International Journal For Technological Research In Engineering
Volume 7, Issue 3, November-2019 *ISSN (Online): 2347 - 4718*

INSULATION MATERIALS IN WIRE AND CABLE INDUSTRY - AN OVERVIEW

A.P.Athane[1], Dr. Prashant D. Gangawane[2]
[1,2]Assistant Professor, Department of Textiles , D.K.T.E.Society's Textile & Engineering Institute, Ichalkaranji , Dist.: Kolhapur, Maharashtra, India. Pin-416 115

Abstract: Before the invention of electricity human being relied on fire for the luxuries of light, heat, and cooking. But nowadays electricity becomes a basic need for the human beings all over the world. Wind, water and sunlight, fossils fuels and nuclear energy these are main sources of electricity. We know very well that generation, transmission and distribution these are the essential requirement in the field of the electricity. As proverb, prevention is better than cure, the incomparable care must be taken in every steps of electricity and specially during the transmission and distribution. And this cannot be possible without insulating materials .If wires and cables are not insulated properly, it can result in injuries, deaths, fires, and many other problems. In this paper various insulating materials used for wires and cables described in detail which may be familiar to the end user.

Keywords: Electricity, wires , cables , wind, water and sunlight, fossils fuels and nuclear energy.

I. INTRODUCTION

Electricity – an indispensable requirement of life.

Electricity is one of the extreme technological innovations of mankind. It has also become a part of modern life and one cannot think of a world without it. Electricity has many uses in our everyday routine . It is used for lighting rooms, working fans and domestic appliances like using electric stoves, A/C and more. All these provide comfort to people. In industries, large machines are worked with the help of electricity. Vital items like food, cloth, paper and many other things are the product of electricity. (1- 30) It is well known that every electric circuit, regardless of where it is or how large or small it is, has four basic parts: an energy source (AC or DC), a conductor (wire), an electrical load (device), and at least one controller (switch). (32) In short, wire and cables are an indispensable part of electricity. A wire is a cylindrical and flexible strand or rod of metal. (33) The evidence of wire has been found in archaeological sites dating back 5,000 years ago. Initially, wire was used in jewelry. Metal strips would be pushed through holes in stone beads so the metal would fold over into a tube shape. The first wire mills began to pop up in England in the 1500s. As time passed and human technology became more sophisticated, wire began to be used for electrical purposes and to be made into wire ropes. (34) Nine times out of ten, the terms wire and cable are used to describe the same thing, but they are actually quite different. Wire is a single electrical conductor, whereas a cable is a group of wires swathed in sheathing. The term cable originally referred to a nautical line of multiple ropes used to anchor ships, and in an electrical context, cables (like wires) are used to carry electrical currents. Whether indoors or outdoors, proper wire and cable installation is of paramount importance - ensuring a smooth electricity supply, as well as passing electrical inspections. Each wire and cable needs to be installed carefully, from the fuse box to the outlets, fixtures and appliances. (35) Electricity is like a kitchen knife. If you use it wisely, it can cut food and prepare delicacies. If you use it unwisely, it can end up cutting your finger. Electricity flows through anything that is a "conductor." Interestingly, humans are very good conductors of electricity. Since electricity is a form of energy, a strong current has the ability to seriously harm you. If the current is strong enough, you can be fatally injured. Due to the strong possibility of a fatal injury occurring, electric cables are insulated. Another important reason why they are insulated is to prevent energy from dissipating into the surroundings, allowing it to be conserved.Cables and wires are insulated using electrical insulators. The electrical insulators are non-conducting materials that encircle the cables and provide a buffer between the cable and anyone or anything that may come in contact with it. (36-40) . If something is not wired properly, it can result in injuries, deaths, fires, and many other problems.

In order to avoid any damage there are various insulating material different material used for the purpose of insulation from the intervention of electricity. In this paper materials used for coating of wires and cables described in detail. This paper reviews the various insulating material which used in electricity for the inception of it.

II. CONSTRUCTION OF CABLE

The power cable mainly consists of three main components, namely, conductor, dielectric, and sheath. The conductor in the cable provides the conducting path for the current. The insulation or dielectric withstands the service voltage and isolates the conductor with other objects. The sheath does not allow the moistures to enter and protects the cables from all external influences like chemical or electrochemical attack, fire, etc. The main components of electrical power cables are explained below in details.

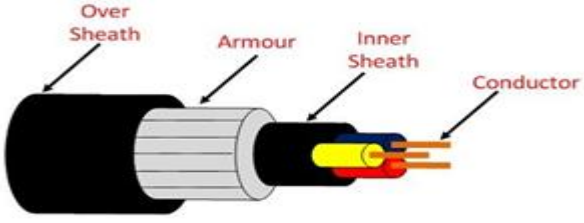

Fig.1: Electrical Power Cable.

Basic Component of cable

A. Conductor

Coppers and aluminum wires are used as a conductor material in cables because of their high electrical conductivity. Solid or number of bare wires made of either copper or aluminum are used to make a power cable.

B. Insulation

The most commonly used dielectric in power cables is impregnated paper, butyl rubber, polyvinyl chloride cable, polyethylene, cross-linked polyethylene. Paper insulated cables are mostly preferred because their current carrying capacity is high, generally reliable and having a long life. The dielectric compound used for the cable should have following properties.

- The insulator must have high insulation resistance.
- It should have high dielectric strength so that it does not allow the leakage current to pass through it.
- The material must have good mechanical strength.
- The dielectric material should be capable of operating at high temperature.
- It should have low thermal resistance.
- It should have a low power factor.

The cables used for submarine and damp soil should use synthetic dielectrics like polyvinyl chloride, polyethylene, etc. These materials are comparatively lighter and have nonmigratory dielectric. Also, such type of dielectric material has good dielectric strength, low power loss, and low thermal resistance.

C. Inner Sheath

It is used for protecting the cable from moistures which would affect the insulation. Cable sheath is made up of lead alloy, and these strengths withstand the internal pressures of the pressurized cables. The material used for inner sheath should be nonmagnetic material.

The aluminum sheath is also used in a power cable because it is cheaper, smaller in weight and high mechanical strength than the lead sheath. In oil-filled cables and telephone, cables corrugated seamless aluminum sheath is used because it has better-bending properties, reduced thickness, and lesser weight.

D. Protective Covering

Lead sheath cables when directly laid down on the ground are damaged by corrosion and electrolyte. For protecting the cables against corrosion layers of fibrous material like paper, hessian, etc., or polyvinyl chloride is used. Layers of fibrous material spread with the waterproof compound to the outside of the electrical cable are called serving.

E. Armouring:

Armouring is the process in which layers of galvanized steel wires or two layers of metal tape are applied over sheath for protecting it from mechanical damage.The steel wires are normally used for armouring because it has high longitudinal strength. Armouring is also used for earthing the cable. When the fault occurs in the cable (due to insulation failure) the fault current flows through the armour and get earthed.

F. OverSheath

It gives the mechanical strength to the cables. It protects the cable from overall damage like moisture, corrosion, dirt, dust, etc. The thermosetting or thermoplastic material is used for making over the sheath. (41)

III. ESSENTIAL PROPERTIES REQUIRED FOR THE INSULATION MATERIAL OF THE CONDUCTORS

The most important part of any cable is the insulation of the conductors. When choosing materials to insulate conductors or cables, many factors should be taken into consideration. These include electrical properties, mechanical properties, chemical properties, thermal properties, and more.

A. Electric properties:

Dielectric strength : The dielectric strength of a material is a measure of the electrical strength of an insulator. It is defined as the maximum voltage required to produce a dielectric breakdown through the material and is expressed in terms of Volts per unit thickness. The higher the dielectric strength of a material the better an electrical insulator it makes. IEC 60243 is a standard referred to for a method of testing dielectric strength of a material. The test is conducted in either air or oil and involves placing the test material between two electrodes and increasing the voltage between the electrodes until an electrical burn-through punctures the sample or decomposition occurs. Usually the specimen is between 0.8 and 3.2mm thick. Samples which are over 2mm in thickness are usually tested in oil to prevent flash over before breakdown.

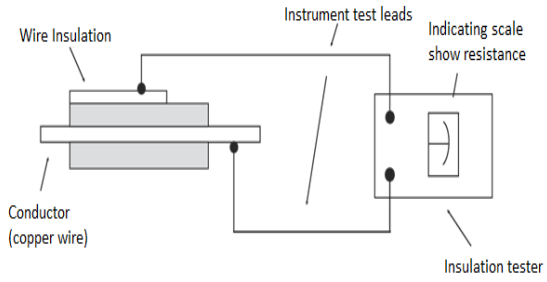

Fig.2 : A method of testing dielectric strength

The dielectric strength is then calculated by dividing the breakdown voltage by the thickness of the sample.

Most plastics have good dielectric strengths in the order of 10 to 30kV/mm.

Examples:

Low Density Polyethylene LDPE = 27kV/mm

Polypropylene PP = 22kV/mm

Polyvinylchloride PVC = 14kV/mm (43)

Insulation resistance : Cable conductor is provided with an insulation of suitable thickness to avoid the leakage of current. The thickness of any cable depends on the purpose of its design. The path of current leakage in such cable is radial. The resistance or opposition offered by the insulation to the flow of current is also radial throughout its length.

For a single core cable conductor of radius r1, internal sheath radius r2, length l and insulation material resistivity ρ, the perimeter of the conductor is $2\pi r l$. The thickness of the

insulation will be given as dr.
Rins = ρdr/2π*rl*
When integrated, we will have:
Rins = ρ/2π*l*[loge r2 /r2]
Rins is inversely proportional to 1/*l* contrary to R = ρ*l*. Where ρ (rho) is a constant known as resistivity. There are some cables that have more than one insulating layers and more than one core. The main wire being at the center, serve as the main conductor. The other core serves the purpose of grounding and preventing the electromagnetic waves and radiations from escaping from the cabled. It serve as a shield. Cables under this category is the Coaxial cables.
Coaxial cable conducts electrical signal using an inner conductor (the inner or main conductor could be any good conductor but copper is mostly preferred because of it's low resistivity, the copper could also be plated) is contained in mostly PVC case. Before the outer PVC case, there are two or more other insulators with either aluminum foil or copper strand between them. The cables are protected from external environment by the outermost PVC case. While voltage is passed through the inner conductor, the shield or case has little or no voltage passing through it.
The advantage of coaxial design is that electric and magnetic fields are confined to the dielectric with little leakage outside the shield. Due to the level of insulation in the cables which prevents outside electromagnetic fields and radiations from penetrating into it, interference is avoided. Since conductors with large diameter have less resistance, less electromagnetic field will be leaked. The same goes for cables with more insulation. Knowing that weaker signals are easily interrupted by little interference, cables with more layers of insulation are always good choice for conveying such signals. (44)
Insulation power factors : Most failures of electrical power equipment are the result of a breakdown in the insulation system. To keep failures at a minimum, periodic maintenance testing of the insulation is recommended to indicate whether it is deteriorating, and how fast.
Power factor tests are used to measure dielectric losses, which relate to the wetness, dryness or deterioration of electrical insulation.
Power factor is defined as the cosine of the phase angle between voltage and current. For an ideal insulation, the phase angle is 90°. In practice no insulation is ideal, but instead has a certain amount of loss, and the total current leads the voltage by a phase angle less than 90°. (45)
Charging current : The charging current I of a single conductor insulated power cable can be obtained from the following formula: ECfI····=π2Where: I = microamperes per 1000 ft. f = Frequency, Hz C = Capacitance, picofarads per ft E = Voltage, phase-to-ground, kV (46).
Arcresistance :The intent of arc resistance testing is to distinguish between solid electrical insulating materials. It examines the specimen's ability to resist an arc with high voltage and low current exposed to the material's insulating surface. (47)
Tracking susceptibility :Tracking susceptibility is a function of the properties of materials used in the fiber optic cable. (48)

B. Mechanical properties:
Toughness and flexibility:
Stiffening is loss of flexibility with age, this can effect machines with moving parts. Wire and cable required excellent physical properties in adverse chemical and thermal environments allowing them to be used when more flexibility and toughness are required. In this case long chain polyamides that offer exceptional performance compared to short chain polyamides including chemical resistance, low moisture absorption, and low density. (49)
Cable flexibility testing is designed to determine whether the materials in a flexible cable can withstand constant flexing under electrical load. Put simply, it tests whether the cable will maintain electrical continuity whilst flexing, which is an essential requirement for flexible cable attached to appliances where they are expected to flex many times during their service lifetime (50).
Tensile, elongation and crushing strengths: Tensile testing, also known as pull testing, is a standard test method where a sample is placed in grips and subjected to controlled tension until it fails. This provides valuable information about materials including ultimate tensile strength, yield strength, elongation and reduction in area. A compression test determines behaviour of materials under crushing loads. The specimen is compressed and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength and, for some materials, compressive strength. (51)
Resistance to abrasion or moisture : Ability of a wire, cable or material to resist surface wear should be taken into account while manufacturing of wire and cables. (52)Moisture ingress can cause significant problems including short circuit and corrosion of the copper conductors. (53)
Brittleness :A material is brittle if, when subjected to stress, it breaks with little elastic deformation and without significant plastic deformation. (54) Plasticizers are always added to wire & cable insulation and jacket compounds to increase flexibility and decrease brittleness. (55) . If material Brittle with age it get stiffens and cracks form leading to shorts

C. Chemical properties:
Moisture absorption : One of the oldest enemies of wire and cable is moisture. When moisture successfully attacks an electric cable, the system design can be seriously affected. By penetrating into the insulation or into interstices, moisture can impair the electrical characteristics of capacitance, power factor, insulation resistance and dielectric strength. Occasionally, because of moisture, a cable will shortcircuit to ground, accompanied by a shower of molten copper, soot, and irate personnel. (56)

Resistance to oil, gas, acids and alkalies :
Electrical apparatus consisting of coils of insulated wire is usually finished off with an insulating varnish. The varnish is used for the resistance to oil, gas, acids and alkalies: (57)
Stability when exposed to sunlight, ozone, or flames :

Additives are used to impart special properties required for the end use of the product, for example, flame retardancy or resistance to weathering by the sun or by microbes. Flame retardancy is a common requirement for wire and cable formulations. Additives such as Antimony Trioxide (ATO) are effective flame retardants. Plasticizers used such as phosphoric esters (i.e. TBP, TOF) can also impart flame retardant properties. UV-absorbers may be added for exterior use applications to prevent weathering by the sun. Carbon Black is effective at protection against light, but only if you are making a black or dark colored compound. For brightly colored or transparent compounds, UV-Absorbers based on Benzotriazole or Benzophenone can be used. Biocides are added to protect PVC compounds from degradation by fungus and microorganisms. OBPA (10′,10′-0xybisphenoazine) is frequently used for this purpose and can be purchased already dissolved in plasticizer. (55)

Example Formulation

Below is an example of a very basic starting point for a PVC wire coating formulation:(55)

Formulation	PHR
PVC	100
ESO	5
Ca/Zn or Ba/Zn Stabilizer	5
Plasticizers (DOP, DINP, DIDP)	20 – 50
Calcium Carbonate	40- 75
Titanium Dioxide	3
Antimony Trioxide	3
Antioxidant	1

D. Thermal properties:

Expansion and contraction :

All materials expand and contract due to temperature changes. (58)

Softening and flow temperature:

The temperature rating of a wire or cable is generally the maximum safe temperature that the wire can carry full-load power without the cable insulation melting, oxidizing, or self-igniting. A full-load wire does heat up due to the metallic resistance of the wire. The table below illustrates the maximum absolute temperature that different insulation types can withstand.(59)

Compatibility with operating, ambient, or emergency overload and short circuit conditions :

When choosing materials to insulate conductors or cables many factors should be taken in to account such as thecompatibility with operating, ambient, or emergency overload and short circuit conditions .(60)

IV. VARIOUS TYPES OF CABLE AND WIRE INSULATION MATERIALS

Insulation is a nonconductive material, or a material resistant to the flow of electric current. It is often called a dielectric in radio frequency cables. Insulation resists electrical leakage, prevents the wire's current from coming into contact with other conductors and preserves the material integrity of the wire by protecting against environmental threats such as water and heat. The safety and effectiveness of the wire depend on its insulation.

There are generally three types of insulation materials namely plastic insulation types, Rubber insulation types and Fluoropolymer insulation types. (61)

Following is a list of insulation materials .

E. Plastic Insulation Types: In this category, plastic is used as insulating material.

Polyvinyl Chloride (PVC) (61-70)

A PVC jacket is a relatively inexpensive and easy-to-use material with the potential to be used in diverse applications. The maximum temperature range is minus 55 degrees Celsius to 105 degrees Celsius and is resistant to flame, moisture and abrasion. It also holds up against gasoline, ozone, acids and solvents.1 It can also be used for medical- and food-related purposes as it is odorless, tasteless and nontoxic. PVC jackets can be used in heavy- and thin-wall applications. PVC should not be used when flexibility and an extended flex life are required at low temperatures. When used in retractile cord applications, it also shows below-average flexibility. PVC jackets display high attenuation and capacitance loss, meaning that power is lost when used in an electrical system.

Semi-Rigid Polyvinyl Chloride (SR-PVC)

A hard semi-flexible polyvinyl chloride compound with low plasticizer content.(71) This is mainly used as a primary insulation and is very abrasion resistant. (For 30-16 gauge, a 10-mil. wall meets UL style 1061, 80 degrees Celsius, 300 volts.) Semi-rigid PVC is also resistant to heat, water, acid and alkali as well as flame-retardant. (61)

Plenum Polyvinyl Chloride (Plenum PVC)

Plenum PVC is suitable for use in building spaces behind dropped ceilings or raised floors left open to allow for air circulation. Standard PVC is considered a nonplenum insulation option because it does not exhibit the qualities necessary for safe usage in plenum areas. To be plenum-rated, the insulation must meet more-stringent fire safety regulations. Plenum cable is used between floors in a building. It has a special flame-retardant coating. (61, 72-80)

Polyethylene (PE)

This compound is used most in coaxial and low-capacitance cables because of its exemplary electric qualities. Many times, it is used in these applications because it is affordable and can be foamed to reduce the dielectric constant to 1.50, making it an attractive option for cables requiring high-speed transmission. Polyethylene can also be cross-linked to produce high resistance to cracking, cut-through, soldering, and solvents. Polyethylene can be used in temperatures ranging from negative 65 degrees Celsius to 80 degrees Celsius. All densities of polyethylene are stiff, hard and inflexible. The material is also flammable. Additives can be used to make it flame-retardant, but this will sacrifice the dielectric constant and increase power loss. (61, 81-86)

Polypropylene (PP)

Polypropylene (PP) is in many aspects similar to polyethylene in both physical and electrical characteristics, but with improved thermal properties. Polypropylene is reasonably economical and can also be foamed to improve its electrical properties. Polypropylene is susceptible to degradation from exposure to heat and UV radiation and is therefore not recommended for outdoor applications where exposure to sunlight is likely. Use of polypropylene as an insulation material for thin walls is typical within the wire and cable industry with an alternative material used as the final jacket.

Performance of Polypropylene (PP) for Wire and Cable Insulation and Jacketing

Category	Rating
Temperature Range	-40°C to 80°C
Flame Resistance	Poor
Chemical Resistance	Fair
Durability	Fair
Flexibility	Poor
UV Resistance	Poor

Polyethylene is suitable for both wire insulation and final cable jacketing. (61, 87-93)

Polyurethane(PUR)

Polyurethane is known for its extreme toughness, flexibility and flex life, even in low temperatures. It also has excellent ratings for chemical, water and abrasion resistance. This material works well in retractile cord applications and can be a good option for salt-spray and low-temperature military purposes. Polyurethane is a flammable material. The flame-retardant version sacrifices strength and surface finish. Polyurethane's main disadvantage though, is its poor electrical properties, making it suitable for jackets only. (61, 94-98)

Chlorinated Polyethylene (CPE) CPE displays very good heat, oil and weather resistance. Many times, CPE serves as a lower-cost, more environmentally friendly alternative to CSPE. Its reliable performance when exposed to fire also makes it a favorable alternative to PVC insulation. Chlorinated polyethylene is commonly found in power and control cables as well as industrial power plant applications. Generally used in very harsh environments. It is lightweight, very rigid, and has a mildly rough surface texture and a low coefficient of friction. It is low-cost relative to the level of oil, moisture, chemical and UV resistance provided. (61, 99-101)

Nylon

Nylon is usually extruded over softer insulation compounds. It serves as a tough jacket, exhibiting strong abrasion, cut-through and chemical resistance, especially in thin-wall applications. It is also extremely flexible. One disadvantage of nylon is its absorption of moisture. This degrades some of its electrical properties. (61, 103)

F. Rubber Insulation Types : In this category, rubber is used as insulating material .

Thermoplastic Rubber (TPR)

In many applications, TPR is used to replace true thermoset rubber. It has improved colorability, higher processing speeds and a wider usable temperature range. It also displays excellent heat, weather and age resistance without curing. TPR is not cut-through resistant but can be used in applications where other properties of rubber are preferred. (61, 104 -106)

Neoprene (Polychloroprene)

This is a synthetic thermoset rubber that must be vulcanized to obtain its desired qualities. It exhibits supreme abrasion, cut-through, oil and solvent resistance. Neoprene is also known for its long service life and wide ranges of temperature and usability. It is remarkably flame retardant and self-extinguishing. Military products often incorporate neoprene. This material is especially desirable for hand-held cordsets. (61, 107-109)

Styrene Butadiene Rubber (SBR)

This is a thermoset compound with qualities similar to neoprene. It has a temperature range of minus 55 degrees Celsius to 90 degrees Celsius. SBR is primarily used in Mil-C-55668 cables. (61, 110-113)

Silicone

This material is extremely heat-resistant and flame-retardant and can be used in temperatures up to 180 degrees Celsius. It is moderately abrasion-resistant. Silicone is also extremely flexible. Benefits include a long storage life and good bonding properties necessary in many electrical applications. (61, 114-116)

Fiberglass

Fiberglass is the most widely used glass insulation. It can be used continuously in temperatures up to 482 degrees Celsius. This material is resistant to moisture and chemicals but only fairly abrasion-resistant. Its common applications include heat treating, glass and ceramic kilns, foundries and extensive applications in aluminum processing. (61,117-121)

Ethylene Propylene Rubber (EPR) EPR is known for its excellent thermal characteristics and electrical properties, allowing a smaller cross-sectional area for the same load-carrying capacity of other cables. It is commonly used in high-voltage cables. The flexibility of this material also makes it appropriate for temporary installations and applications in the mining industry. These rubbers are also valuable for their heat, oxidation, weathering, water, acid, alcohol and alkali resistance. EPR can be used in the temperature range of minus 50 degrees Celsius to 160 degrees Celsius. EPR is not as tear resistant as other insulation options. It is also relatively soft and may require more care during installation to avoid damage. (61, 122-125)

Rubber

Rubber insulation generally refers to both natural rubber and SBR compounds, each available in a variety of formulas for

use in a wide range of applications. Because formulas vary, so do temperature ranges and some other basic characteristics. While this type of insulation has poor oil and ozone resistance, it exhibits good low-temperature flexibility, good water and alcohol resistance, good electrical properties and excellent abrasion resistance. (61, 126-128)

Chlorosulfonated Polyethylene (CSPE): Chlorosulfonated polyethylene is a family of chlorinated elastomers. The materials is made by reacting polyethylene with chlorine and sulfur dioxide to yield chlorosul-fonated polyethylene. The reaction changes the thermoplastic polyethylene into a synthetic elastomer that can be compounded and vulcanised. CSPE works well as low-voltage insulation. It is known for its ability to perform through a wide temperature range as well as for its resistance to chemicals and UV rays. This insulation material can be found in appliance wire, lead wire, coil leads, transformer leads and motor lead wire. Chlorosulfonated polyethylene is sometimes referred to as Hypalon, a registered trademark of Dupont. (61,129-136)

Ethylene Propylene Diene Monomer (EPDM) This synthetic rubber insulation displays outstanding heat, ozone, weather and abrasion resistance. EPDM also exhibits excellent electrical properties. Further benefits include excellent flexibility at both high and low temperatures, from minus 55 degrees Celsius to 150 degrees Celsius as well as good dielectric strength. EPDM replaces silicone rubber in some applications. (61, 137-143)

G. Fluoropolymer Insulation Types: In this category, Fluoropolymer is used as insulating material.

Perfluoroalkoxy Polymer- Chemical Compound (PFA)

Perfluoroalkoxy, also referred to as PFA, is a fluoropolymer. PFA can be rated up to 260°C, thus making it an excellent choice for high temperature applications. Along with excellent temperature ratings, PFA has outstanding resistance to chemicals. A typical use of PFA insulated wire is as a thermocouple wire, but it can be found in various military and aerospace environments. (61, 144-151)

Common Types of PFA Wire or Cable

- Military Industry
- Aerospace Industry
- Oil and Gas Industry
- OEM Appliance Wiring

Polytetrafluoroethylene (PTFE)

Polytetrafluoroethylene or PTFE is a particularly versatile ivory-white and opaque plastic fluoropolymer; it is made by the free-radical polymerisation of many tetrafluoroethene molecules, and is suitable for a wide range of applications in industries as diverse as aerospace, the food and drink industry, pharmaceuticals and telecoms. PTFE is a thermoplastic material that can be used across a wide temperature range of minus 73 degrees Celsius to 204 degrees Celsius. It is extremely flexible as well as resistant to water, oil, chemicals and heat. The mechanical properties of PTFE are low compared with other plastics. (61, 152-160)

Fluorinated Ethylene Propylene (FEP) Fluorinated ethylene propylene (FEP) is very similar to polytetrafluoroethylene (PTFE) in its chemical inertness, dielectric characteristics, coefficient of friction, and high-heat resistance. FEP also sports high stress-crack resistance. This material is widely used due to its processing characteristics and wide range of applications. It is also highly flame-resistant. Improved data transmission can also be achieved when FEP is foamed. Pricing and processing are also being improved. FEP is commonly used in plenum cable and military applications. (61, 161-170)

ETFE (ethylene tetrafluoroethylene) and ECTFE (Halar® or ethylene chlorotrifluoroethylene). These materials are stronger and more flexible than PFA or FEP and can become thermoset through irradiation. Foaming ECTFE and ETFE improves data transmission and reduces weight. ETFE and ECTFE lack many of the electrical advantages of FEP . ECTFE (ethylene chlorotrifluoroethylene) was designed to provide chemical resistance in heavy duty corrosion applications. It is a partially fluorinated polymer (a fluoropolymer), semi-crystalline and can be processed in the melt. Chemically it is a copolymer of ethylene and chlorotrifluoroethylene. It is marketed under the brand name Halar ECTFE by Solvay Specialty Polymers,[1] a subsidiary of Solvay. (61, 171-180).

Polyvinylidene Fluoride (PVDF)

PVDF is a tough, stable fluoropolymer with distinct engineering advantages. Discovered in 1969 by Dr Heijji Kawai, PVDF has a good performance to cost ratio. PVDF is flexible, lightweight and thermally stable as well as resistant to chemicals, heat, weather, abrasion and fire. It is also a relatively low-cost insulation option. This insulation is used in a wide range of industries and applications. It is often found in cables meeting the UL standard 910 Plenum Cable Flame Test, deeming the cables suitable for use in a building's space for air circulation, typically behind dropped ceilings or raised floors. PVDF is also commonly called Kynar, a registered trademark of Arkema Inc. (61, 181- 195)

Thermoplastic Elastomers (TPE)

Thermoplastic elastomers consist of a mix of polymers, typically a plastic and rubber, to combine the benefits of each material into one insulating product. TPE can be molded, extruded and reused similar to a plastic while maintaining the flexibility and stretch of rubber. TPE is commonly used in applications where conventional elastomers are unable to provide the necessary range of physical properties. They are found increasingly in automotive applications and household appliances. Disadvantages of TPE include poor chemical and heat resistance, low thermal stability and higher cost than other types of insulation. (61, 196-202)

V. POPULAR INSULATION TYPES

Thermoplastic and Thermosetting these are the two types of popular insulations. (203)

THERMOPLASTIC: A material which will soften, flow, or distort when subjected to sufficient heat and pressure. These compounds are heated and extruded over conductor. Likewise, the insulation on the finished product can be re-melted or soften if exposed to heat.

Thermoplastics having following characteristics:

- Easy to manufacture
- Normally less expensive
- No cure required
- Will melt when subjected to heat
- Can be extruded in very thin walls

THERMOSETTING: A material which will not soften, flow, or distort when subjected to heat and pressure. Once extruded over conductor, these compounds will not re-melt, however, they can be burnt or deteriorate due to heat.
Thermosetting having following characteristics:

- Will harden and age when overheated
- Forgiving when exposed to overloads
- Better low temperature properties
- Higher temperature potential
- Usually more expensive
- Requires a cure process when extruded
- Not extruded smaller than 22 AWG in CV processes. Irradiated products can be extruded in smaller sizes.

	Thermoplastic			Thermoset		
	PVC	Polyurethane	CPE	Neoprene	EPR	CPE
Oxidation Resistance	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Heat Resistance	Excellent	Good	Excellent	Good	Excellent	Excellent
Low-Temperature Flexibility	Poor to Good	Good	Excellent	Fair to Good	Good to Excellent	Fair
Weather/Sun Resistance	Good to Excellent	Good	Excellent	Good	Excellent	Excellent
Abrasion Resistance	Fair to Good	Outstanding	Excellent to Outstanding	Good to Excellent	Good	Good to Excellent
Flame Resistance	Excellent	Poor	Excellent	Good	Poor	Good
Water Resistance	Fair to Good	Poor to Good	Outstanding	Excellent	Good to Excellent	Good to Excellent
Underground Burial	Poor to Good	Good	Excellent to Outstanding	Good to Excellent	Excellent	Excellent

Fig 3: Comparison of few Thermoplastic and Thermoset insulating material. (204)

VI. CONCLUSION

Wires and cables play a vital role in electrical energy consumption, transmission and distribution system. To conduct all this processes smoothly and without any risk, different types of insulation cover (coating) is necessary. All cable jackets are not created equal and one has to choose the jacket material that is best suited for their installation environment. In other words, there are different materials are available for the insulation of wire and cables and the manufacture utilize these material as per necessity

REFERENCES

[1] https://medium.com/leyonhjelm/media-release-electricity-is-essential-not-a-luxury-78b595107b71
[2] https://www.essentialenergy.com.au/-/media/Project/EssentialEnergy/Website/Files/Our-Network/LivingWithEasements.pdf?la=en&hash=F547F35E5DCA13F30AC7552B9969029BEF3C72A4
[3] https://www.thehindu.com/features/kids/Importance-of-electricity/article16544961.ece
[4] http://blog.rallison.com/electricity-importance-in-daily-life/
[5] https://www.cram.com/essay/The-Importance-Of-Electricity/PKJHZEDKXC
[6] https://www.quora.com/In-our-daily-life-how-important-is-electricity
[7] https://www.electronicslovers.com/2018/04/importance-of-electricity-in-our-daily-lives-and-its-impact-on-modern-society.html
[8] https://www.forbes.com/sites/judeclemente/2015/02/21/the-need-and-value-of-more-electricity/#3d1fb5ad23b2
[9] https://www.springerprofessional.de/en/electricity-an-essential-necessity-in-our-life/6857428
[10] https://hawi-energy.com/electricity-is-the-indispensable-part-of-our-lives/
[11] https://www.dep.pa.gov/Citizens/JustForKids/Energy/Pages/Why.aspx
[12] https://www.iec.ch/smartenergy/importance/
[13] http://enerjicocuk.org/en/content/why-is-energy-important/45
[14] https://en.wikipedia.org/wiki/Electricity
[15] https://www.eia.gov/energyexplained/index.php?page=electricity_use
[16] https://www.renewableenergyworld.com/ugc/articles/2015/12/the-different-uses-of-energy-in-our-daily-lives.html
[17] http://www.99business.com/articles/electricity-is-now-a-basic-necessity-of-life.html
[18] https://powermin.nic.in/en/content/national-electricity-policy
[19] https://www.indiastudychannel.com/resources/153139-Energy-resources-their-influence-daily-life.aspx
[20] https://wattsun.in/solar-power-plant-a-reason-to-choose-for/
[21] https://www.academia.edu/23560402/Importance_of_energy_and_power_sector_in_economic_development_An_Indian_perspective
[22] http://shrinkthatfootprint.com/how-do-we-use-electricity
[23] https://alertforce.com.au/the-importance-of-electrical-safety/
[24] http://www.rturnerelectric.com/why-is-electricity-important/
[25] https://www.studentenergy.org/topics/electricity
[26] https://www.eia.gov/energyexplained/index.php?page=electricity_home
[27] http://www.edisonfoundation.net/iei/publications/Documents/Electricity%20Relevant%20Essential%20and%20Collaborative_Bill%20Loveless.pdf
[28] https://en.wikipedia.org/wiki/Electric_power_industry
[29] https://www.puc.state.or.us/Renewable%20Energy/SB978-AccessGrp.pdf

[30] https://financialrights.org.au/wp-content/uploads/2014/02/FRLC-Factsheet-Cant-Pay-Electricity.pdf
[31] Dr. Prashant D. Gangawane and A.P.Athane , WIRE AND CABLE INDUSTRY AND COLORANTS – AN OVERVIEW , International Journal For Technological Research In Engineering, 6 (9) , May-2019 .
[32] https://www.hunker.com/12003706/the-four-and-more-basic-parts-of-an-electrical-circuit
[33] https://en.wikipedia.org/wiki/Wire
[34] https://phsinverter.com/history-of-wire-baskets/
[35] https://www.dfliq.net/electrical-materials-products/electrical-wires-cables/
[36] https://www.dfliq.net/blog/understanding-the-insulation-resistance-of-a-cable/
[37] https://energyeducation.ca/encyclopedia/Electrical_insulator
[38] https://www.newworldencyclopedia.org/entry/Insulator_(electrical)
[39] https://sciencing.com/insulators-8031301.html
[40] https://www.electricaleasy.com/2016/11/electrical-insulators.html
[41] https://circuitglobe.com/electrical-power-cable.html
[42] https://www.multicable.com/resources/reference-data/choosing-proper-primary-insulations-for-electrical-multi-conductor-cables/
[43] https://www.elandcables.com/the-cable-lab/faqs/faq-what-is-dielectric-strength.
[44] https://www.electricaltechnology.org/2015/03/insulation-resistance-of-a-cable.html
[45] https://testguy.net/content/250-3-Basic-Modes-of-Power-Factor-Testing
[46] https://na.prysmiangroup.com/sites/default/files/atoms/files/General%20Calculations%20Rev%205.pdf
[47] https://www.nts.com/services/testing/materials/arc-resistance/
[48] http://www.tutorials.fomsn.com/fiber/fiber-optic-cables/effect-of-high-voltage-on-fiber-optic-cables/
[49] https://www.extrememateriales-arkema.com/en/markets-and-applications/electronics-and-electrical/cables/
[50] https://www.elandcables.com/the-cable-lab/independent-cable-testing-and-inspection-services/mechanical-test-for-flexible-cable
[51] https://www.divinelaboratory.com/mechanical_testing.php
[52] https://www.sbeecables.in/glossary.pdf
[53] https://www.elandcables.com/the-cable-lab/faqs/faq-what-are-the-main-causes-of-electrical-cable-failure
[54] https://en.wikipedia.org/wiki/Brittleness
[55] https://www.chemceed.com/product-news/formulation-101-wire-cable-insulation-jacket-pvc-compounds/
[56] https://apps.dtic.mil/dtic/tr/fulltext/u2/656243.pdf
[57] https://www.ee.co.za/article/varnish-insulation-wire-enamels.html
[58] https://www.cabletrays.org/thermal-contraction-expansion-cable-tray/
[59] http://irinformir.blogspot.com/2010/05/wire-insulation-temperature-limits.html
[60] https://www.aluminum.org/sites/default/files/Chapter%208%20Insulation%20and%20Related%20Cable%20Components.pdf
[61] https://www.awcwire.com/insulation-materials
[62] https://en.wikipedia.org/wiki/Polyvinyl_chloride
[63] https://www.kristechwire.com/insulation-polyvinyl-chloride-pvc/
[64] https://www.chemicalsafetyfacts.org/polyvinyl-chloride/
[65] https://electrical-engineering-portal.com/polyvinyl-chloride-pvc-as-jacketing-material
[66] http://www.rajasthanelectric.com/blog/why-are-pvc-insulated-wires-needed-by-electrical-industries/
[67] https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic
[68] https://www.wireandcabletips.com/benefits-pvc-cable-designs/
[69] https://www.hunker.com/12518567/characteristics-of-pvc
[70] https://www.sab-cable.com/cables-wires-harnessing-temperature-measurement/technical-data/cables-and-wires/polyvinylchloride-pvc.html
[71] https://www.wirenet.org/the-book-of-terms/semi-rigid-pvc
[72] https://www.blackbox.co.jp/en-jp/page/29590/Information/Technical-Resources/Black-Box-Explains/cables/cables-iii/pvc-vs-plenum
[73] https://www.ecmag.com/section/integrated-systems/plenum-vs-non-plenum
[74] https://serverfault.com/questions/79917/what-is-the-difference-between-pvc-and-plenum-cabling
[75] https://en.wikipedia.org/wiki/Plenum_cable
[76] https://www.distributorwire.com/pvc-v-s-plenum/
[77] http://www.newtechindustries.com/blog/-what-is-the-difference-between-pvc-and-plenum-cable/
[78] https://www.alphagary.com/case-studies/wire-cable/plenum-pvc-compound-replaces-data-cable-insulation-and-jacket-materials/2910/
[79] https://www.electricianslibrary.com/pvc-vs-plenum-rated/
[80] https://patents.google.com/patent/EP1023380A1
[81] https://www.kristechwire.com/types-of-material-used-for-wire-insulation/
[82] https://en.wikipedia.org/wiki/Cross-linked_polyethylene
[83] http://www.paigewire.com/PEvsPVC_Valve_wires.aspx?AspxAutoDetectCookieSupport=1
[84] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/pe-polyethylene/
[85] https://www.lyondellbasell.com/globalassets/documents/polymers-technical-literature/the-chemistry-of-polyethylene-insulation.pdf
[86] http://www.alphawire.com/en/Company/Blog/2015/November/PE%20is%20for%20Polyethylene
[87] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/pp-polypropylene/

[88] https://link.springer.com/article/10.1007/s10853-006-4504-8
[89] https://www.linkedin.com/pulse/polypropylene-based-power-cable-insulation-systems-future-raikisto
[90] https://www.mercurywire.com/plastics-pp/
[91] https://www.intechopen.com/books/new-trends-in-high-voltage-engineering/a-review-of-polypropylene-and-polypropylene-inorganic-nanocomposites-for-hvdc-cable-insulation
[92] https://www.researchgate.net/publication/314220187_The_Application_of_Novel_Polypropylene_to_the_Insulation_of_Electric_Power_Cable
[93] https://link.springer.com/article/10.1007/s10853-006-4504-8
[94] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/pur-polyurethane/
[95] https://www.sab-cable.com/cables-wires-harnessing-temperature-measurement/technical-data/cables-and-wires/polyurethane-pur.html
[96] http://www.wirecable.in/2011/11/thermoplastic-polyurethane-tpu-in-wire-and-cable-applications/
[97] http://www.borsodchem-pu.com/Construction/Cable---wire-insulation.aspx
[98] https://lapplimited.lappgroup.com/products/polyurethane-high-tough-cables.html
[99] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/cpe-chlorinated-polyethylene/
[100] https://www.multicominc.com/training/technical-resources/cable-jacket-materials-whats-right-for-you/
[101] https://www.mercurywire.com/plastics-cpe/
[102] https://www.rrshramik.com/nylon-coated-enamelled-wires/
[103] https://iaeimagazine.org/magazine/2013/09/16/if-the-nylon-on-thhn-is-scuffed-is-the-insulation-damaged/
[104] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/tpr-thermoplastic-rubber/
[105] https://www.omnicable.com/cable-services/cable-knowledge/2017/05/04/basics-of-wire-and-cable-jackets-vs-insulations
[106] http://www.alphawire.com/en/Company/Blog/2015/November/Thermoplastic%20Insulations
[107] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/neoprene/
[108] https://www.bhuwalinsu.com/insulated-cables-neoprene-insulated-cables.html
[109] https://www.daburn.com/rubber-and-neoprene.aspx
[110] https://www.britannica.com/science/styrene-butadiene-rubber
[111] https://www.businesswire.com/news/home/20190408005578/en/India-Styrene-Butadiene-Rubber-SBR-Techno-Commercial-Market
[112] https://omnexus.specialchem.com/selection-guide/styrene-butadiene-rubber-sbr-guide
[113] https://www.marketresearchengine.com/emulsion-polymerized-styrene-butadiene-rubber-market
[114] https://www.elandcables.com/the-cable-lab/faqs/faq-what-are-the-benefits-of-silicone-insulated-cables
[115] https://www.bhuwalinsu.com/silicon-rubber-cables-silicon-rubber-insulated-wires.html
[116] https://www.rrkabel.com/silicon-cables
[117] https://www.bhuwalinsu.com/fibre-glass-cables-fiberglass-insulated-cables.html
[118] http://www.tanyacables.com/fiberglass-insulated-cable.html
[119] http://www.yorkwire.com/Fiberglass-900F-482C.html
[120] https://blog.tewire.com/blog/why-use-fiberglass
[121] https://www.nationalplastics.com/fiberglass-sleeves-electrical-insulation/
[122] https://www.elandcables.com/the-cable-lab/faqs/faq-what-are-the-benefits-of-epr-insulated-cables
[123] https://www.bhuwalinsu.com/rubber-cables-ethylene-propylene-rubber-cables.html
[124] https://en.wikipedia.org/wiki/Ethylene_propylene_rubber
[125] https://rubberchemtechnol.org/doi/abs/10.5254/1.3535228?journalCode=rcat
[126] https://www.kei-ind.com/cables-and-wires/rubber-cables/
[127] https://wesbellwireandcable.com/Electrical wire/3-types-of-rubber-insulated-electrical-wire.html
[128] https://inspectapedia.com/electric/Old-Fabric-Insulated-Electrical-Wire-ID.php
[129] http://www.greenspec.co.uk/building-design/chlorosulfonated-polyethylene-cspe-environment-and-health/
[130] http://polymerdatabase.com/Elastomers/Hypalon.html
[131] http://www.industrialrubbergoods.com/chlorosulfonated-polyethylene.html
[132] http://www.liandacorp.com/Chlorosulfonated_Polyethylene.php
[133] https://www.coruba.co.uk/blog/what-you-need-to-know-about-chlorosulfonated-polyethylene/
[134] https://www.britannica.com/science/chlorosulfonated-polyethylene
[135] https://www.hofftech.com/en/rubber-dictionary/csm/
[136] https://brpmfg.com/additional-polymers/chlorosulphonated-polyethylene-rubber/
[137] https://silicone.co.uk/news/silicone-rubber-vs-epdm/
[138] https://en.wikipedia.org/wiki/EPDM_rubber
[139] https://polymerdatabase.com/Elastomers/EPDM.html
[140] https://www.timcorubber.com/rubber-

materials/epdm/
[141] https://www.polymersolutions.com/blog/silicone-epdm/
[142] https://www.rubbercal.com/sheet-rubber/what-is-epdm-material/
[143] https://www.sciencedirect.com/topics/engineering/ethylene-propylene-diene-monomer-rubber
[144] https://en.wikipedia.org/wiki/Perfluoroalkoxy_alkane
[145] https://www.rtpcompany.com/products/product-guide/perfluoroalkoxy-pfa/
[146] https://www.polyfluor.nl/en/materials/pfa/
[147] https://www.plasticsintl.com/shop-by-material/pfa
[148] http://www.fluorocarbon.co.uk/news-and-events/post/15/what-is-perluoroalkoxy-polymer-pfa
[149] https://www.emerson.com/documents/automation/white-paper-ptfe-pfa-similarities-differences-rosemount-en-585104.pdf
[150] https://www.substech.com/dokuwiki/doku.php?id=perfluoroalkoxy_pfa
[151] https://www.galaxywire.com/custom-wire-cable/jacket-insulation/pfa-perfluoroalkoxy/
[152] https://en.wikipedia.org/wiki/Polytetrafluoroethylene
[153] https://www.britannica.com/science/polytetrafluoroethylene
[154] https://omnexus.specialchem.com/selection-guide/polytetrafluoroethylene-ptfe-fluoropolymer
[155] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/polytetrafluoroethylene
[156] https://www.fluorotec.com/news/blog/the-properties-and-advantages-of-polytetrafluoroethylene-ptfe/
[157] https://pslc.ws/macrog/ptfe.htm
[158] http://www.essentialchemicalindustry.org/polymers/polytetrafluoroethene.html
[159] https://link.springer.com/article/10.1007/s42114-018-0023-8
[160] https://pubs.acs.org/doi/10.1021/acs.chemrev.8b00458
[161] https://en.wikipedia.org/wiki/Fluorinated_ethylene_propylene
[162] https://www.polyfluor.nl/en/materials/fep/
[163] http://www.fluorocarbon.co.uk/news-and-events/post/14/what-is-fluorinatedethylenepropylene-fep
[164] https://www.sciencedirect.com/topics/engineering/fluorinated-ethylene-propylene
[165] http://www.goodfellow.com/E/Fluorinated-Ethylene-Propylene-Copolymer.html
[166] https://www.rtpcompany.com/products/product-guide/fluorinated-ethylene-propylene-fep/
[167] https://www.metcoat.com/fep-coating.htm
[168] http://polymerdatabase.com/Polymer%20Brands/FEP.html
[169] https://holscot.com/glossary/fep/
[170] https://www.azom.com/article.aspx?ArticleID=414
[171] https://en.wikipedia.org/wiki/ECTFE
[172] https://www.solvay.com/sites/g/files/srpend221/files/2018-08/Halar-ECTFE-Design-and-Processing-Guide_EN-v2.7_0.pdf
[173] https://www.baltro.cz/en/etfe-vs-ectfe-halar/
[174] http://www.edlon.info/coatings.php
[175] https://liningcoating.com/coating-of-pvdf-halar-etfe-fep-pfa.html
[176] http://www.ftcoat.com/Tefzel(ETFE).html
[177] https://toefco.com/what-is-halar-coating/
[178] https://www.solvay.us/en/markets-and-products/featured-products/Halar-ECTFE-for-Coatings.html
[179] http://www.stamarindustrialcoatingsla.com/products
[180] https://ntrs.nasa.gov/search.jsp?R=20140005750
[181] https://en.wikipedia.org/wiki/Polyvinylidene_fluoride
[182] https://omnexus.specialchem.com/selection-guide/polyvinylidene-fluoride-pvdf-plastic
[183] http://www.fluorocarbon.co.uk/news-and-events/post/19/what-is-polyvinylidene-fluoride
[184] https://www.britannica.com/science/polyvinylidene-fluoride
[185] https://www.sciencedirect.com/topics/medicine-and-dentistry/polyvinylidene-fluoride
[186] https://www.rtpcompany.com/products/product-guide/polyvinylidene-fluoride-pvdf/
[187] https://www.polyfluor.nl/en/materials/pvdf/
[188] https://holscot.com/glossary/pvdf/
[189] https://shop.pall.com/us/en/laboratory/advanced-materials/liquid-filtration/polyvinylidene-fluoride-pvdf-membrane-hydrophilic--zidgri78m6s
[190] https://www.hindawi.com/journals/jnm/2008/759825/
[191] https://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+8275
[192] https://www.tandfonline.com/doi/abs/10.1080/00150193.1991.11876614
[193] https://aip.scitation.org/doi/10.1063/1.4994968
[194] https://pslc.ws/macrog/pvdf.htm
[195] http://jes.ecsdl.org/content/166/10/A2151.full
[196] https://en.wikipedia.org/wiki/Thermoplastic_elastomer
[197] https://www.timcorubber.com/rubber-materials/thermoplastic-elastomers-tpe/
[198] https://www.sciencedirect.com/topics/materials-science/thermoplastic-elastomer
[199] https://www.polyone.com/products/thermoplastic-elastomers/tpe-knowledge-center/tpe-faqs
[200] https://www.bpf.co.uk/plastipedia/polymers/thermoplastic_elastomers.aspx
[201] https://www.rtpcompany.com/products/ela

stomer/understanding-tpes/
[202] http://polymerdatabase.com/Elastomers/TPEs.html
[203] https://www.iewc.com/resources/technical-guide/popular-insulation-types
[204] https://www.anixter.com/en_us/resources/literature/wire-wisdom/cable-jackets-types-101.html

