3. INSULATION AND JACKET MATERIALS

3.1 PURPOSE

Conductors need to be electrically isolated from other conductors and from the environment to prevent short circuits. Insulation is applied around a conductor to provide this isolation. Most wire and cable insulations consist of polymers (plastics), which have a high resistance to the flow of electric current. A jacket is the outermost layer of a cable whose primary function is to protect the insulation and conductor core from external physical forces and chemical deterioration.

3.2 TYPES AND APPLICATIONS

3.2.1 Thermoplastics

Chlorinated Polyethylene (CPE)
CPE is one of the few polymers available in both thermoplastic and thermoset (cross-linked) versions. As a rule, thermoset formulations have better high-temperature properties than thermoplastics but are also higher in cost. Thermoplastic CPE is more common than thermoset CPE. Properties of both thermoplastic and thermoset CPE are given in Section 3.4.

Polyvinyl Chloride (PVC)
Sometimes referred to simply as "vinyl," PVC does not usually exhibit extremely high- and low-temperature properties in one formulation. Certain formulations may have a –55°C to 105°C rating, while other common vinyls may have a –20°C to 60°C rating. The many varieties of PVC also differ in pliability and electrical properties. The price range can vary accordingly. Typical dielectric constant values range from 3.5 to 6.5.

When properly formulated, thermoplastic jackets of PVC provide cables with the ability to resist oils, acids, alkalis, sunlight, heat, weathering and abrasion. This range of properties makes PVC a suitable outer covering for such cable types as underground feeders (Type UF), control, aerial, street lighting and cables for direct burial.

PVC is frequently used as an impervious jacket over and/or under metal armor where the installation requires PVC's protective characteristics. Flamarrest is a plenum grade, PVC-based jacketing material with low smoke and low flame spread properties. Plenum-rated cables jacketed with Flamarrest meet NFPA 262 (formerly UL Standard 910).

Fluoropolymers
Fluoropolymers, with the exception of PTFE Teflon (sometimes called TFE), are extrudable thermoplastics used in a variety of low-voltage insulating situations. Fluoropolymers contain fluorine in their molecular composition, which contributes to their excellent thermal, chemical, mechanical and electrical characteristics. The most commonly used fluoropolymers are Teflon (PTFE, FEP and PFA), Tefzel (ETFE), Halar (ECTFE) and Kynar or Solef (PVDF).

Teflon has excellent electrical properties, temperature range and chemical resistance. It is not suitable where subjected to nuclear radiation and does not have good high-voltage characteristics. FEP Teflon is extrudable in a manner similar to PVC and polyethylene. This means that long wire and cable lengths are available. PTFE Teflon is extrudable in a hydraulic ram type process. Lengths are limited due to the amount of material in the ram, thickness of the insulation and preform size. PTFE must be extruded over a silver- or nickel-coated wire. The nickel- and silver-coated designs are rated 260°C and 200°C maximum, respectively. The cost of Teflon is approximately 8 to 10 times more per pound than PVC compounds.

Teflon PTFE is the original Teflon resin invented by DuPont in 1938. It is an opaque, white material, although some forms are translucent in thin sections. It does not melt in the usual sense. To coat wire for insulating purposes, Teflon PTFE is extruded around the conductor as a paste, then sintered. Conductors can also be wrapped with tape of Teflon PTFE. Maximum continuous service temperature of Teflon PTFE is 260°C (500°F).

Specific advantages of wire insulated with Teflon PTFE include:

- Nonflammability
- Extremely high insulation resistance
- Very low dielectric constant
- Small size compared to elastomer insulated wires
- Excellent lubricity for easier installation
- Chemical inertness.

Teflon FEP was also invented by DuPont and became commercially available in 1960. It has a glossy surface and is transparent in thin sections. Teflon FEP is a true thermoplastic. Wire insulated with Teflon FEP can be melt extruded by conventional methods. Maximum continuous service temperature is 400°F (205°C). Teflon FEP is an excellent nonflammable jacketing material for multiconductor cables.

Specific advantages of wire insulated with Teflon FEP include:

- High current carrying ability (ampacity)
- Easy color coding
- Smallest diameter of any high-temperature wire
- Nonflammability
- Very low moisture absorption.

Teflon PFA is a perfluoroalkoxy copolymer resin supplied by DuPont. Wire insulated with PFA is rated up to 250°C (482°F) and has excellent high-temperature creep resistance, low-temperature toughness and flame resistance.

Tefzel (ETFE) is commonly used in computer backplane wiring and has the highest abrasion and cut-through resistance of any fluoropolymer. Tefzel is a thermoplastic material having excellent electrical properties, heat resistance, chemical resistance, toughness, radiation resistance and flame resistance. Tefzel's temperature rating is –65°C to 150°C.

Halar (ECTFE) is similar to Tefzel and is also used in wirewrap applications, but because it is less expensive than Tefzel, it is often used as insulation on multipair plenum telephone cables. It has a maximum operating temperature of 125°C (UL). Halar has excellent chemical resistance, electrical properties, thermal characteristics and impact resistance. Halar's temperature rating is –70°C to 150°C.

Kynar (PVDF) is one of the least expensive fluoropolymers and is frequently used as a jacketing material on plenum cables. Because of its high dielectric constant, however, it tends to be a poor insulator. PVDF has a temperature maximum of 135°C (UL).

Polyolefins (PO)

Polyolefin is the name given to a family of polymers. The most common polyolefins used in wire and cable include polyethylene (PE), polypropylene (PP) and ethylene vinyl acetate (EVA).

Polyethylene (PE)

Polyethylene has excellent electrical properties. It has a low dielectric constant, a stable dielectric constant over a wide frequency range, and very high insulation resistance. However, polyethylene is stiff and very hard, depending on molecular weight and density. Low density PE (LDPE) is the most flexible, with high-density, high-molecular weight formulations being least flexible. Moisture resistance is excellent. Properly formulated PE has excellent weather resistance. The dielectric constant is 2.3 for solid and 1.6 for cellular (foamed) insulation. Flame retardant formulations are available, but they tend to have poorer electrical properties.

Polypropylene (PP)
Similar in electrical properties to polyethylene, this material is primarily used as an insulation material. Typically, it is harder than polyethylene. This makes it suitable for thin wall insulations. The UL maximum temperature rating may be 60°C or 80°C, but most UL styles call for 60°C maximum. The dielectric constant is typically 2.25 for solid and 1.55 for cellular designs.

Thermoplastic Elastomer (TPE)
TPE, sometimes called TPR (thermoplastic rubber), has excellent cold temperature characteristics, making it an excellent insulating and jacketing compound in cold climates. It is resistant to aging from sunlight, oxidation and atmospheric ozone. It retains most of its physical and electrical properties in the face of many severe environmental conditions such as a salt water environment. TPE compounds can be rated as high as 125°C (257°F).

TPE has good chemical resistance to all substances except hydrocarbons. It has a tendency to swell in a hydrocarbon environment, causing the material to degrade. It has good abrasion resistance. It will resist wear, cutting and impact. These properties make TPE jackets an excellent choice for use in control cables that are dragged around or frequently moved.

TPE compounds are used as insulating materials up to a 600-volt rating. The most common cables using TPE insulation are portable control cables such as SEO and SJEO.

Polyurethane (PUR)
Polyurethane is used primarily as a cable jacket material. It has excellent oxidation, oil and ozone resistance. Some formulations also have good flame resistance. It has excellent abrasion resistance. It has outstanding “memory” properties, making it an ideal jacket material for retractile cords.

3.2.2 Thermosets

Chlorinated Polyethylene (CPE)
Cross-linked chlorinated polyethylene is a material with outstanding physical and electrical properties for many cable jacket applications. It is highly resistant to cold flow (compression set) and other forms of external loading as well as heat, light and chemical attack. CPE is also often supplied in a thermoplastic (non-cross-linked) version.

CPE compares favorably with most other synthetic elastomers currently used for cable jacketing. It is resistant to ozone and ultraviolet (sunlight) degradation. Properly compounded, CPE will withstand prolonged immersion in water. It will not support combustion, but under the right conditions of excessive heat, oxygen supply and flame source, it will burn slowly. Removal of the ignition source, will extinguish the flame. CPE jacketed cables pass the IEEE 383, UL, CSA and ICEA flame tests.

CPE maintains its flexibility at –18°C (0°F) and does not become brittle unless temperatures are below –40°C (–40°F). Its low temperature impact resistance is excellent. CPE jackets are suited to 105°C (221°F) and intermittently to higher temperatures. They will maintain adequate flexibility after repeated aging at elevated temperatures. They are known for abrasion resistance and long life in mining cable applications. CPE does not support the growth of mold, mildew or fungus.

CPE is resistant to most strong acids and bases and many solvents except for chlorinated organics. It is particularly well-suited to chemical plant use where both above ground (ultraviolet and flame retardancy) and below ground (water and chemical resistance) properties are desired. CPE’s resistance to oils and fuels is good. CPE can be conveniently colored over a wide range and will maintain color upon aging.

Neoprene (CP)
Neoprene is a vulcanized synthetic rubber also referred to as chloroprene. It provides a resilient jacket that resists permanent deformation under heat and load, and does not embrittle at low temperatures. It is highly resistant to aging from sunlight and oxidation, and is virtually immune to atmospheric ozone.

Samples of neoprene-jacketed cable, tested outdoors under constant exposure for 40 years, have remained tough, resilient, uncracked and completely serviceable. Neoprene jackets are "flame resistant," i.e., not combustible without directly applied heat and flame. Neoprene will burn slowly as long as an outside source of flame is applied, but is self-extinguishing as soon as the flame is removed. Neoprene-jacketed power cable can be flexed without damage to the jacket at –40°C (–40°F) and will pass a mandrel wrap test down to about –45°C (–49°F). Neoprene jackets resist degradation for prolonged periods at temperatures up to 121°C (250°F). Satisfactory performance at even higher temperatures is possible if the exposures are brief or intermittent.

Neoprene jackets have excellent resistance to soil acids and alkalis. Mildew, fungus and other biological agents do not deteriorate properly compounded neoprene. These jackets perform well in many chemical plants. They are tough, strong, resilient and have excellent resistance to abrasive wear, impact, crushing and chipping. Because of these properties, neoprene is the jacketing material frequently used for mine trailing cables and dredge cables.

Cross-linked Polyethylene (XLP or XLPE)
Cross-linked polyethylene is a frequently used polymer in wire and cable. It is most often used as the insulation of 600 volt building wire (e.g., Type XHHW), as the insulation in 5 to 69 kV and higher rated power cables and as the insulation in many control cables.

XLP has very high insulation resistance (IR), high dielectric strength and low dielectric constant (2.3). It also is a very tough material at temperatures below 100°C, so it is resistant to cutting, impact and other mechanical forces. Its low-temperature performance is also very good: down to –40°C and below. XLP's fire resistance, however, is poor unless flame retardants are added. XLP is lower in cost than EPR.

Ethylene Propylene Rubber (EP, EPR, or EPDM)
Ethylene propylene rubber is a common synthetic rubber polymer used as an insulation in electrical wire and cable. EPR is used as the insulation in 600 volt through 69 kV power cables, as an integral insulation/jacket on welding cables and as an insulation in many cords, portable mining cables and control/instrumentation cables.

Because of its rubber-like characteristics, EPR is used in many highly flexible cables. Its dielectric strength is good but not as high as that of PE or XLP. Dielectric constant ranges from 2.8 to 3.2 depending on the specific EPR formulation. EPR is abrasion resistant and is suitable for use at temperatures down to –60°C. It is fairly flame retardant and can be made even more flame retardant by careful formulation. Flame retardant versions are often referred to as "FREP" or "flame retardant EP." EPR's high-temperature characteristics are very good. Some formulations can withstand continuous temperatures as high as 150°C.

Hypalon (CSP)
Hypalon is a thermosetting, cross-linked, chlorosulfonated polyethylene made by DuPont with many excellent physical and electrical properties. It is inherently resistant to cold flow (compression set) resulting from clamping pressures and other forms of external loading; it is immune to attack by ozone; and it is highly resistant to aging from sunlight and oxidation. Water absorption of properly compounded Hypalon cable sheathing is extremely low.

Hypalon sheathing will not support combustion. It will burn slowly as long as an outside source of flame is applied but is self-extinguishing as soon as the flame is removed. It remains flexible at –18°C (0°F) and will not become brittle at –40°C (–40°F). Hypalon jacketed constructions pass both the Underwriters Laboratories' vertical flame test and the U.S. Bureau of Mines' flame test for mining cable.

At high temperatures, Hypalon will perform satisfactorily after short-term exposure at up to 148°C (300°F) – even higher if compounded for maximum heat resistance. It is well-known for its resistance to chemicals, oils, greases and fuels. It is particularly useful as a cable sheathing in plant processing areas, where airborne chemicals attack ordinary jacketing materials and metal conduit.

Hypalon surpasses most elastomers in resistance to abrasion. It is highly resistant to attack by hydrocarbon oils and fuels. It is especially useful in contact with oils at elevated temperatures. Sheathing of Hypalon provides high resistance to impact, crushing and chipping. Hypalon's electrical properties make it appropriate as insulation for low-voltage applications (up to 600 volts) and as jacketing for any type of wire and cable.

Silicone
Silicone is a soft, rubbery insulation that has a temperature range from –80°C to 200°C. It has excellent electrical properties plus ozone resistance, low moisture absorption, weather resistance, and radiation resistance. It typically has low mechanical strength and poor scuff resistance.

3.2.3 Fibrous Coverings
Fibrous coverings are commonly used on high-temperature cables due to their excellent heat resistance. They are normally constructed of a textile braid (e.g., fiberglass or K-fiber) impregnated with a flame and heat-resistant finish.

K-fiber insulating materials are a blend of polyaramid, polyamid, phenolic-based and fiberglass fibers. They are available as roving and yarn for insulating applications and as rope for use as fillers. They provide a non-asbestos, abrasion-, moisture-, flame- and temperature-resistant, non-melting insulating material for all applications requiring a 250°C (482°F) temperature rating, which would have previously utilized asbestos.

3.2.4 Additional Information
Additional information on the selection of cable jackets is available in IEEE 535 "Guide for Selecting and Testing Jackets for Power, Instrumentation and Control Cables."

3.3 COLOR CODING

3.3.1 Power, Control, Instrumentation and Thermocouple

ICEA standard S-73-532 (NEMA WC57) contains several methods for providing color coding in multiconductor power and control cables. Methods 1, 3 and 4 are the most widely used.

Method 1 – Colored compounds with tracers

Method 2 – Neutral colored compounds with tracers

Method 3 – Neutral or single-color compounds with surface printing of numbers and color designations

Method 4 – Neutral or single-color compounds with surface printing of numbers

Method 5 – Individual color coding with braids

Method 6 – Layer identification

Method 7 – Paired conductors

Historically, ICEA has established the sequence of colors used for Method 1 color coding, which consists of six basic colors, then a repeat of the colors with a colored band or tracer. This sequence of colors is referred to as K-1 color coding because it was formerly found in Table K-1 of many ICEA standards. (See Tables 3.1 through 3.5.) In the latest ICEA standard the color sequences are located in Tables E-1 through E-7.

The National Electrical Code (NEC) specifies that a conductor colored white can only be used as a grounded (neutral) conductor and that a conductor colored green can only be used as an equipment grounding conductor. The use of Table E-1 (formerly K-1) color coding would therefore be in violation of the Code in a cable having more than six conductors if conductors #7 (white/black), #9 (green/black), #14 (green/white), etc. are energized.

To address this issue, a different color coding sequence was developed by ICEA for cables that are used in accordance with the NEC. Table E-2 (formerly K-2) of the ICEA standard provides this color sequence. The ICEA standard provides further guidance stating that if a white conductor is required, this color may be introduced into Table E-2 as the second conductor in the sequence. If a green insulated conductor is required, it likewise can be introduced into the table. However, the white and green colors may only appear once.

The most popular multiconductor control cables in sizes 14 AWG–10 AWG have Method 1, Table E-2 color coding. The cables do not contain a white or green conductor. The most popular control cables used in sizes 8 AWG and larger are three conductor cables having black insulation surface ink printed with the numbers 1, 2 and 3. This is Method 4 color coding in the ICEA standards.

The electric utility industry often specifies control cables with the E-1 color coding sequence.

For applications where the NEC is applicable, such as in industrial and commercial applications, the E-2 color sequence is normally used.

ICEA standard S-82-552 (NEMA WC55) contains methods and color sequence tables for instrumentation and thermocouple cables.

Table 3.1—E-1 (Formerly K-1) Color Sequence for Control Cables

Conductor Number	Background or Base Color	First Tracer Color	Second Tracer Color	Conductor Number	Background or Base Color	First Tracer Color	Second Tracer Color
1	Black	–	–	31	Green	Black	Orange
2	White	–	–	32	Orange	Black	Green
3	Red	–	–	33	Blue	White	Orange
4	Green	–	–	34	Black	White	Orange
5	Orange	–	–	35	White	Red	Orange
6	Blue	–	–	36	Orange	White	Blue
7	White	Black	–	37	White	Red	Blue
8	Red	Black	–	38	Black	White	Green
9	Green	Black	–	39	White	Black	Green
10	Orange	Black	–	40	Red	White	Green
11	Blue	Black	–	41	Green	White	Blue
12	Black	White	–	42	Orange	Red	Green
13	Red	White	–	43	Blue	Red	Green
14	Green	White	–	44	Black	White	Blue
15	Blue	White	–	45	White	Black	Blue
16	Black	Red	–	46	Red	White	Blue
17	White	Red	–	47	Green	Orange	Red
18	Orange	Red	–	48	Orange	Red	Blue
19	Blue	Red	–	49	Blue	Red	Orange
20	Red	Green	–	50	Black	Orange	Red
21	Orange	Green	–	51	White	Black	Orange
22	Black	White	Red	52	Red	Orange	Black
23	White	Black	Red	53	Green	Red	Blue
24	Red	Black	White	54	Orange	Black	Blue
25	Green	Black	White	55	Blue	Black	Orange
26	Orange	Black	White	56	Black	Orange	Green
27	Blue	Black	White	57	White	Orange	Green
28	Black	Red	Green	58	Red	Orange	Green
29	White	Red	Green	59	Green	Black	Blue
30	Red	Black	Green	60	Orange	Green	Blue

Note: The former K-1 color sequence was the same as E-1 through conductor number 21. K-1 then repeated. The above table is only applicable to control cables. The color sequence for instrumentation cables can be found in ICEA S-82-552 (NEMA WC 55).

Table 3.2—E-2 (Formerly K-2) Color Sequence for Control Cables

Conductor Number	Background or Base Color	Tracer Color
1	Black	—
2	Red	—
3	Blue	—
4	Orange	—
5	Yellow	—
6	Brown	—
7	Red	Black
8	Blue	Black
9	Orange	Black
10	Yellow	Black
11	Brown	Black
12	Black	Red
13	Blue	Red
14	Orange	Red
15	Yellow	Red
16	Brown	Red
17	Black	Blue
18	Red	Blue
19	Orange	Blue
20	Yellow	Blue
21	Brown	Blue
22	Black	Orange
23	Red	Orange
24	Blue	Orange
25	Yellow	Orange
26	Brown	Orange
27	Black	Yellow
28	Red	Yellow
29	Blue	Yellow
30	Orange	Yellow
31	Brown	Yellow
32	Black	Brown
33	Red	Brown
34	Blue	Brown
35	Orange	Brown
36	Yellow	Brown

Note: The above table is only applicable to control cables. The color sequence for instrumentation cables can be found in ICEA S-82-552 (NEMA WC 55).

Table 3.3—E-3 (Formerly K-3) Color Sequence for Control Cables

Conductor Number	First Tracer Color (e.g., Wide Tracer)	Second Tracer Color (e.g., Narrow Tracer)
1	Black	—
2	White	—
3	Red	—
4	Green	—
5	Orange	—
6	Blue	—
7	White	Black
8	Red	Black
9	Green	Black
10	Orange	Black
11	Blue	Black
12	Black	White
13	Red	White
14	Green	White
15	Blue	White
16	Black	Red
17	White	Red
18	Orange	Red
19	Blue	Red
20	Red	Green
21	Orange	Green

Note: The above table is only applicable to control cables. The color sequence for instrumentation cables can be found in ICEA S-82-552 (NEMA WC 55).