TECHNOLOGY FOCUS

टैक्नोलॉजी फोकस

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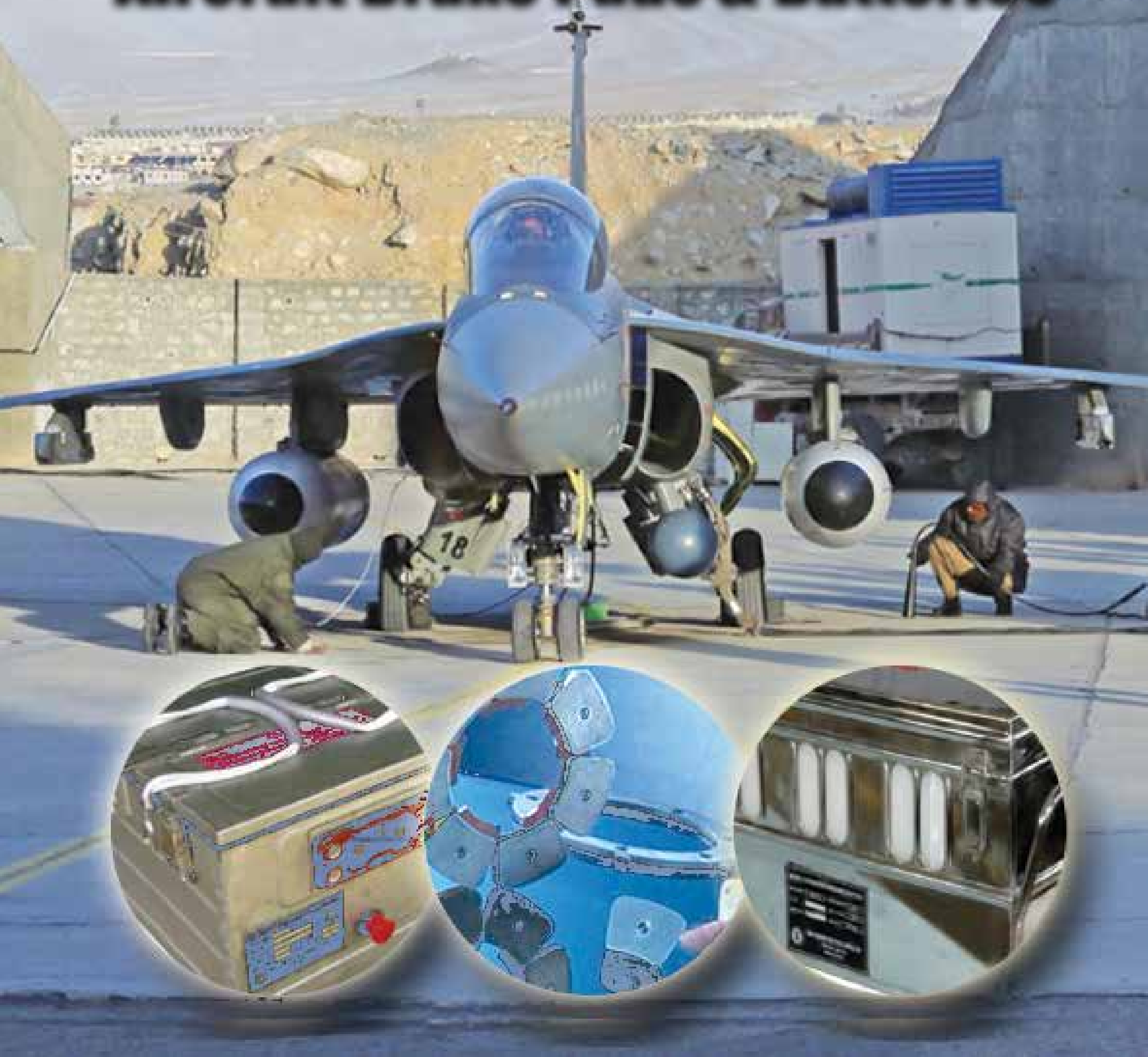
Certification of Aircraft Brake Pads & Batteries



Technology Focus
टैक्नोलॉजी फोकस

Technology Focus focuses on the technological developments in the organisation covering the products, processes and technologies.

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From the Desk of Guest Editor

Centre for Military Airworthiness and Certification (CEMILAC), Bengaluru, with its 14 Regional Centres of Military Airworthiness (RCMA's), each with a specific core competence, carries out airworthiness certification of military aircraft, aero-engines and airborne stores being designed and developed by DRDO laboratories, ordinance factories, public sector units such as HAL, BEL, MIDHANI, etc., and many private sectors. CEMILAC has been given the responsibility of type approving system, equipment and material for aerospace use. Among the 14 RCMA's, Foundry and Forge-Fuel Oil Lubricants, i.e., RCMA (F&F-FOL) is carrying out airworthiness and certification activities of the ferrous and non-ferrous castings, forgings, powder metallurgy components such as aircraft brake pads, smart materials, surface coatings, rubber compounds, aircraft turbine fuel, oil and lubricants required for all Indian military airborne platforms (Aircraft, Helicopter, Engines, Missiles).

A wide variety of components made from a variety of materials are used in realization of an aircraft. Numerous processing technologies are used for manufacturing such critical and non-critical components in the aircraft industry. Brake pads are safety critical component 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, have made powder metallurgy an attractive and unique choice.

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 has led to thorough understanding of the functional additives like friction materials, lubricating additives, inter-particle bonding agents 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 inter-particle bonding is achieved through sintering. Thus, for a variety of aircraft depending on the energy levels associated, powder compacts have been functional additives in either polymer-based matrix materials or metal-based powder matrix. This issue of Technology Focus is a collation of various types of brake pads and their route to qualification and certification for military aircraft operated in our country. I hope the issue will be useful for the developers, users and the aviation industries.

CEMILAC is extremely grateful to Dr (Mrs) Tessy Thomas, Distinguished Scientist, Director General (Aero Systems), DRDO for inspiring us to publish this work and to serve as a quick reference to the Technology Focus readers.

APVS Prasad
Chief Executive (Airworthiness)
CEMILAC

Airworthiness Certification of Indigenously Developed Friction Materials For Military Aircraft Brake Pads & Batteries

Friction materials used as brake pads and discs in aircraft brakes are carefully engineered man made composite materials. These composite materials are designed and developed to withstand severe and diverse operating conditions of aircraft braking as they have to absorb enormous quantum of energy (3-16 MJ) within a very short interval of 10-12 seconds after landing.

The development work of these material range from characterizing material powder to establish manufacturing process and to stipulate 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 sub-systems of the vehicle. Stringent aircraft brake pad operational requirements such as high kinetic energy (3-16 MJ), high energy loading rate, limited heat sink mass, severe temperature generation, noise, vibration and specific environmental corrosion require brake pad material to exhibit diverse range of the following characteristics:

- ◊ High strength
- ◊ Moderate co-efficient of friction
- ◊ Stability over a range of temperatures
- ◊ Ability to withstand adhesion and seizure
- ◊ Good thermal conductivity to facilitate fast heat dissipation
- ◊ High specific heat and thermal stability
- ◊ Low wear rate
- ◊ Minimal damage to its mating surface

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 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 and rejected take-off.

The dynamometer tests are followed by actual taxi trials on aircraft to evaluate accurate field performance, landing characteristics and pilot's feel of the newly developed brake pad material.

Types of 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 for aircraft braking application. These are:

- ◊ Organic friction materials
- ◊ Bi-metallic friction materials
- ◊ Metallo-ceramic friction materials
- ◊ Carbon-carbon composite friction materials

Organic Friction Materials

Organic brake linings, were the earliest friction materials developed and used extensively on lightweight, low-speed trainer aircraft and in helicopter rotor brakes. The organic 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 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

Organic Insulator and Brake Pad

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

Bi-metallic Friction Materials

The earlier bi-metallic friction material was of grey cast iron type. The cast bi-metallic pads are now replaced with the powder metallurgy route as it enables non-stoichiometric combination, better interfacial bonding, near net shape processing, clean manufacturing environment, increased productivity and other techno-economic advantages. Bimetallic cast brake pad route is essentially conventional grey cast iron foundry technique.

Bi-metallic Brake Pads

Metallo-ceramic Friction Materials

The metal-based sintered metallo-ceramic material of Metal Matrix Composites (MMC) are most widely used friction materials in aircraft braking application. These are much stronger, more heat resistant and are developed in response to energy inputs and temperature, which exceed the capabilities of organic friction materials. Metallo-ceramic friction materials are used as speed brakes for majority of military and civilian aircraft. The steel brake heat sink consists of a sintered metallo-ceramic friction material bonded to a steel supporting backing plate. This class of brake pad materials is made by the modern route of powder metallurgy and can be further classified in to two categories depending on the metallic matrix material used. Iron and copper as metallic matrix are commonly used as base in these friction materials.

Iron-based Friction Material

Iron-based friction material consist of ceramic additives, solid lubricant and friction modifiers in the iron rich matrix. Iron-based sintered friction materials are used under extreme operating conditions since they allow higher operating temperatures of up to 900 °C and in some emergency cases even higher. Iron, as the friction material matrix, is used because of its high melting point 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 by

Iron-based Brake Pads

power metallurgy route in a hydraulic press followed by pressure sintering in the bell type sintering furnace.

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

Copper-based Brake Pads

materials. These friction materials are compacted by powder metallurgy route followed by sintering in the bell type or pusher type sintering furnace.

Carbon-carbon Composite Friction Materials

The carbon-carbon fibre composite friction materials are the latest entry into the field of friction materials and have been developed mainly to cater to the severe 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.

Metallo-cermaic brake is heavier with higher wear rate and lower cost per brake landing compared to the carbon brake. Carbon-carbon friction materials are Polymer Matrix Composites (PMC) comprising high-density carbon fibres embedded in a carbon matrix. The carbon fibres used in carbon brakes are made from two precursors: Polyacrylonitrile (PAN) or pitch. Fibre properties are normally controlled by the manufacturing process of the fibre.

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 °C, cutting the fabric to shape, impregnating with a polymer resin, carbonizing and densifying by Chemical Vapour Deposition (CVD) by the decomposition of natural gas at low pressure.

Challenges in Aircraft Brake Pad Development

Among the various types of brake pads discussed above, the metallo-ceramic brake pads are widely used in Indian military aircrafts.

Single homogeneous material cannot render diverse properties requirement for brake pads, hence composite material is the only viable choice to develop diverse properties. The methodology of development of the unique brake pad material for a given aircraft brake 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 in deciding base matrix material 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 co-efficient of friction, thermal conductivity and stability properties of the material.

Selection of Matrix Material

The analyses of the aircraft brake design specifications, brake performance characteristics and the study of the relative characteristics of the Iron and Copper base form the basis for selection of the matrix material.

The next step in the design of composition is the selection of the following secondary ingredients:

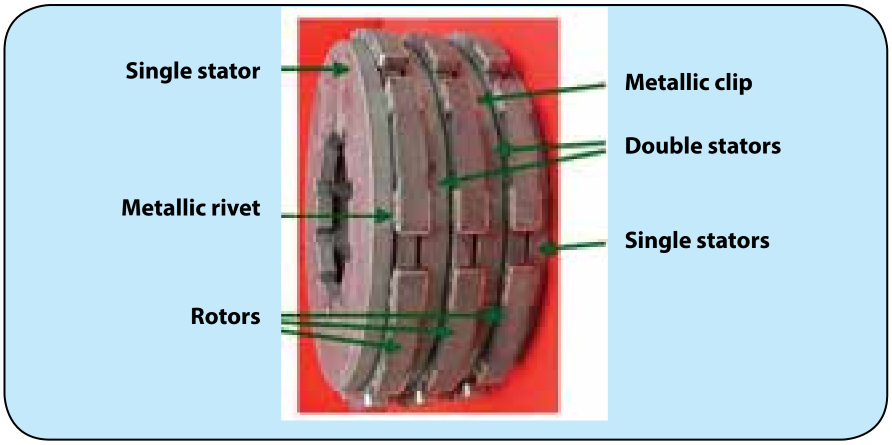
Abrasive/Friction Ingredient

The abrasive component is the next most important ingredient as this gives rise to friction and metal transfer of the matrix material on to the mating part during braking. Silica and Mullite are suitable for low and medium energy friction material whereas the carbides and nitrides of silicon are most desirable for high energy brakes of high heat sink loading.

Dry Lubricant/Anti-seizure Additive

To avoid gross seizure between the friction element and mating part, dispersed dry lubricants are added. These lubricants provide smoothness of engagement during braking by forming a self-regulating smooth film on the friction surface.

High graphite contents are suitable for low brake temperatures and high thermal conductance. But graphite is not suitable for temperatures above 600 ^{0}C. Hence a secondary high



Carbon/Carbon Brake Discs

temperature lubricant is also required. Secondary lubricant additions are normally kept very low, as higher amounts added leads to excessive wear of the friction material.

Friction and Wear Stabilisers Modifiers

A critical requirement that a high energy friction material must fulfill, 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 are also used for the purpose. $BaSO_4$ is very commonly used in Iron base materials. The resultant composition of the Iron base friction material for a typical high energy aircraft brake pad could be tentatively fixed as given in table below:

Friction Material Formulation for High Energy Aircraft Brake Pad

INGREDIENT	WEIGHT (%)
$BaSO_4$	8 to 12
Graphite	6 to 8
Silicon Carbide	7 to 10
High Temperature Lubricant	1 to 2
Copper	5 to 7
Iron	Balance

Design and Selection of other Functional Layers

In Iron-based friction elements, a pure sponge Iron powder layer of 0.5 to 2.0 mm thickness is incorporated between the friction material and the nickel plated steel backing frame as a special feature by making a multi-layer compact. The sponge Iron layer acts as a cushion layer. This characteristic allows the effective damping of vibrations judder during braking and acts as a medium to further ensure good bonding between the friction material and the steel back plate.

Development of Powder Metallurgy Process for Fabrication of Brake Pads

The next step is development of appropriate powder metallurgy process for fabrication of frictional material into brake pads/elements by controlled experimentation.

The various steps involved in development of the appropriate powder metallurgy process for fabrication of frictional material into brake pads/elements are:

- Selection and optimisation of raw materials based on composition
- Powder mixing
- Powder compaction
- Process of back plate frame
- Pressure sintering of brake pads

Selection and Optimization of Raw Materials Based on Composition

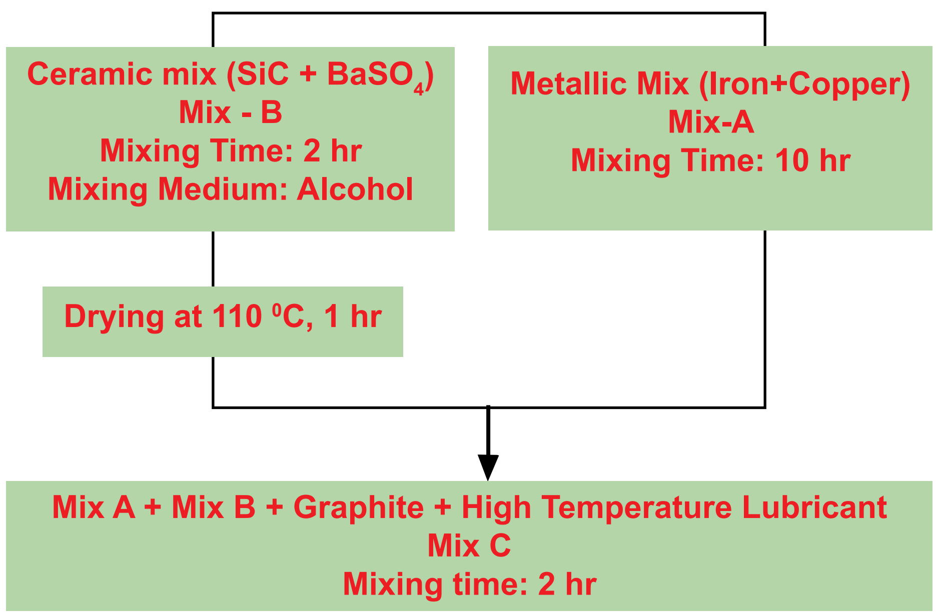
Prototype brake pad samples made from a few alternative raw materials of each ingredient are tested for basic properties such as friction and wear. From the results of these experiments each raw material type and specification is then fixed and optimized.

Powder Mixing

Optimum mixing process is arrived by varying sequence and method of mixing, mixing time and mixing medium to establish an optimum mixing procedure for the best bulk density and flow rate characteristics.

Powder Compaction

Pressure for compacting the friction material into the desired shapes for the final brake pad is chosen and optimised based on experiments, which yield the most optimum green density value of the resultant compact.



Powder Mixing Process for the Military Transport Aircraft Friction Material Formulation Established by CEMILAC

Higher pressure leads to marginal increase in the green density but may cause cracking of the compact due to high residual stresses.

Processing of Back Plate Frame

A single or multi-layer friction material compact is a composite with about 40 per cent by volume of non-metallic ingredients and possesses quite low strength.

To withstand the stringent service environment and also for assay into brake rotor and stator plates by riveting, the friction material is either housed in a backing steel container or diffusion bonded, during pressure sintering operation, onto a steel back plate frame of the same shape and contour. Steels normally used are AISI-4340, BS-S155 and M-300.

Back plate segments are fabricated by shearing operations using press tools. The steel backing segments are then given a Nickel or Copper plating for Iron-based and Copper-based friction materials respectively. After plating, the back plate is given diffusion anneal treatment to ensure proper metallurgical bonding of the plated layer to the underlying steel plate.

Pressure Sintering of Brake Pads

A pressure sintering bell type furnace with a hydraulic charge pulling arrangement is used for pressure sintering. CEMILAC has optimised sintering temperature, pressure, time and sintering atmosphere of friction material of military aircraft.

Challenges in Qualification and Airworthiness Testing of Prototype Brake Pads

Airworthiness for all types of military aircraft brake pad materials and components is governed by MIL-W-5013 and Technical Standard order-26 issued by Federal Aviation Administration, USA. CEMILAC, which begins with preparation of test schedule comprising various tests for airworthiness qualification. These tests are selected based on various international standards, specifications, operating conditions, environments and user requirements.

The entire testing clusters in test schedule for multi-layer metal matrix composite brake pads are divided into the following three stages based on type of tests:

- ◊ Laboratory qualification test
- ◊ Brake dynamometer test
- ◊ Aircraft trial

Laboratory Qualification Test

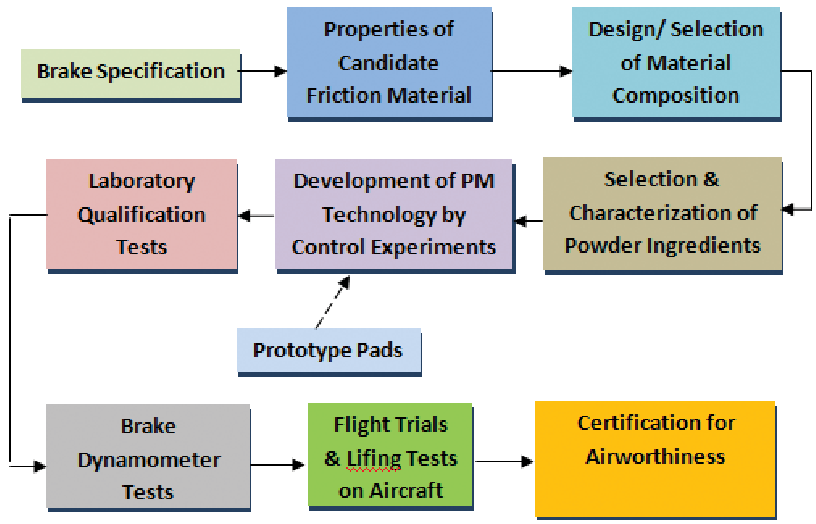
The sample brake pads are subjected to rigorous laboratory qualification tests to assess their quality characteristics and performance against the laid down property requirements. This stage of testing is to assess and certify the basic physical and metallurgical properties. The laboratory test requirements evolved for brake pads are:

Hardness

- ◊ Friction lining
- ◊ Steel back plate
- ◊ Density of friction material
- ◊ Microstructure
- ◊ Friction test (on 2 prototype pads)
  - Average coefficient friction
  - Stopping time(sec)
  - Wear by weight loss
  - Wear by thickness

Brake Dynamometer Test

To simulate actual field performance, brake dynamometer



Brake Pad Certification Route

test 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 normal and Rejected Take-Off (RTO) brake energy conditions. The conditions simulated for the brake dynamometer test on the metallo-ceramic friction material brake pads are derived from the respective brake specification of aircraft.

Aircraft Trial

The brake pads are tested for confirmatory field evaluation service performance trials after successful completion of the dynamometer test using the actual aircraft as a test bed. The test aircraft is fitted with test brakes assembled with the prototype brake pads.

A number of accelerate–stop, landing and braking and taxing and turning tests are carried out under various combinations of progressively increasing aircraft weight, speed and braking effort up to the most critical combination. The trials are carried out by experienced pilots and their observations are recorded. The data recorded in each trial are

- ◊ Stopping distance and time
- ◊ Maximum brake temperature rise at each braking
- ◊ Turn-around time
- ◊ Outside wind condition and air temperature
- ◊ Pilot's feel of brake effectiveness, Brake judder, Aircraft swing, brake binding tendency and any other such unusual observation
- ◊ Physical condition of the pads such as chipping, flaking, etc., after each block of trials.

After successful completion and satisfactory performance of all the above qualification tests, airworthiness clearance is accorded based on a comprehensive type test report furnishing the design specification, drawings and manufacturing process sheets and test results.

As Indian aviation industry began with production and overhaul of various aircraft and helicopters under license agreement with collaborators, India was completely dependent on procurement of aircraft brake pads from collaborators. To become self-reliant in aircraft brake pads, lot of emphasis has been laid down on indigenisation.

Over the years, *ab initio* projects like Light Combat Aircraft (LCA), HJT, Advanced Light Helicopter (ALH), LUH, Pilotless Target Aircraft (PTA), etc., have been successfully completed in India. As the production of these aircrafts began in the country, significance arose in the indigenisation and airworthiness certification of large varieties of aircraft brake pads for use on various licensed aircraft/ helicopters.

Conditions Simulated for Brake Dynamometer Test

Parameter	Normal	Overload	Rejected Take-Off
Kinetic energy per brake (MJ)	3.48	4.09	5.92
Brake application speed (kwm/h)	227	217	261
Stop distance (m)	653.8	597.5	864.2
Stop time (s)	20.7	19.8	23.8
Brake pressure (psi)	602.0	774.2	774.7

Parameter Evaluated during Brake Dynamometer Test

Normal Energy Test	Expected avg stop time(s)
	Expected avg stop distance(m)
	Wear by weight loss (gm)
	Wear by thickness loss(mm)
	Mean coefficient of friction
	Brake temperature rise of double stator (°C)

Some of the Significant Contributions in Certification of Brake Pads:

MIG 29

Project :	**MiG-29**
Type :	**Iron Based**
Characteristics	
Max. Brake Energy :	**9 M Joules**
Wear Life :	**250 Landing**

AN-32

AN-32 Rotor Pad

AN-32 Stator Pad

Project :	**AN-32**
Type :	**Iron Based**
Characteristics	
Max. Brake Energy :	**15 M Joules**
Wear Life :	**250 Landings**

Jaguar

Jaguar Brake Pad

Jaguar Insulator Pad

Project:	**Jaguar**
Type:	**Iron Based and Organic Based**
Characteristics:	
Max. Brake Energy:	**8 M Joules**
Wear Life:	**250 Landings**

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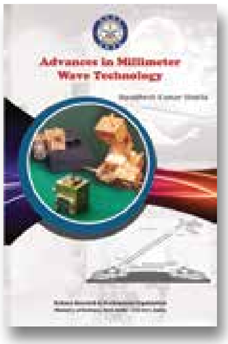
DRDO MONOGRAPH SERIES

Advances in Millimetre Wave Technology



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For the growing need in wireless spectrum by wide bandwidth applications such as ultra-high data rate transfer, at speeds of 10 Gbps and up, millimetre wave plays important role in providing reliable spectrum solutions. Worldwide R&D in millimetre wave area has demonstrated many successful tests to establish the technology with its promising potential for the future of defence and security.

The monograph explores the design and implementation of millimetre wave active/passive circuits and systems using waveguide/MMIC (Monolithic Microwave Integrated Circuit) and planar waveguide technology). Extensive use is made of photographs of systems, line diagrams showing various techniques, and important system characteristics.

It begins with an introduction to frequency bands, unique millimetre wave applications in communication. It presents detailed discussions about millimetre wave devices and circuits, generating devices, e.g., IMPATT oscillators and Gunn oscillators, where concept of injection locking phenomenon in oscillators and power combining techniques, etc., have been highlighted. Receiver components, millimetre wave transceiver configurations and development of millimetre wave systems technology useful for defence services are presented. It also discusses future trends and technology challenges, which enlighten about exploitation and challenges of millimetre wave frequency spectrum in futuristic military applications such as broadband communication technology, optical technique of millimetre wave generation with low phase noise signal for applications in imaging and phased array radar systems and millimetre wave options for mobile cell phones.

The monograph is written to support and supplement millimetre wave and sub-systems/system courses of scientific institutions/universities as well as a reference for researchers, professionals, and high RF frequency design engineers working in this exciting field of millimetre wave technology.

Military Aircraft Battery Technology and Qualification

The battery is a device that converts the chemical energy contained in its active materials directly into electric energy using electrochemical oxidation-reduction (redox) reactions. In case of a rechargeable system, the battery is recharged by a reversal of the above process. The aircraft batteries are used for engine start on the ground as well as in-flight engine re-start under emergency conditions. The power supply for emergency avionics system is also provided by onboard batteries. These requirements classify the aircraft battery as a flight critical system. There are three classes of batteries, viz, Silver-Zinc, Lead-acid and Ni-Cd batteries mostly used for the airborne platforms.

Currently, RCMA, Hyderabad, is working on the certification of the Lead-acid and Ni-Cd batteries for the platforms like HAWK-AJT and Boeing P8I to replace the imported batteries. The Indian vendors who are in design, development and manufacturing business of aircraft batteries are HAL, Hyderabad, HBL, Hyderabad and HEB, Trichy. The aircraft batteries are safety critical and require compliance to stringent tests as part of airworthiness certification. The aircraft batteries are high-rate batteries as compared to commercial batteries. For example, an aircraft battery with 15Ah rating is capable of delivering 15C or 225A current during engine start without any degradation whereas a commercial battery will not be able to deliver such a high current. Further, the aircraft batteries must be able to perform at extreme environmental conditions encountered during flight. These are the challenges for designing and manufacturing any aircraft battery. Initially, all the aircraft were fitted with Silver-Zinc batteries because of their high discharge capability and small size. Due to shorter life span (9-12 months) and high cost, these batteries were replaced by Ni-Cd batteries. A Ni-Cd battery has five years of service life or 700 discharge cycles and are the most preferred for aircraft applications due to stable performance even though periodic maintenance is required. Lead-acid batteries are also preferred on some platforms like HAWK and helicopters for the advantages of being inexpensive, simple to manufacture and low maintenance.

While the term battery is often used, the basic electrochemical unit is the cell. A battery consists of one or more of these cells connected in series or parallel or both depending on the desired output voltage and capacity.

Ni-Cd Battery and Cell

Silver-Zinc (Ag-Zn) Battery

The airborne Silver-Zinc battery comprises 15 cells each having open circuit voltage (OCV) of 1.8 V.

Silver Zinc Battery for LCA

Lead-Acid (LA) Battery

The secondary cell of a LA battery has an OCV of 2.1 V when fully charged. When connected to a substantial load, the voltage is approximately 2 V. Aircraft storage batteries of the LA type are generally rated at 12 V or 24 V, i.e., they have either 6 or 12 cells connected in series. Two types of LA batteries currently being used in aviation sector are:

◊ The vented cell and

◊ The sealed (recombinant gas) battery

The modern sealed-cell LA batteries are more powerful and require less maintenance than the older vented LA aircraft batteries. For this reason, LA batteries are being used to replace the more expensive Ni-Cd batteries in some turbine powered aircraft.

28 AH, 24 V, Sealed Lead Acid (VRLA) battery for MI-8 MI-17 Helicopter

Ni-Cd Battery

The Ni-Cd cell is an electrochemical system in which the electrodes containing the active materials undergo changes in oxidation state without any change in physical state. This is because the active materials are highly insoluble in the alkaline electrolyte; they remain as solid and do not dissolve while undergoing changes in oxidation state. This is what makes the cell voltage essentially constant throughout the discharge.

The Ni-Cd battery is susceptible to thermal runaway if not maintained, which makes them susceptible to safety of the aircraft. To overcome these limitations, Ni-Cd batteries are designed with thermal sensors to indicate the over-temperature condition to pilot to disconnect them from onboard charging.

27AH, 24 V, Ni-Cd Battery for Mig-21, Mig-27, Su-30 Aircraft

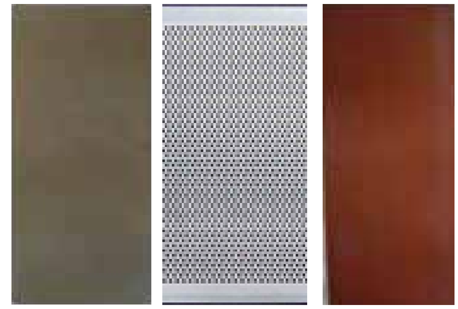
Ni-Cd Battery Technology

Ni-Cd batteries have been in industrial production almost as long as LA batteries. The airborne Ni-Cd battery uses sintered electrodes resulting in superior electrical and mechanical characteristics. For high rate applications, accurate, thin section, closely spaced electrodes need to be produced, and since the active material is in close contact with the current collector, the cell resistance remains fairly constant right up to the end of the discharge. The sintered plate substrates are made by pressing and then sintering at 800-1000 °C in hydrogen-nickel powder (usually formed by thermal decomposition of $Ni(CO)_4$ on a supporting nickel perforated foil or wire screen

By incorporating gas forming materials such as $(NH4)_2CO_3$ in the nickel powder before sintering, a highly porous, mechanically stable matrix is produced. Up to 75-85 per cent of the volume is void and by carefully controlling the starting materials and thermal treatment, uniform pore radii (≈5-30 μm) can be guaranteed in plaque. This is the most used technology for aircraft storage batteries.

The porous plaque is impregnated with nickel salts to make the positive plates and cadmium salts to make the negative plates. After the plaques have absorbed sufficient active material to provide the desired capacity, they are placed in an electrolyte and subjected to an electric current, which converts the nickel and cadmium salts to the final form. The plaques are then washed and dried and cut into plates. These plates are welded with tabs to form the final electrodes. A separator is a permeable membrane placed between a battery's anode and cathode. The main function of a separator is to keep the two electrodes apart to prevent electrical short circuits while also allowing the transport of ionic charge carriers that are needed to close the circuit during the passage of current in an electrochemical cell.

Separators are critical components in liquid electrolyte batteries. A



CRCA Substrate | Ni Plated Punched Substrate | Sintered Plaque

Process of Electrode Formation

Ni Tab | Cut Plate | Tab Welded Plate

Process of Tab Welding

Positive Electrode | Negative Electrode | Separator

Finished Electrode with a Separator for Cell Assembly

Stack Assembly and Finished Cell

separator generally consists of a polymeric membrane forming a micro-porous layer. It must be chemically and electrochemically stable with regard to the electrolyte and electrode materials and mechanically strong enough to withstand the high tension during battery construction. They are important to batteries because their structure and properties considerably affect battery performance, including the energy and power densities, cycle life, and safety. The process of electrodes, stack and cell formation.

Battery Design Parameters

The battery is designed based on the following design parameters:

Power Rating (WH or Ah)

This parameter is decided based on the requirement of emergency load current and duration as well as engine start profile. The airborne batteries are high-performance batteries and are designed to deliver up to 40C (C is rated capacity) current for engine start.

Maximum Voltage (24 V)

The standard voltage for airborne batteries is specified to be 24 V. The OCV of fully charged Ag-Zn cell is 1.8 V, and the battery requires 15 cells to produce 27 V. As the load is applied, the voltage drops to approximately 24 V. A LA battery requires two mono-blocs each consisting of 6 cells. The OCV of the fully charged LA cell is 2.1 V, and the total battery voltage reaches to 25.2 V under open circuit condition. The Ni-Cd battery uses 20 cells in one battery. The OCV of the fully charged Ni-Cd cell is 1.2 V and this produces 24 V.

The aircraft electrical system generates 28 V for avionics systems, and the same supply is used for charging the on-board battery. The maximum design voltage of 24 V allows efficient battery charging during flight.

Minimum Voltage (20 V)

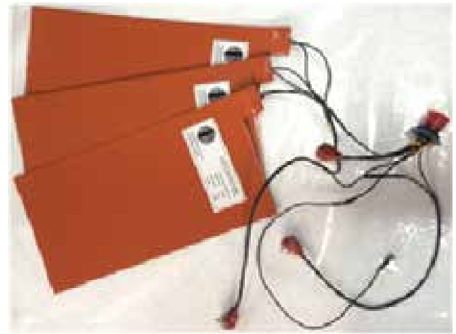
The minimum voltage specified for battery is 20 V as most of the avionics systems are capable of working without degradation up to this voltage (MIL-STD-704 E/F).

Number of Cells

The number of cells required in a battery is decided by the End Cell Voltage. The End Cell Voltage for Ni-Cd is 1 V, for LA 1.8 V and for Ag-Zn 1.4 V. The minimum voltage specified for the airborne battery is 20 V, this requires 20 cells for Ni-Cd, 12 Cells for LA and 15 cells for Ag-Zn battery.

Minimum Operating Temperature

The minimum operating temperature is an important input parameter as the battery, being electro-chemical system, will not be able to perform below the lower operating temperature. If minimum operating temperature is lower than the battery lowest operating temperature, it requires thermal sensor and heating element to be incorporated in the design to ensure the battery operation at a minimum specified temperature.



Thermal Sensor and Heating Element

Aging Factor

Battery performance is relatively stable through out its life. To ensure the battery can meet the design requirement throughout its life, standard suggests the initial capacity should be 125 percentage of the design capacity. The aging factor used in the design is 1.25.

Energy Density

Energy density is the amount of energy stored in a given system or region of space per unit volume or mass though the latter is more accurately termed specific energy. Specific energy, or gravimetric energy density, defines battery capacity in weight (Wh/kg); energy density, or volumetric energy density, reflects volume in liters (Wh/l).

Type of Battery Connector

The aircraft battery connectors are selected based on the current rating and the aircraft installation requirements. The connectors selected or designed should meet the MIL-3509, MIL-P-18148 and MIL-PRF-18148 standards.

TECHNOLOGY FOCUS

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Battery Physical Weight

The specified weight along with capacity requirement governs the basic technology to be used for battery design (Ag-Zn, Ni-Cd or LA).

Battery Tray and its Container

The battery mounting requirement governs the mechanical design of containers and overall form factor.

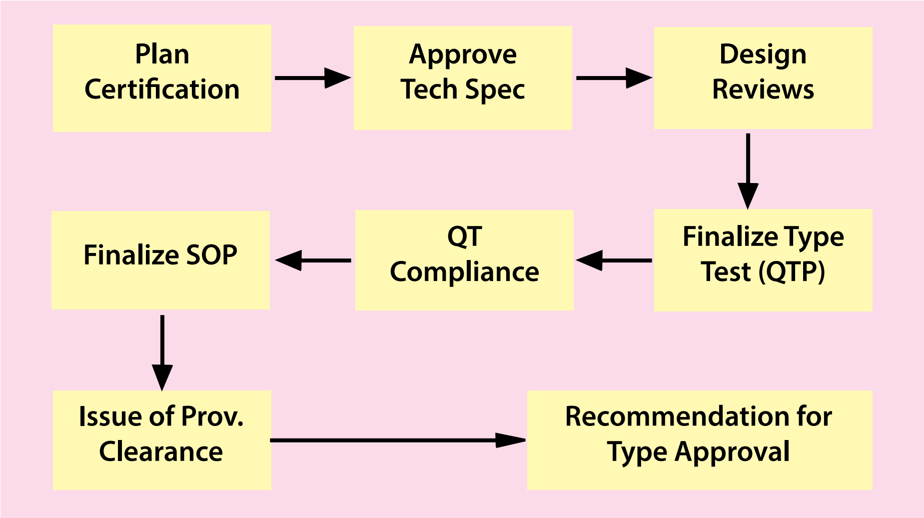
Environmental Specifications

The aircraft batteries are designed to meet the performance requirement under the given environmental conditions. The specified operating conditions plays a major role in battery design. CEMILAC is involved in the design evaluation of various indigenously developed aircraft batteries and has certified nearly 22 types of batteries for various platforms.

Battery Qualification

The battery being a non-repairable system, the qualification is carried out over a sample size of 4 to 5 batteries. The battery being electro-chemical system, the electrical tests conducted on battery takes away the life of the battery. The electrical tests and environmental tests during qualification are distributed over the sample size, and two batteries are cleared for development flight trials after limited environmental tests (Safety of Flight Tests). The various standards being followed for battery qualification are:

- ◊ MIL-PRF-81757D
- ◊ JSS-6410-2013
- ◊ RTCA-DO-293A
- ◊ BSEN-2570:1996
- ◊ IS 13300:1992



Qualification Process for Airborne Batteries

Electrical Tests

The electrical tests conducted as part of the qualification of the battery are:

Capacity Test Capacity Test 1C at ambient low and high operating temperatures is carried out by applying the load as per rating. The battery should deliver the rated current for the specified duration.

Constant Voltage Discharge at Ambient, Low and High Operating Temperature: This test is of stringent nature and the initial current drawn is almost 30 times of rated current.

Rapid Discharge Capacity at Ambient and Low Temperature: The battery should discharged at the 10C rating.

Charge Retention: Fully charged battery is stored for 28 days. After storage, the battery is checked for any degradation during a capacity test.

Short Circuit Test**:** This test is conducted for the worst case of battery failure and that the failure is contained within the battery case. This test also provides information on the amount of output current that can be delivered to help in sizing wiring and circuit breakers.

Charge and discharge test at -18 °C and -40 °C**:** The battery is charged and discharged at -18 °C and -40 °C as per the specified rating during these temperature conditions.

Insulation Resistance: Insulation resistance is a measurement in MΩ of the resistance to current leakage through the insulating materials used in the battery. The insulation resistance shall be measured by applying 500V/250 V DC, and it should be greater than 10 MΩ.

Dielectric Strength Test: A potential of 1500 V (RMS) at commercial frequency is applied between current-carrying parts and the battery container for 1 minute. Battery should not be chattering or should not breakdown of insulation during the test.

Engine Start Profile**:** This test is carried out according to aircraft specification. Efforts are made to measure the engine start profile. If not possible, then 20 second pulse discharge test is conducted.

***Water Consumption Test for Ni-Cd Battery*:** The battery is subjected to a charge at a constant voltage of 28.5 V ± 0.1 V at a temperature of 23 °C ± 5 °C for 2000 hours or until the maximum weight loss, commensurate with the safe operation as declared by the manufacturer has been reached. The loss in weight is a measure of water consumption.

***Cycle Endurance*:** This test is conducted to determine the number of charge-discharge cycles that can be performed without performing maintenance on Ni-cd battery.

***Deep Discharge Test*:** This test is conducted to establish the ability of the battery to recover from a deep discharge state. To conduct this test the battery is discharged completely, then 1Ω resistor is connected between a positive and negative terminal for two weeks. Then charging-discharging is conducted to check that battery has recovered.

***Induced Destructive Overcharge Test*:** This test is conducted to determine the effects of the battery going into thermal run away. The test determines the safety of the battery.

Test Set-up for Battery

The aircraft batteries require specialized equipment for charging and discharging. The LA batteries are charged preferably at a constant potential whereas Ni-Cd and Ag-Zn batteries are charged preferably at constant current. During the qualification, the batteries are charged and discharged at different rates and under different environmental conditions as part of performance checks. This requires sophisticated calibrated charge/discharge equipment. Figure shows the CP/CI charger used for various batteries. The high rate discharge system used for battery qualification testing controlled, and various high rate discharge such as 1C, 5C, 10C, engine start profile, and CV discharge are possible with this system. This system is capable of discharging 2000 A current.

Programmable high rate-discharge set-up (left), and Programmable Constant Current/ Constant Potential Charger at M/s HBL Power System, Hyderabad

Environmental Tests

The environmental tests conducted on battery as part of qualification are:

***Physical Inspection*:** The dimensions, weight, and finish of the battery shall conform to the requirements of individual specifications.

***Vibration Test*:** The vibration test is carried out as per MIL-STD-810G Method 514.6. The test consists of a resonance search and an accelerated life test.

***Resonance Search*:** Resonance search is carried out at 0.5 g from 5 Hz to 500 Hz and the resonance frequencies >2 times of limit. For Rotary wing platform, the vibration profile specified as per standard is Sine over Random. The severity of vibration is estimated based on the number of blades, main rotor & tail rotor speed, and location of battery installation.

For the fixed wing platform—jet aircraft and propeller aircraft—the vibration specification as per standard is 'random vibration' for jet aircraft and 'random on random' for propeller aircraft. The battery is subjected to 9C discharge for 5 minutes after the test.

***Operational Shock and Crash Safety*:** As per RTCA/DO-160 Section 7, operational (peak 6 g for 11 msec, three shocks in each axis) and crash safety (peak 20 g for 11 msec, three shocks in each axis) tests have to be conducted. After the test, battery is discharged at the 9C rate for 5 minutes.

***Temperature and Altitude Testing*: As per RTCA/DO-293A Section 3.5, this test is conducted to verify the safety of the battery under conditions that may be encountered during operation. The battery should not exhibit cracking of the case cell containers and components and heating of connector area.

***Temperature Shock*: As per RTCA/DO-160 Section 3.6, battery should not show mechanical failure of any part, electrolyte leakage or spillage of the electrolyte at any time during the test.

***Fungus Resistance Test*: As per MIL-STD-810G Method 508.6. This test is undertaken to assess the fungal resistance of the battery components.

Humidity Test: As per MIL-STD-810G Method 507.5. The battery should not show corrosion of any parts, physical/mechanical failure of any parts, cracking of cases or covers of either cell or batteries, the breakdown of insulation and losing of protective coating from any battery part.

***Fluid Contamination*: As per MIL-STD-810G Method 504.1, aviation fuel, hydraulic oil, lubricating oil, solvent/ cleaning fluid, de-icing fluid, coolant fluid is applied to entire battery surface.

***Salt Spray*: As per RTCA/DO-160 Section 14. The battery should not show any evidence of corrosion after being tested.

Physical Integrity at 85 °C: As per RTCA /DO-293A Section 3.11, battery is lifted by its handles and place on a flat surface, then by its vent tubes and placed back on a flat surface. Evidence of shearing, breaking, bending, or deterioration at the point of connection of the vent tube and the battery or other distortions of the case is observed.

***Electrolyte Resistance*: As per RTCA/DO-293A Section 3.12, battery should not show cracking, pitting, scaling, corrosion, or other deleterious effects during or after the testing. Identification markings shall not exhibit smudging, smearing, chipping, crazing or other deleterious effects during or after testing.

***Vent Valve Test*: As per RTCA/DO-293A Section 3.14, the battery cell is immersed in tap water, and the location from which gasses are venting is noted. Cells shall not have gases venting from any location other than from the filler cap vents.

Cell Container Test: As per RTCA/DO-293A Section 3.14.13. The cell container test is conducted to assure that the cell cases will operate over the vent valve pressure range without cracking or causing insulation resistance failure of the battery.

***Strength of Connector Receptacle*: As per RTCA/DO-293A Section 3.15. This test is conducted to ensure that connector receptacle does not disconnect during the dynamic aircraft environment.

***Handle Strength Test*: As per RTCA/DO-293A Section 3.16. Each battery handle is subjected to a tension load of 1.5 times the battery weight. This test is conducted to ensure that the handle functions properly. If the battery is equipped with a thermal sensor or electronic circuits for sensing the temperature and isolating the battery from over charging, it will require additional tests for qualification.

The process of flight trial and qualification is concurrent. Two sample batteries are subjected to SOF tests and cleared for aircraft ground integration, engine start and emergency load tests. On successful completion of airworthiness evaluation, the Provisional Clearance for production is accorded by RCMA Hyderbad, which is valid of one year. Subsequently, Type Approval is issued by CEMILAC, which is valid for five years.

Connector Qualification

The connector used on battery requires an additional test for its qualification. These tests are:

***Physical Inspection*: The dimensions, weight, and finish of the connector shall conform to the specifications.

Dielectric Strength Test: Apply a potential of 2500±500 volts of any frequency up to 600Hz between electrical connections of the connector for 61±1 sec. There should not be any spark of dielectric breakdown.

***Insulation Resistance Test*: Apply a potential having an effective value of 500±100 volts at any frequency up to 600Hz for 61±1 second measure the maximum current. Calculate the resistance.

***Operating Torque*: Torque the plug handle while engaging the plug completely with its mating receptacle. Measure the maximum torque value. Torque the plug to disengage the plug and measure the maximum torque applied. Record the value and inspect the plug.

***Contact Resistance Test*: The pins of the receptacles are shorted with the copper strip having cross-section area more than the pin. The receptacle is engaged with the mating connector, and a current of 750±15 A is applied for 5±0.1 minutes, and the voltage drop across connector is measured with a proper instrument. The maximum voltage drop measured is used for calculating the contact resistance.

Life Test: The plugs are subjected to 5000 cycles where as receptacle are subjected to 1500 cycles at the rate not greater than 30 cycles per minute.

A cycle is one engagement and one disengagement of the plug and receptacle. The other environmental tests such as temperature shock, mechanical shock, humidity test, immersion test, salt fog test, and vibration test are conducted along with battery qualification.

Life Cucle Policy of Ni-Cd Battery

For the uniformity in life spans specification across the manufacturers. RCMA, Hyderabad, has taken the initiative with users and standardized the life cycle policy for life span of the Ni-Cd battery as follows:

Life Cycle Policy for Ni-Cd Batteries

Parameter	Mandatory Criteria to be Fulfilled
Total Technical Life (Storage Life + Operation Life)	Max 5 years from the date of manufacture
Storage Life	Max 3 Years from the date of manufacture provided batteries are stored in OEM packed condition
Operation Life	Max 5 years from the date of manufacture, provided the total of storage life + operation life is less than or equal to 5 years and also the storage is not more than 3 years
Capacity Testing Value	Should be equal to or more than 85 % of rated capacity
Life of Battery Container	Max 5 years from the date of manufacture

Batteries Type Approved by CEMILAC

Battery	Platform	TA No.
3.5Ah, NI-CD	Kiran- I	1096
40AH, NI-CD	Jaguar, Cheetah, Chetak, Mirage, Kiran- II	1033
25AH, NI-CD	AN-32	1049
25AH, NI-CD	IL-76, SU-30, KA 28, KM-31	1048
25AH, NI-CD	MI-8/MI-17	1041
16AH, NI-CD	HPT-32	1070
45AH, Ag-Zn	MIG-21	900R
45AH, Ag-Zn	MIG-21	605R
23AH, NI-CD	HS-748 (Chitra)	726R
18AH, NI-CD	Kiran/IA	1132
14.4 Lithium Thyonil Chloride Battery Type 4/10 & 4/27	Personal Rescue Beacons	968

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