1.2 Materials for Electrical apparatus

The main material characteristics of relevance to electrical machines are those associated with conductors for electric circuit, the insulation system necessary to isolate the circuits, and with the specialized steels and permanent magnets used for the magnetic circuit.

Conducting materials:

Commonly used conducting materials are copper and aluminum. Some of the desirable properties a good conductor should possess are listed below.

1. Low value of resistivity or high conductivity
2. Low value of temperature coefficient of resistance
3. High tensile strength
4. High melting point
5. High resistance to corrosion
6. Allow brazing, soldering or welding so that the joints are reliable
7. Highly malleable and ductile
8. Durable and cheap by cost

For the same resistance and length, cross-sectional area of aluminum is 61% larger than that of the copper conductor and almost 50% lighter than copper. Though the aluminum reduces the cost of small capacity transformers, it increases the size and cost of large capacity transformers. Aluminum is being much used now a day's only because copper is expensive and not easily available. Aluminum is almost 50% cheaper than Copper and not much superior to copper.

Magnetic materials:

The magnetic properties of a magnetic material depend on the orientation of the crystals of the material and decide the size of the machine or equipment for a given rating, excitation required, efficiency of operation etc.

The some of the properties that a good magnetic material should possess are listed below.

1. Low reluctance or should be highly permeable or should have a high value of relative permeability μr.
2. High saturation induction (to minimize weight and volume of iron parts)
3. High electrical resistivity so that the eddy EMF and the hence eddy current loss is less
4. Narrow hysteresis loop or low Coercively so that hysteresis loss is less and efficiency of operation is high
5. A high curie point. (Above Curie point or temperature the material loses the magnetic property or becomes paramagnetic, that is effectively non-magnetic)
6. Should have a high value of energy product (expressed in joules / m3).

Magnetic materials can broadly be classified as Diamagnetic, Paramagnetic, Ferromagnetic, Antiferromagnetic and Ferromagnetic materials. Only ferromagnetic materials have properties that are well suitable for electrical machines. Ferromagnetic properties are confined almost entirely to iron, nickel and cobalt and their alloys. The only exceptions are some alloys of manganese and some of the rare earth elements.

The relative permeability μ_r of ferromagnetic material is far greater than 1.0. When ferromagnetic materials are subjected to the magnetic field, the dipoles align themselves in the direction of the applied field and get strongly magnetized.

Further the Ferromagnetic materials can be classified as Hard or Permanent Magnetic materials and Soft Magnetic materials.

a) Hard or permanent magnetic materials have large size hysteresis loop (obviously hysteresis loss is more) and gradually rising magnetization curve. Ex: carbon steel, tungsten steal, cobalt steel, alnico, hard ferrite etc.
b) Soft magnetic materials have small size hysteresis loop and a steep magnetization curve. Ex: i) cast iron, cast steel, rolled steel, forged steel etc., (in the solid form). Generally used for yokes poles of dc machines, rotors of turbo alternator etc., where steady or dc flux is involved. ii) Silicon steel (Iron + 0.3 to 4.5% silicon) in the laminated form. Addition of silicon in proper percentage eliminates ageing & reduce core loss. Low silicon content steel or dynamo grade steel is used in rotating

electrical machines and are operated at high flux density. High content silicon steel (4 to 5% silicon) or transformer grade steel (or high resistance steel) is used in transformers. Further sheet steel may be hot or cold rolled. Cold rolled grain oriented steel

c) Special purpose Alloys: Nickel iron alloys have high permeability and addition of molybdenum or chromium leads to improved magnetic material. Nickel with iron in different proportion leads to

   (i) High nickel permalloy (iron +molybdenum +copper or chromium), used in current transformers, magnetic amplifiers etc.,
   (ii) Low nickel Permalloy (iron +silicon +chromium or manganese), used in transformers, induction coils, chokes etc.
   (iii) Perminvor (iron +nickel +cobalt)
   (iv) Pemendur (iron +cobalt +vanadium), used for microphones, oscilloscopes, etc.
   (v) Mumetal (Copper + iron)

d) Amorphous alloys (often called metallic glasses): Amorphous alloys are produced by rapid solidification of the alloy at cooling rates of about a million degrees centigrade per second. The alloys solidify with a glass-like atomic structure which is non-crystalline frozen liquid. The rapid cooling is achieved by causing the molten alloy to flow through an orifice onto a rapidly rotating water cooled drum. This can produce sheets as thin as 10μm and a meter or more wide.

Insulating materials:

To avoid any electrical activity between parts at different potentials, insulation is used. An ideal insulating material should possess the following properties.

1. Should have high dielectric strength.
2. Should with stand high temperature.
3. Should have good thermal conductivity
4. Should not undergo thermal oxidation
5. Should not deteriorate due to higher temperature and repeated heat cycle
6. Should have high value of resistivity (like 1018 Ωcm)

7. Should not consume any power or should have a low dielectric loss angle δ
8. Should withstand stresses due to centrifugal forces (as in rotating machines), electro dynamic or mechanical forces (as in transformers)
9. Should withstand vibration, abrasion, bending 10) Should not absorb moisture 11) Should be flexible and cheap 12) Liquid insulators should not evaporate or volatilize.

Insulating materials can be classified as Solid, Liquid and Gas, and vacuum. The term insulting material is sometimes used in a broader sense to designate also insulating liquids, gas and vacuum.

Classification of insulating materials based on thermal consideration

Insulation class		Maximum operating temperature in ℃	Typical materials
Previous	Present		
Y		90	Cotton, silk, paper, wood, cellulose, fiber etc., without impregnation or oil immersed
A	A	105	The material of class Y impregnated with natural resins, cellulose esters, insulating oils etc., and also laminated wood, varnished paper etc.
E	E	120	Synthetic resin enamels of vinyl acetate or nylon tapes, cotton and paper laminates with formaldehyde bonding etc.,
B	B	130	Mica, glass fiber, asbestos etc., with suitable bonding substances, built up mica, glass fiber and asbestos laminates.
F	F	155	The materials of Class B with more thermal resistance bonding materials
H	H	180	Glass fiber and asbestos materials and built up mica with appropriate silicone resins
C	C	>180	Mica, ceramics, glass, quartz and asbestos with binders or resins of super thermal stability.

The insulation system (also called insulation class) for wires used in generators, motors transformers and other wire-wound electrical components is divided into different classes according the temperature that they can safely withstand.

As per Indian Standard (Thermal evaluation and classification of Electrical Insulation, IS.No.1271,1985, first revision) and other international standard insulation is classified by letter grades A, E, B, F, H (previous Y, A, E, B, F, H, C).

The maximum operating temperature is the temperature the insulation can reach during operation and is the sum of standardized ambient temperature i.e. 40 degree centigrade, permissible temperature rise and allowance tolerance for hot spot in winding. For example, the maximum temperature of class B insulation is (ambient temperature 40 + allowable temperature rise 80 + hot spot tolerance 10) = 130ºC.

Insulation is the weakest element against heat and is a critical factor in deciding the life of electrical equipment. The maximum operating temperatures prescribed for different class of insulation are for a healthy lifetime of 20,000 hours. The height temperature permitted for the machine parts is usually about 2000C at the maximum. Exceeding the maximum operating temperature will affect the life of the insulation. As a rule of thumb, the lifetime of the winding insulation will be reduced by half for every 10 ºC rise in temperature. The present day trend is to design the machine using class F insulation for class B temperature rise.