the element may be produced in the shape of individual sintered segments or coins which are subsequently rivetted to the brake disc assembly [Fig.1] or they may be in the form of a monolithic friction material layer directly diffusion bonded on to a steel brake disc [Fig.2].

The configuration of each individual friction element in case of segmental shapes can also vary. In one type, the friction material segment made separately is diffusion bonded on to a steel frame or back plate segment of the same size and shape. This configuration is usually preferred for the stronger irregular shapes and relatively less friction material thickness. In another configuration, the friction material is totally encased in cup shaped steel container which provides strength and lateral support to the friction material element. This configuration is preferred for relatively weaker copper-based materials and higher friction material thicknesses. Fig.3 illustrates the two types of configurations.

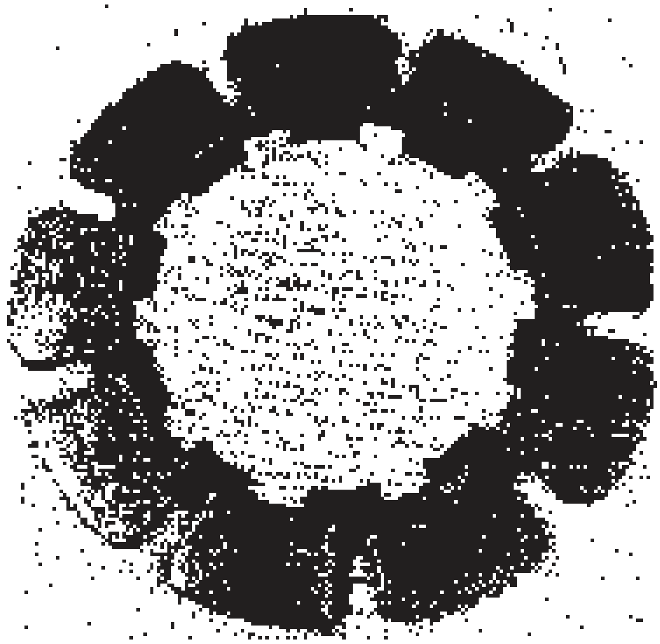


Fig.1(a) Segment shaped brake pads

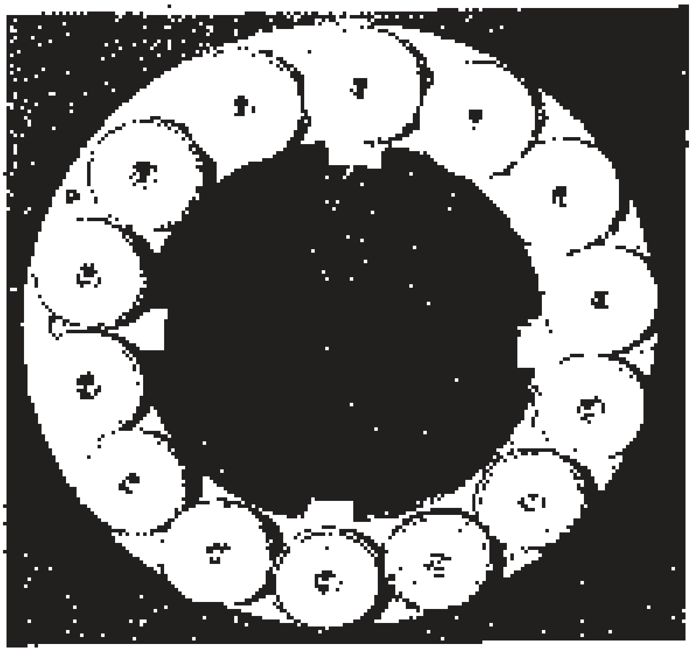
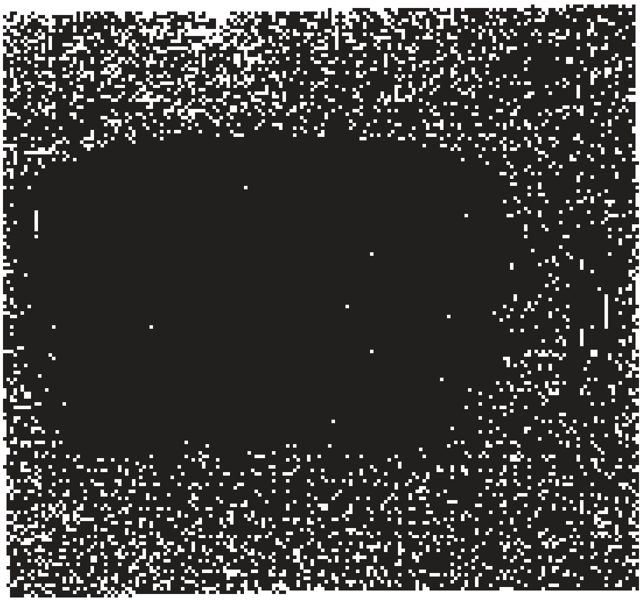


Fig.1(b) Coin shaped brake pads

Fig.2 Friction material brake disc



g.3(a) Segmental friction material bonded to flat steel back plate.

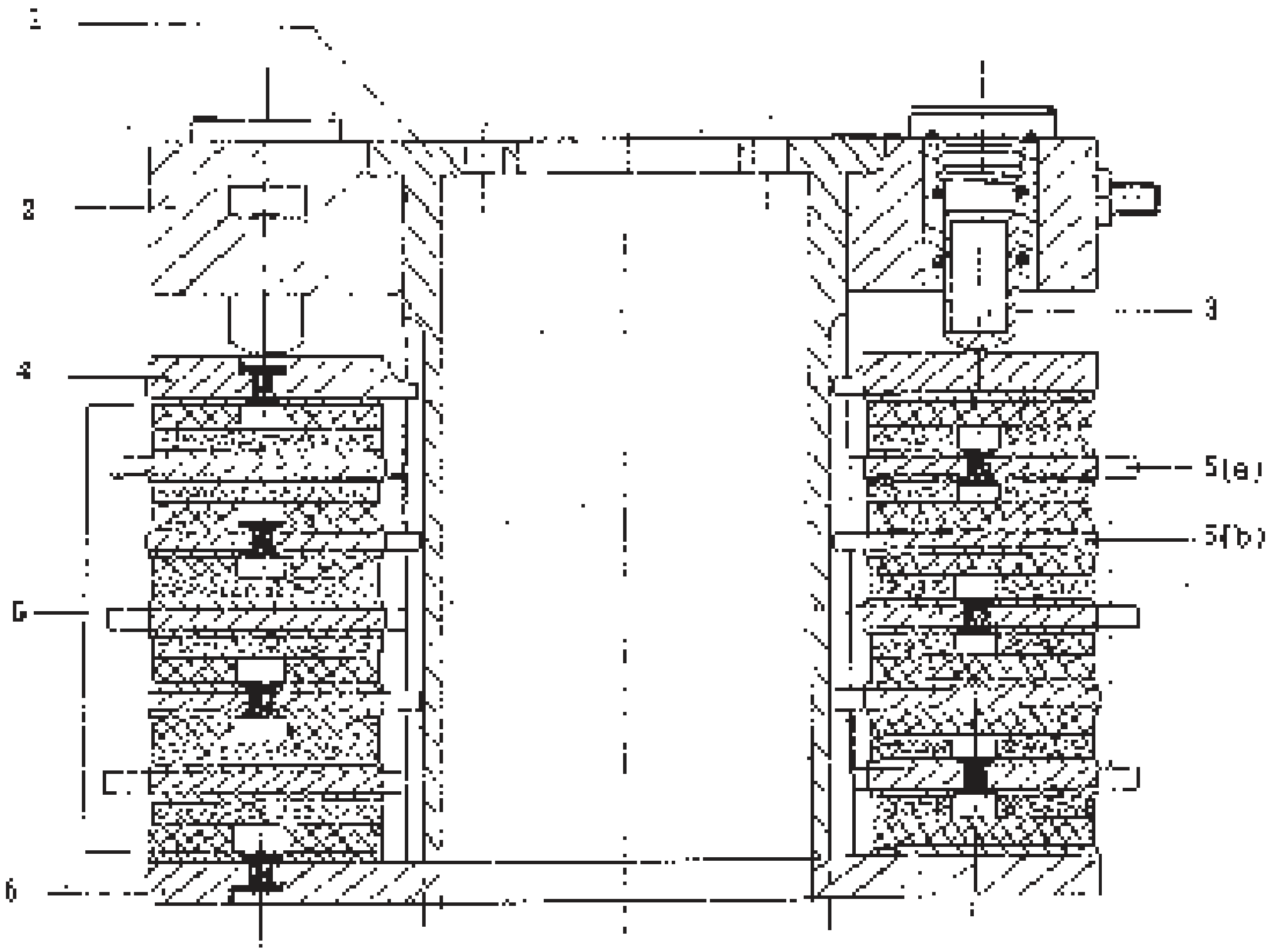
Fig.3(b) Segmental friction material housed in steel cup-shaped container

BRAKE HEAT SINK DESIGN

Fig.4 shows a typical aircraft showing the position of its landing gear and wheel. The brake unit is housed inside the wheel hub as shown in Fig.4(b). An aircraft brake is a multiple disc assembly consisting of a brake housing, pressure plate, torque tube, disc stack and backing or thrust plate as shown in the schematic cross-sectional view of an aircraft brake in Fig.5.

The disc stack is the most vital part of the brake unit and is called the heat sink. The heat sink absorbs the kinetic energy of motion converts it to heat, stores and then dissipates the heat to the atmosphere. The heat sink consists of a series of alternate rotating discs and stationary discs. Friction material elements such as brake pads or segments are mounted either on rotor or stator by riveting or bonding. The mating disc is of a low alloy steel or a steel disc rivetted with cast-iron segments.

On landing, the rotor discs which are coupled with the wheel hub through suitably designed drive blocks and tenons, rotate along with the wheel. On application of brake pressure, the stator discs are displaced axially and get pressed against the rotor discs. This creates friction between the rotor and stator discs, a high brake torque is developed and the wheel and aircraft



1.	Torque Tube	5.	Disc Stack
2.	Cylinder Block	5(a)	Rotor disc
3.	Brake Piston	5(b)	Stator disc
4.	Pressure Plate	6.	Backing (Thrust) Plate

Fig.5 - Schematic cross-section of a disc type aircraft brake

The efficiency of the brake depends on a proper design of the heat sink. A heat sink is designed using the following three parameters:

a) Heat Sink Loading is the kinetic energy absorbed per unit heat sink weight and is expressed in Joules/kg. or Kgfm/kg. This parameter gives an indication of the bulk brake temperature to be expected for a given brake energy input.

For an iron-based friction material brake, typical heat sink loading is 30000 kgfm per kg. for a normal landing and 90000 kgfm per kg.for a Rejected Take-off stop. For a carbon-carbon composite brake, these values could be three times more.

b) Area Loading is the kinetic energy absorbed per unit swept area. This parameter together with heat sink loading and area loading rate would indicate the surface temperature of the rubbing faces.

c) Area Loading Rate is the kinetic energy absorbed per unit swept area per unit time. The value of thermal conductivity of the friction material decides whether the material can absorb the energy at the particular rate. A high loading rate applied to a poor conductivity material will give rise to high surface temperature and cold core temperature on the friction material element thus resulting in thermal stresses which in turn affect the physical integrity of the friction material and braking performance also could fall throughout the stop.

The area loading and loading rate together with the physical constraints of the wheel and the axle dictate the design of the brake, the number of rotor and stators discs and number and arrangement of friction material elements.

METHODOLOGY OF DEVELOPMENT OF SINTERED FRICTION MATERIALS FOR AIRCRAFT BRAKES

R&D activity involved in development of an aircraft brake pad starts with an in-depth analysis of the aircraft brake design specification to derive the physical and metallurgical properties desired in the candidate friction material. This is illustrated below:

Physical/Metallurgical Properties of candidate friction material		Brake Design Specification
1. Mean Co-efficient of friction	D E R	- Mean brake torque or brake energy. - Brakes ON speed and stopping time or distance
2. Wear Rate	I V E	- Specified number of landings. - Maximum allowable temperature rise. - Area loading rate
3. Specific heat and thermal conductivity	D F R	- Brake kinetic energy. - Heat sink mass, area loading and loading rate. - Maximum allowable temperature rise.
4. Shear strength. Compressive strength and hardness at room and elevated temperatures.	O M	- Mean and peak brake torque. - Maximum brake pressure. - Area loading rate. - Maximum temperature rise

A step by step approach is then adopted in designing an appropriate friction material composition, selecting and characterising raw material ingredients, controlled experimentation for optimising the P/M process for fabricating the friction material element and finally subjecting the material, so developed, to elaborate laboratory evaluation and simulated performance tests to qualify the material for airworthiness and reliability. This step-by-step methodology is illustrated in Fig.6.

The minimum friction material properties derived from the brake specification form the basis of design and selection of an appropriate friction material composition.

The first step in the above process is the selection of either a copper [illegible]

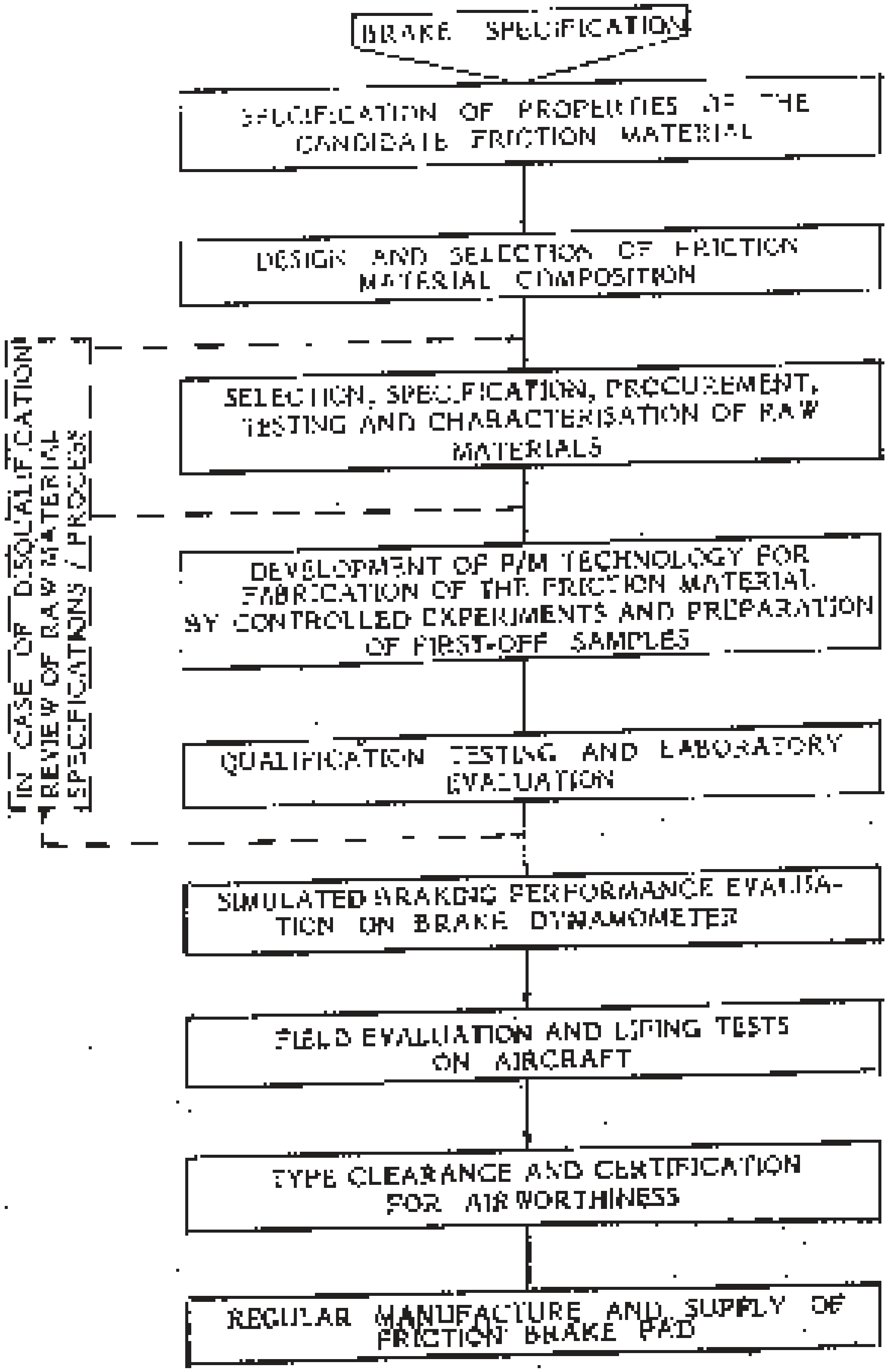


Fig.6 - Methodology of Development of aircraft brake friction material

property requirements such as energy absorption capacities, specific heat, thermal conductivity, melting point, wear and strength properties. The relative characteristics of iron and copper matrix materials are given in Table-2.

TABLE-2 – SELECTION OF MATRIX FOR FRICTION MATERIAL (IRON OR COPPER)

Characteristics	Iron	Copper
1. Specific heat (Joules/gm/C_k)	0.50	0.42
2. Tensile Strength (M-A)	410	340
3. Thermal conductivity(J/M/Sec/C_k)	59	345
4 Coeff. of Linear Expansion $(C_k^{-1}$ x $10^6)$	14	18
5. Kinetic Energy loading capacity (Joules/kg)	450,000	280,000
6. Anti-seizure	Good	Poor
7. Tolerance to ceramic and non-metallic additives	Poor	Good
8. Elevated temperature softening resistance	Good	Poor
9. Ease of manufacture into friction materials	Poor	Good

The next step is to select the other ingredients such as friction additives, dispersed solid lubricants, stabilisers, etc. Examples of various ingredients used to fulfil the various functional characteristics have been illustrated in Table-1 earlier. Those secondary ingredients are selected based on the level of functional characteristics desired.

The preliminary design and selection of a friction material composition could be done from first principles, i.e., starting from the brake specification, by judiciously selecting the matrix and other additives, but is more often done based on past experience on similar friction materials or from recommended/patented compositions published which are proven to meet similar brake design requirements such as kinetic energy and heat sink loading characteristics.

After selection of the composition, the next step is to select and specify the characteristics desired of the various powder ingredients. This is normally done based on data available in published literature and hand books on friction materials. The selected raw materials are then procured from reputed and [illegible]

Typical characterisation studies involve the following:

i) Apparent density and flow measurement.

ii) Sieve analysis.

iii) Chemical analysis

iv) Green strength and compressibility test on matrix powders.

v) Measurement of moisture, ash and volatile matter contents of non-metallic powders.

vi) Crystal structure and phase identification studies on ceramic and solid lubricant additives by X-ray Diffraction.

The quality of the various powders and their sources of supply are tentatively established and approved based on the above studies.

The tentative P/M technology is then developed based on a systematic series of controlled experiments. Data on possible process variables such as mixing sequence of powders, sintering temperatures, etc. are available in various hand books, publications and other literature on friction materials which serve as valuable guides for determination of the right combination of processing parameters to be employed for the experiments. Past experience on development of similar friction materials also serves as a guiding factor. Based on the above data, various experiments are designed to establish the optimum P/M process.

"First-off" samples are prepared following the various experimental P/M routes. These samples are then subjected to rigorous laboratory qualification tests to assess their quality characteristics and performance against laid down property requirements. The sample which meets the requirements satisfactorily is then standardised i.e., the raw materials and the P/M process used for making the sample are optimised and frozen. If on the other hand none of the samples meet the requirements then further review and modification of the raw material specification and the P/M process is done and the entire cycle repeated till a satisfactory sample is obtained.

Since the friction material developed is a complex multiphase composite and, if qualified, has to withstand severe service conditions repeatedly and reliably, the qualification testing stage to assess and certify the basic physical and metallurgical properties assumes critical importance. In this stage, indepth analysis and evaluation of the friction material "first-offs" is carried out repeat-

Standards Parts 23, 25, 27 and 29. In addition to FAR Standards, Technical Standard Orders such as TSO-C-26, issued by the FAA are also followed for calculation of brake energies and acceptance criteria for dynamometer tests.

The Dynamometer test results, on the newly developed friction material brakes are then compared with the brake design specification and acceptance standards given in the above specifications. If the test results meet the above requirements satisfactorily, the friction material elements qualify for fitment and use on aircraft.

The Dynamometer tests are followed by further field evaluation/service trials on a test aircraft fitted with the newly developed friction material. In this stage, tests such as "accelerate-stop", "landing and braking", "taxying and turning" and other aircraft compatibility tests are carried out. The final certification for airworthiness is then granted to the newly developed friction material elements by the airworthiness authorities.

Fig.6(a) to (b) present the results of EPMA phase identification studies on a copper-based friction material developed for a civilian transport aircraft brake.

Fig.6(a) X 400 Fig.6(b) X 400

EPMA Micrograph (Electron Image) X-ray Image of Copper

Figs.7 and 8 present optical microstructures of a copper-base friction material brake disc and of an iron-based brake pad respectively which have been developed recently by HAL.

Fig.7 X 100

Microstructure of a Copper-based friction material showing Silica grains (grey) and graphite flakes (black) and Copper rich matrix (white).

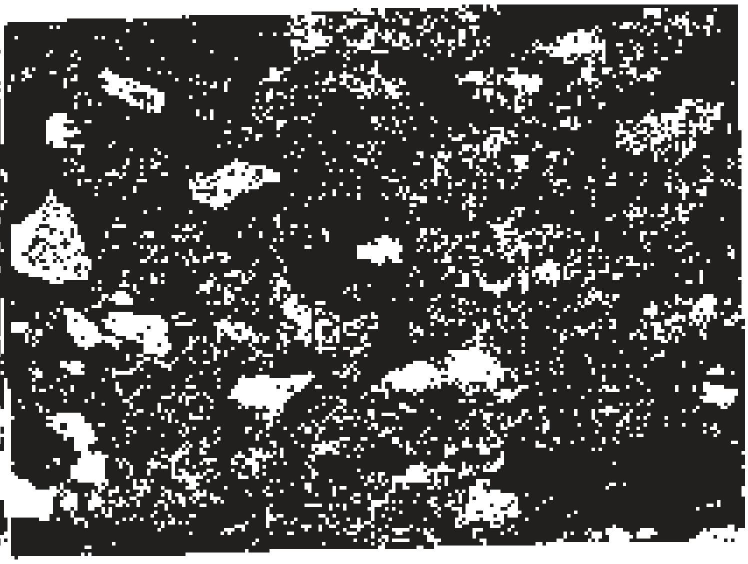


Fig.8 X 100

Microstructure of an iron-based friction material showing Silicon Carbide grains (grey) and graphite flakes (black) in a pearlitic steel matrix.

Table-4 presents the results of some qualification tests and brake dynamometer tests carried out on the copper-based friction material brake disc and the iron-based brake pad successfully developed by HAL.

STATUS OF INDIGENOUS DEVELOPMENT OF SINTERED BRAKE PADS

In the last two decades significant strides have been made in the Country for indigenous development of P/M metalloceramic friction materials for various military and civil aircraft. Pioneering R&D efforts in this field was made by DMRL which led to the successful indigenisation of the iron-base brake pads for the MIG 21 aircraft in the early 70s. Subsequently, R&D and manufacturing activity on friction materials was taken up by HAL on a large scale. HAL has since developed a full fledged infrastructure and technical expertise for applied R&D and production of aircraft brake friction materials which includes the P/M metalloceramic materials as well as organic resin based friction materials.

TABLE-4 – RESULTS OF LABORATORY QUALIFICATION TESTS AND DYNAMOMETER TESTS

Parameter Evaluated	RESULTS OBTAINED	
	Copper-based brake disc	Iron-based brake pad
1. Chemical Composition	Fe – 10% C – 6% Pb – 4% BN – 1% SiO_2 – 10% Cu – Remainder	Cu – 9% C – 7% MoS – 3% SiC – 5% Al_2O_3 – 1% Cr – 1.3% BN – 1% Fe – Remainder
2. Hardness (BHN)	44	125
3. Microhardness (VPN)	Matrix – 60 SiO_2 – 1280 Fe – 700	Matrix – 325 SiC – 1300
4. Sintered Density (gms/cc)	5.8	5.8 to 6.0
5. Dynamometer Test Results (R.T.O. Test)		
a) RPM of fly wheel	870	1240
b) Brake Pressure (kg/sq.cm.)	36	95
c) Run down revolution	352	372
d) Stopping time (seconds)	44	28
e) Brake energy (kgfm)	261980	1273200
f) Maximum brake torque (kgfm)	180	1040
g) Mean Brake torque (kgfm)	155	769
h) Mean Co-efficient of friction	0.29	0.28
i) Brake temperature rise (°C)	645	776

TABLE-6 - STATUS OF INDIGENISATION OF SINTERED AIRCRAFT BRAKE PADS AT HAL

Sl. No.	Description	Status of indigenisation	Year of indigenisation	Minimum F.E. savings (Rs. Lakhs)	Remarks
	IRON BASE				
1.	MiG.21 Main and Nose Wheel brake pads	Indigenised by DMRL. Under regular production at HAL.	1978	300	
2.	MIG 23 Main Wheel brake pads	-do-	1982	25	
3.	AN.32 Main Wheel Rotor and Stator brake pads	Indigenised by HAL. Production to commence in 1992.	1991	300	
4.	Jaguar Main Wheel Stator brake pads	Development completed at HAL. Under type testing.	-	110	Expected to be productionised in 1992.
5.	MIG 27 Main Wheel Rotor and Stator brake pads	Development work under progress at HAL.	-	200	Expected to be indigenised in 1992.
	COPPER BASE				
6.	Avro 748 Main Wheel Stator brake pads	Indigenised by DMRL. Under regular production at HAL.	1983	72	
7.	Kiran Mk.II Main Wheel Stator brake pads	Indigenised by HAL. Under regular production at HAL.	1990	150	
8.	Dornier 228-200 Rotor brake disc	-do-	1991	10	
9.	Air Bus A-300 and Boeing 737/747 Main Wheel Stator brake pads	Laboratory qualification tests completed at HAL.	-	100	Expected to be indigenised in 1992-93

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

GOVERNMENT OF INDIA

THE PATENT OFFICE

PATENT A-CH 0961

(RULE-74)

No. 198715 of 15-01-2002 20

WHEREAS HINDUSTAN AERONAUTICS LTD., 15/1, CUBBON ROAD, BANGALORE - 560 001, INDIA, AN INDIAN COMPANY

has/have declared that he is/they are in possession of an invention for Preparation of metal-ceramic friction composites

and that he is /they are the true and first inventor(s) thereof (or the legal representative(s) or assignee(s) of the true and the first inventor) and that he is/they are entitled to a patent for the said invention having regard to the provisions of the Patents Act, 1970, as amended and that there is no objection to the grant of a patent to him/them.

And whereas he has/they have , by an application, requested that a patent may be granted to him/them for the said invention;

And whereas he has /they have by and in his complete specification particularly described the said invention and the manner in which the same is to be performed;

Now, these presents(s) that the above-said applicant(s) (including his/their legal representative(s) and assignee(s) or any of them) shall, subject to the provisions of the Patents Act, 1970, as amended and the conditions specified in Section 47 of the said Act, and to the conditions and provisions specified by any other law for the time being in force, have the exclusive right to prevent third parties from making, using, offering for sale, selling or importing for those purposes the Preparation of metal-ceramic friction composites and using the XXX XXX and using, offering for sale, selling or importing for those purposes the product obtained if any, directly by that process in India, provided that the product obtained if any is not a product in respect of which no patent shall be granted under this Act for a term of twenty years from the Fifteenth day of January 2002 and of authorizing any other person to do so, subject to the conditions that the validity of the patent is not guaranteed and that the fees prescribed for the continuance of this patent are duly paid.

In witness thereof, the Controller has caused this patent to be granted as of the Twenty Seventh day of January 2006.

Controller of Patents

Date of Grant: 27-01-2006 / 07th Magha 1927 (Saka)

Note: The fees for renewal of this patent, if it is to be maintained will fall due on Fifteenth day of January 20.. and on the same day in every year thereafter.

4. GLOSSARY OF TERMS RELATED TO AIRCRAFT BRAKE PADS

Friction Material Glossary

A

Abrasion – mechanical wear during sliding of two surfaces against each other.

Additive – substance added in small amounts to improve properties and performance of product.

Adhesive – substance, applied as an intermediate, is capable of holding materials together by surface attachment. It is interposed between Friction material and support (back-plate)

Ageing resistance–resistivity against ageing which might occur due to oxidation, overheating and presence of certain metals like Copper, Lead, Silver etc. The resistance to ageing can be improved by certain additives (antioxidants)

Aircraft Brake Pads –Special types of heavy-duty friction materials, which are made up of either polymer / resin based composite or metalloceramic composite in aircraft brake assembly and they absorb kinetic energy of motion, convert it to heat & dissipate the latter to the atmosphere.

Anatomy of Friction Material (heavy-duty) - metalloceramic composites with five major constituents contributing individually to overall performance of brake systems. (i) matrix or base (ii) friction agents (iii) anti-seizure agent (iv) heat sink and (v) stabilizers or modifiers.

Anti-seizure agents - controlled lubricants to prevent *in-situ* friction welding of the engaging surface under load and heat (and thus performs a function totally opposite to that of the friction agents). Molybdenum disulphide (MoS_2), Graphite and Boron Nitride are used as common anti-seizure agent. Because of exfoliating nature, these spread out as thin non-reacting film causing easy separation of wear debris. They also act as a heat sink and also provide high damping attributes under cyclic stress.

Anti-squeal shims – single or multiple metal plates located between the brake pad and caliper to reduce brake squeal.

Area Loading - kinetic energy absorbed per unit swept area of the rubbing faces (brake pads on the rotor discs).

Area Loading Rate – area loading per unit braking time.

Asbestos – a gray, non-burning, non-conductive and chemical resistant material occurring in long fibers or fibrous masses, sometimes used as filler for reinforcement

Asbestos materials - for a long time, the most popular kind of material used was asbestos fibers, but that has been phased out of the market in recent years due to health concerns associated with asbestos (due to connections to lung disease). Asbestos was banned on usage by the government, forcing manufacturers to discover new forms of materials as substitute. Although asbestos materials are legal in some countries, they are fading from the market as new materials are finding their way into the forefront of the industry. Glass fiber coated with phenolic resin is used as alternative to asbestos.

A generic name of a group of minerals used in brake friction materials and made up of individual fibers.

ASTM – American Society for Testing of Materials.

Automatic adjusters – brake adjusters that use shoe movement or parking brake application to continually reset the lining to drum clearance.

B

Back pressure or residual pressure – a constant pressure held in the brake hydraulic circuit when brakes are not applied.

Base of Friction Material – see **Matrix (or Base) of Friction Material.**

Baking – A process of heating the Brake Pad in an oven in a desired temperature.

Bedding-in or Break-in – process of wearing in friction surface so that the contact between the friction material and the rotor or drum becomes stable.

Binder – the continuous phase which holds together the reinforcement in a reinforced product e.g. thermo-hardening phenolic resin.

Bi-metallic Sector – a composite brake pad. The metal used is cast iron or steel.

Bleeding –method of purging the air from the brake system's hydraulic lines and cylinders. Air is compressible and contaminates brake fluid. Air is released (bled) via a "bleeder valve" on each wheel cylinder

Or

method by which overheated or spoiled brake fluid and air bubbles are removed from the brake system

Bonded lining – brake lining (friction material) attached to the brake shoe with adhesive.

Boosted Brake – a form of brake source using a master cylinder in which the hydraulic pressure from the aircraft hydraulic power system is used to aid the pilot in applying force to the master cylinder.

Brake Chattering – heavy vibration in the brakes produced by the brake friction varying as the discs rotates.

Brake disc (or rotor)/Brake Drum – the basis of a disc brake system. A round metal disc rotates with the road wheel and in order to generate braking power, a caliper holding two-friction lining (pads) clamps the disc.

Brake dust – the dust created when brake friction materials wear during brake application.

Brake fade – a reduction or loss in braking force due to loss of friction between the disc pad and the rotor. Fade is caused by heat build-up through repeated or prolonged brake application.

Brake hose – flexible rubber (or synthetic) hose used to join the hydraulic brake components.

Brake line – network of steel tubing and rubber hoses used to transmit brake hydraulic pressure.

Brake Lining - friction materials that presses against the disc/drum to create braking force and retard the relative movement between two surfaces. Heat produced during this process is dissipated through heat sink mass.

Brake Pad - made of friction materials and bonded to metal plates. Brake pads need to be replaced occasionally due to heavy wear / surfaces abnormality.

Braking distance – The distance traveled by Aircraft while it is in being tried to stop.

C

Carbon brakes – the latest development in the field of aircraft brakes where both rotating and stationary discs are made of carbon. They are used for high-energy dissipation.

Caliper - assembly that houses the brake pad(s) and applies them on to rotor. This also houses the hydraulically operated pistons to which the pads are bonded.

Ceramic friction materials - These are very popular because of their high energy absorbing capacity and they eliminate squeal and audible vibrations. They are also less abrasive to rotors and their brake pads tend to have a longer life span than those of other materials.

Clutch –various contraptions used to engage and disengage two moving parts (driving part and driven part) of a shaft or shaft and driving mechanism. Clutches transmit energy of the power source (driving part) to another mechanism (driven part), which is brought to the speed of the former. When changing gears, the clutch pedal is pressed; disengaging the clutch and allowing the gear change; when released, the clutch engages and transfers the rotating motion throughout the entire drive shaft.

Clutch Facings – used to maintain lower coefficients of friction, which provide smooth and stable clutch engagement / disengagement. They help reduce clutch chatter, are available in molded and woven compositions and can be found with asbestos or asbestos-free materials.

Coefficient of Friction – ratio of force necessary to move an object compared to the weight of the object itself. This is an index of shearing force of the contacting parts, which, in turn, determines the degree of performance of the friction material. Required level of the coefficient of friction is dependent on the operating condition and end use of the product.

Coefficient of Friction (Dynamic) – coefficient of friction between two mating surfaces with relative speed greater than zero ($\mu_{dynamic}$). Usually $\mu_{dynamic} < \mu_{static}$

Coefficient of Friction (Static) – coefficient of friction between two mating surfaces with zero relative speed (μ_{static}). Usually $\mu_{static} > \mu_{dynamic}$

Curing - The heat treatment process employed mainly on organic pads for converting the green compact in to an end product similar to sintering of a metallic pad.

D

Disc Brake – consists of brake pads, caliper and rotor. This is the part of the brake system that actually stops the vehicle.

Dragging brakes – brakes that have not fully released and which maintain some friction as the wheel rolls. Dragging brakes cause serious overheating.

DTV - Disc Thickness Variation; the variation in thickness between two points on the friction surface of a rotor. It is usually caused by poor alignment of the rotor / caliper or the rubbing of the friction material against the rotor when the brakes are off

Dynamic Friction – see Sliding Friction.

Dynamometer – a test rig in a laboratory used to test brake system performance like coefficient of friction, wear rate of the friction material, stop distance, stop time etc; by simulating the actual kinetic energies of braking under various required conditions

E

Emery Paper – Paper with different grit size used to scorch to remove glassy layer.

F

Fading (or Fade) – temporary reduced braking power. Fading (or Fade) results from overheating of the friction material.

Fiberglass materials – a composite material wherein a fiber is reinforced with glass matrix. These are new to the market and are currently being tested for durability, preservation of rotors and drums and noise level.

Friction –resistance to relative motion that opposes the direction of travel of an object, mainly caused by surface roughness. It is created by contact of solid bodies with one another.

Friction agent –hard abrasive particles (e.g. silica, silicon nitride, silicon carbide, alumina and mullite) embedded in matrix to generate required friction force by scoring the mating surface

Friction Couple – combination of friction disc and mating disc is friction couple. In a brake or clutch assembly, the energy is absorbed or transmitted by generating controlled friction within it. Rubbing friction disc against a mating disc, in turn, normally generates the controlled friction. Depending on the applications, however, the friction couple may take different configurations.

Friction Disc – a disc in a friction couple bonded metallurgical (diffusion-bonded) to a friction material, rubbing on which a controlled friction is generated. The design of friction disc can be varied (e.g. segmented or monolithic) depending on the application requirements.

Friction, Laws of – see **Laws of friction**

Friction Material – components of a mechanism that converts mechanical energy into heat upon sliding contact. The conversion product, heat, is absorbed or dissipated by the friction material. Friction materials are essentially used to induce friction in applications when slow or decreasing movement is desired, such as in brakes and clutches.
In case of braking, the friction materials press against the drum or disc to create friction. The byproducts of friction are debris and heat. It is important that friction

materials used in brakes have (i) good energy absorption capacity (in view of the high temperatures that result from braking) and (ii) low wear rate (ensuring less debris and more service life)

Brake systems use friction materials to stop wheels from rotating. When a brake is pressed, it activates a system that places the materials against a disc or drum that slows the vehicle down. Clutches also need friction materials in order to engage after gear changes. Without them, the clutch slips and cannot transfer power.

Friction Material, Desired properties – desired properties of any good friction material is tabulated here –

Properties	Level	***Reasons***
Friction coefficient (μ)	Moderate	Rapid energy dissipation (short brake application time)
Strength (shear & compressive)	High	Should not fail or flow under rubbing
Thermal conductivity	High	Conducts the heat generated by friction rapidly, avoid thermal softening of matrix and localized melting
Anti-seizure character	High	Minimize incipient melting & localized welding of asperities, slippage of rubbing surfaces, torque fluctuations.
Wear rate	Low	Ensure long life
Stability	High	Ensure steady and reliable performance; minimize "fading" under repeated thermal cycling.
Damage of opposing surface	Low	Long life of brake assembly, low debris generation

G

Glazing or glazed lining – process whereby a brake lining or disc rotor becomes smooth and glossy due to excess heat resulting in reduced braking efficiency. This is also called as "Beilby layer".

Graphitic materials – materials having graphite crystal structure. These are used in applications that have a higher temperature because of their good energy absorption. These materials help hold in heat for a long period of time.

Groove Patterns – grooves on friction material help dispel heat, get rid of debris and eliminate noise.

Grit – Mesh size of emery paper.

Heat Dissipation – process whereby braking components rid them of heat caused by friction. Most heat is dissipated into the surrounding air or through mating metal components such as the wheel. Various forms of ventilation can accelerate dissipation.

Heat sinks – an important part in the brake unit, which facilitate rapid heat removal / dissipation from heat generation source. Normally, copper is used commonly as heat sink because of high thermal conductivity.

Heat sink loading – kinetic energy absorbed per unit heat sink mass.

Heat spots – shiny dark areas on a rotor caused by extreme heat.

High-speed judder - vibration during high speed braking not related to DTV. It is caused by hot spots or foreign material on the rotor.

Howl – noise generated in the range of 500 to 1000 Hz caused by stick slip.

Hygroscopic – an affinity or attraction for water.

Hydraulic Pads – pads operated by hydraulic energy.

Hardness of Brake Pad – resistance to scratch or indentation on Brake Pads.

K

Kevlar fiber – Proprietary of Deposit used in variety of organic material of application including organic brake composition.

L

Laws of friction – classic laws of friction have been re-worded by Amontons as follows–

First Law: friction force between two sliding surfaces opposes their relative motion

Second Law: friction force is independent of area of contact of the given surfaces when the normal reaction is constant

Third Law: The limiting frictional force is proportional to the normal reaction. (Static friction). The frictional force is proportional to the normal reaction and is independent of the relative velocity of the surfaces (Dynamic friction).

Laws of friction (Classic) – three classic laws of friction are–

First Law: The friction force that resists sliding is proportional to the normal load. (Or the force that squeezes the surface together). This proportionality constant is usually referred to as the coefficient of friction (μ).

Second Law: The amount of friction is independent of the area of contact (for a wide range of areas).

Third Law: The friction force is independent of sliding speed (once the sliding starts).

Lubricant – substance, which impart lubrication property

Lubrication – phenomenon of reducing sliding and rolling frictions between friction element and the mating part and to prevent wear and friction welding.

M

Mass Loading rate – heat sink loading per unit braking time.

Master Cylinder – cylinder that contains hydraulic fluid. It is connected directly to the brake pedal and transmits pressure to the brake operating system.

Material, Friction – see Friction Material.

Mating Disc – in a brake or clutch assembly, the friction disc is rubbed against another disc in order to absorb or transmit energy by generating controlled friction within it. The latter is called mating disc. Normally, the mating disc is made of non-friction materials, which are harder than the corresponding friction material rubbing against it. This ensures less wear of the mating surface and more service life. Depending on the applications, however, the mating disc may take different configurations.

O

Organic Brake Pads – Brake pads with phenolic resin as matrix material with other additives, generally used in low energy aircraft.

P

Piston – is the moving part of the brake caliper. Upon receiving increased pressure from the brake fluid, the piston is forced outwards and against the back of the brake pad, which is forced against the disc.

R

Resin – Binder used for reinforcement of pads.

Rotor scoring – grooves on the friction surface of the brake rotor, usually caused by the friction material.

Running-in – surface asperities of new sliding surfaces are modified during the running – in period.

S

Scorch – Process of roughening of the surface with the use of heat usually in resin based pads. Sort of bed-in process.

Scorching Temperature – Temperature at which scorching action takes place normally 440-560 deg C.

Scoring marks – band-shaped marks in metal, caused by machining or by scuffing.

Scuffing – damage to material surface through inadequate supply of lubricant, or as a result of overloading when the lubrication film is broken.

Semi-metallic (friction materials) – Resin based friction material composed of 30% to 60% steel / metallic material fiber. These are used for high performance and designed to prevent fade and squeal. They handle heat better than many other organic pads.

Sintered metal – Predominantly metallic powder with suitable additives. The compacted and sintered material is of various shapes

Sliding Friction (also termed as kinetic friction or dynamic friction) – friction produced when objects, slide (or move) over each other.

Slip ratio – difference between the vehicle's body speed and the speed of the wheel measured as a percentage.

Squeal – high-pitched noise made when braking. Squeal indicates that brakes should be inspected for wear.

Stabilizers (or modifiers) – are used to prevent "fading", i.e. to ensure uniformity of friction co-efficient (μ) during period of application and nullify the adverse effect of heat generated. They also ensure prolonged reliability despite use (and abuse!) by protecting the friction agents from thermal cracking by forming a envelope. Magnesium oxide (MgO) and Barium sulphate ($BaSO_4$) are used commonly for this purpose.

Static friction – friction needed to start a body at rest into motion. Static frictional forces from the interlocking of the irregularities of two surfaces increase to prevent any relative motion up until some limit where motion occurs. It is that threshold of motion which is characterized by the coefficient of static friction.

The coefficient of static friction is typically larger than the coefficient of kinetic friction, $\mu_{static} > \mu_{dynamic}$

Stopping time – ratio of Maximum Brake Application Speed to the deceleration required from brake

Surface Roughness – The roughness (R_a) of emeried metallic surface. Surface Roughness is measured in Perthometer.

T

Torque – Twisting moment.

Tightening torque – effective leverage turned into rotating movement to tighten a screw connection.

Transfer layer - transfer of friction material to the brake drum or rotor. The thickness increases with temperature and the number of braking cycles; thickness is also directly related to the amount of stick-slip.

Tribology – science, which deals with the relation between friction, wear and lubrication.

Temperature Controller (Thermocouples)– A temperature measuring device set for baking the brake pads.

W

Warping – a condition experienced by the disc when it becomes out of round. Often caused when the brakes are used excessively then the vehicle is stopped and heat from the pads/caliper dissipates unevenly, through the rotor. Rotors, which are warped or out-of-true, have excess runout, meaning the surface varies or wobbles as it rotates around a fixed point.

Wear – caused by friction and contact between bearing surfaces after break through of the lubricating film.

Wear Pin – Mechanism in brake units for external monitoring of wear rate.

XXX

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