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CONDUCTING AND INSULATING MATERIALS

1. Conducting materials

Conducting materials may be classified into three groups: conductors, semiconductors and imperfect insulators. This section will cover only conductors.

In general, metals and alloys are conductors of electricity. The most common metals used in electricity are copper, aluminium and their alloys.

The main electric characteristic of conductors is resistance that varies with temperature, presenting copper a lower resistance than aluminium.

The relation of the resistance at two different temperatures θ_1 and θ_2 is given by the equation:

$$R_{\theta 1} = R_{\theta 2} \times \alpha \times [1 - (\theta_1 - \theta_2)]$$

"α" is the temperature coefficient of the metal (0.0039 for copper; 0.004 for aluminium).

- **Copper and its alloys**

Copper has the highest electrical and thermal conductivity of the common industrial metals.

It has good mechanical properties, is easy to solder, is readily available and has high scrap value.

It is widely used in wire form.

Cadmium copper, chromium copper, silver copper, tellurium copper and sulphur copper find wide application in the electrical industry where high conductivity is required.

Cadmium copper is particularly suitable for the contact wires in electric railways, tramways, trolley buses, gantry cranes and similar equipment, and is also used in overhead telecommunications lines and transmission lines of long span.

Castings of cadmium copper have application in switchgear components and in the secondaries of transformers for welding machines. Cadmium copper can be soft soldered, silver soldered and brazed in the same way as ordinary copper.

Chromium copper is particularly suitable for high-strength applications such as spot and seam types of welding electrodes. Strip and wire are used for light springs which carry current. In its heat-treated state, the material can be used for commutator segments in rotating machines where the temperatures are higher than normal.

Silver copper has the same electrical conductivity as ordinary high-conductivity copper, but its softening temperature, after hardening by cold work, is much higher and its resistance to creep at moderately elevated temperatures is enhanced. Its principal uses are in electrical machines which operate at high temperatures or are exposed to high temperatures in manufacture.

Tellurium copper offers free-machining, high electrical conductivity, retention of work hardening at moderately elevated temperatures and good corrosion resistance. A typical application is magnetron bodies, which are often machined from solid. Tellurium copper can be soft soldered, silver soldered and brazed without difficulty.

Sulphur copper has applications in all machined parts requiring high electrical conductivity, such as contacts and connectors; its joining characteristics are similar to those of tellurium copper.

- **Aluminium and its alloys**

For many years aluminium has been used as a conductor in most branches of electrical engineering. Several aluminium alloys are also good conductors, combining strength with acceptable conductivity. Aluminium is less dense and cheaper than copper, and its price is not subject to the same wide fluctuations as copper.

There are two specifications for aluminium, one for pure metal grade ZE and the other for a heat-treatable alloy. Aluminium and its alloys are used in cables, bus bars and overhead lines.

- **Resistance alloys**

Many alloys with high resistivity have been developed, the two main applications being resistors and heating elements. The actual used alloys are Ni-Cr-Al (nickel-chromium-aluminium), coppernickel, Ni-Cr (nickel-chromium) and Cr-Fe-Al (chromium-iron-aluminium).

2. Insulating Materials

Insulating materials are used to separate electrically the conducting parts of equipment from each other and from earthed and "no live" components of equipments and networks.

A dielectric is an electrical insulator that can be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material as they do in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization.

Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field which reduces the overall field within the dielectric itself.

It is important to note that while the term "insulator" implies low electrical conduction, "dielectric" is typically used to describe materials with a high polarizability.

Insulating materials may be divided into basic groups which are solid dielectrics, liquid dielectrics, gas and vacuum.

- **Solid dielectrics**

Solid dielectric insulating materials may be divided, according to IEC standards and their application into the following groups:

- Inorganic (ceramic and glass) materials
- Plastic films
- Flexible insulating sleeving
- Rigid fibrous reinforced laminates
- Resins and varnishes
- Pressure-sensitive adhesive tapes
- Cellulosic materials
- Combined flexible materials
- Mica products
- Textile insulation
- Elastomers and thermoplastics

We will discuss now the most common used. A major application for inorganic materials in this category is in high voltage overhead lines as suspension insulators or as bushings on high voltage transformers and switchgears.

Plastic films have been used as films in a variety of applications such as the insulation between foils in capacitors and slot insulation in rotating electrical machines. Common use for flexible insulating sleevings is the protection of cables and components from the deleterious effects of mechanical and thermal damage, and may find application in electrical machines, transformers, domestic and heating appliances, light fittings, cable connections and switchgears.

Resins and varnishes are used by in the impregnation and coating of electrical equipment (dry type transformers, as an example) in order to improve its resistance to working conditions, to enhance its electrical characteristics and to increase its working life. The more common types are phenolic, polyester, epoxy, silicone and polyimide.

Elastomers and thermoplastics cover a very wide range of polymeric and rubber-like insulation materials, with a large use in cables insulation. The most common used are PVC (Polyvinyl chloride), MDPE (Medium-density polyethylene), XLPE (Cross-linked polyethylene) and EPR (Ethylene propylene rubber).

- **Liquid dielectrics**

Nowadays the principal uses of liquid dielectrics are as a filling and cooling medium for transformers, capacitors and rheostats, and as an impregnant of absorbent insulation used mainly in transformers, earth reactors and shunt reactors.

The important properties of dielectric liquids are therefore electric strength, viscosity, chemical stability and flashpoint. Typical materials include highly refined hydrocarbon mineral oils obtained from selected crude petroleum, silicone fluids, synthetic esters and hydrocarbons.

- **Gas insulation**

Two gases already in common use for insulation are nitrogen and sulphur hexafluoride (SF6). Nitrogen is used as an insulating medium in some sealed transformers, while SF6 is finding increasing use in transmission and distribution switchgears because of its insulating properties and its arc-extinguishing capabilities.

3. Properties and behavior of dielectric materials

The most important properties of dielectric materials are:

- Volume resistivity or specific resistance.
- Relative permittivity, or dielectric constant, which is defined as the ratio of the electric flux density produced in the material to that produced in a vacuum by the same electric field strength.
- Dielectric loss, or electrical dissipation factor, which is defined as the ratio of the power loss in a dielectric material to the total power transmitted through it. It is given by the tangent of the loss angle and is commonly known as “tanδ”.

The most important characteristic of an insulating material is its ability to withstand electric stress without breaking down.

This ability is known as dielectric strength and is usually quoted in kV/mm. Typical values may range from 5 to 100 kV/mm. Another significant aspect of all insulating materials is the maximum temperature at which they will perform satisfactorily.

Generally speaking, insulating materials deteriorate more quickly at higher temperatures and the deterioration can reach a point at which the insulation ceases to perform its required function.

This characteristic is known as ageing, and for each material it has been usual to assign a maximum temperature beyond which it is unwise to operate.

The ageing of insulation depends not only on the physical and chemical properties of the material and the thermal stress to which it is exposed, but also on the presence and degree of influence of mechanical, electrical and environmental stresses.

Dielectric materials may be deteriorated when subjected to excessive heat and overvoltages and may be contaminated by other materials, such as copper particles, water and gas, causing dielectric failure.

The definition of a useful lifetime will also vary according to the type and usage of equipment; that must be taken into account when choosing the insulating material for a particular application.