



IEEE Guide for Selecting and Testing Jackets for Power, Instrumentation, and Control Cables

IEEE Power Engineering Society

Sponsored by the
Insulated Conductors Committee

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**Insulated Conductors Committee
of the
IEEE Power Engineering Society**

Approved 27 September 2007
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Abstract: This guide covers properties of commonly used jackets as well as selection and testing of jackets. It is written for those responsible for optimizing cable designs. The purpose is to present a reasonably complete picture of the role of jackets so that the subject can be approached in an orderly and organized manner. An effort has been made to avoid the highly technical language and theory commonly used by electrical engineers and chemists to discuss the more detailed application of jackets.

Keywords: cables, jackets, testing

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Introduction

This introduction is not part of IEEE Std 532-2007, IEEE Guide for Selecting and Testing Jackets for Power, Instrumentation, and Control Cables.

This guide is concerned with jackets as they are defined in *The Authoritative Dictionary of IEEE Standards*, Seventh Edition (“A thermoplastic or thermosetting plastic covering, sometimes fabric reinforced, applied over the insulation, core, metallic sheath, or armor of a cable”). Users should note that this guide makes reference to standards developed by the Insulated Cable Engineers Association (ICEA), the Association of Edison Illuminating Companies (AEIC), and other organizations.

This guide is written to provide cable users guidance in the selection of jackets and protective covers for the purpose of optimizing cable design. A secondary purpose is to present a reasonably complete picture of the types and functions of jackets so that the user can approach the subject in an orderly and logical manner.

An effort has been made to avoid the highly technical language and theory commonly used by electrical engineers and chemists to discuss the more detailed application of jackets. As a result, the various topics covered in this guide are not necessarily exhaustive in every respect.

This guide provides recommendations for the properties, characteristics, design, and testing of various types of cable jackets. It is the intent of this guide to ensure that jacket materials are suitably specified for their intended applications. Also, jackets should provide a level of electrical, thermal, mechanical, and chemical durability to ensure that cable performance is reliable under normal use and should reduce the danger to the user or surroundings. The users of this guide are cautioned that all data contained herein are presented for information purposes only. Where deemed necessary, additional, as well as more detailed, information should be obtained by consultation with the cable manufacturer and other experts in the field.

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IEEE Guide for Selecting and Testing Jackets for Power, Instrumentation, and Control Cables

1. Overview

This guide provides recommendations for the properties, characteristics, design, and testing of various types of extruded cable jackets. It is the intent of this guide to ensure that jacket materials are suitably specified for their intended applications. Also, jackets should provide a level of electrical, thermal, mechanical, and chemical durability to ensure that cable performance is reliable under normal use, and to reduce danger to the user or surroundings.

1.1 Scope

This guide covers the selection and testing of jackets and other protective coverings for power, instrumentation, and control cables. It is written for those individuals responsible for optimizing cable designs. The purpose is to present a reasonably complete picture of the role of jackets so that the subject can be approached in an orderly and organized manner. An effort has been made to avoid the highly technical language and theory commonly used by electrical engineers and chemists to discuss the more detailed application of jackets.

1.2 Purpose

The purpose of this guide is to provide cable users guidance in the selection of jackets and protective covers to optimize cable design. A secondary purpose is to present a reasonably complete picture of the types and functions of jackets so that the user can approach the subject in an orderly and logical manner.

1.3 General historical perspective

Various compounded-textile sandwich-type coatings were the predominant jackets used up to and into the 1950s. Experience has indicated that the electrical resistivity required to isolate effectively the metallic sheath or shield, or both, from their environment could not be satisfied by these jackets. In many situations, the dielectric integrity of the jacket is more important than the resistivity.

Factors that influenced improvement of jackets for cable sheaths/shields include:

- a) Consideration of the destructive effects of galvanic and electrolytic corrosion.
- b) The use of amphoteric metals (lead or aluminum) for cable sheaths, which are difficult to protect cathodically.
- c) The use of metals (tinned copper, brass, or steel) to reinforce lead sheaths requiring a jacket that would reliably protect the pressure-retaining metallic components from deterioration when placed in earth or ducts.
- d) The introduction of aluminum-sheathed cables requiring a protective jacket of good mechanical and dielectric properties.
- e) The use of single-conductor cable systems that, by their nature, involve induced voltages on the sheath/shield (see Eaton and Issa [B6]¹ and Kellam [B9]). It is desirable that the sheath/shield be isolated from its environment.
- f) Practices to reduce electrical losses by minimizing circulating sheath/shield currents result in the appearance of voltages on the sheath/shield (see Halperin et al. [B7], Halperin and Miller [B8], and Watson and Erven [B11]); under transient conditions, these voltages may be substantial.

2. Acronyms and abbreviations

The following abbreviations are used in this guide:

CPE	chlorinated polyethylene
CPE-TP	thermoplastic chlorinated polyethylene
CPE-XL	cross-linked chlorinated polyethylene
CSPE	chlorosulfonated polyethylene
DRTP	deformation-resistant thermoplastic
EBA	ethylene butyl acrylate polyethylene copolymer
ECTFE	ethylene chlorotrifluoroethylene
EEA	ethylene ethyl acrylate polyethylene copolymer
EPDM	ethylene propylene diene monomer
EPR	ethylene propylene rubber
EVA	ethylene vinyl acetate polyethylene copolymer
FEP	fluorinated ethylene propylene
HDPE	high-density polyethylene
IRM oils	industry reference material
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
LSHF-FR	low-smoke/halogen-free flame retardant
LSZH	low-smoke zero halogen
MDPE	medium-density polyethylene
NBR	nitrile butadiene rubber
PE	polyethylene
PE-TP	thermoplastic polyethylene
PP	polypropylene
PVC	polyvinyl chloride
PVDF	polyvinylidene fluoride
TPE	thermoplastic elastomer
UD-CN	underground distribution concentric neutral
URD	underground residential distribution
ULDPE	very low-density polyethylene
XLPE	cross-linked polyethylene

¹ The numbers in brackets correspond to those of the bibliography in Annex A.

3. Jacket characteristics

Jackets furnish protection for cables during installation and service in several properties that are highlighted in 3.1 through 3.6. Evaluation criteria for these properties are dependent on the intended use of the product. Variations in applications require that jackets be evaluated to many, but not necessarily all, of the following criteria.

3.1 Physical properties

Jackets furnish mechanical protection during installation and service. Certain types of jackets can be modified by the addition of fillers, plasticizers, activators, inhibitors, and other additives to enhance particular physical or performance characteristics. Depending on the application, the properties of importance may include one or more of the following:

- Toughness, tear, and abrasion resistance
- Sufficient flexibility to facilitate cable installation
- Flexibility at low temperatures
- Resistance to sunlight and weather
- Reliability for extra-heavy-duty service such as required of portable power cables

3.2 Chemical and moisture resistance

Jackets retard the ingress of water and environmental chemicals into the underlying core. Depending on the application, the properties of importance may include one or more of the following:

- Resistance to high concentrations of organic and inorganic chemicals
- Resistance to ozone concentrations higher than normally encountered in the atmosphere
- Low moisture absorption
- Oil resistance
- Jackets over metallic shields, sheaths, and concentric neutral wires provide protection against corrosion and oxidation

3.3 Thermal stability

The jackets are chosen for their thermal resistance and aging characteristics. Depending on the application, the properties of importance may include one or more of the following:

- Physical stability over a range of temperatures from the minimum installation temperature to the emergency and short-circuit temperatures [excessive shrinkback of the jacket (at cable ends) can lead to physical instability of a cable splice or terminations]
- Resistance to heat aging for the operating conditions of the cable
- Resistance to deformation for the operating conditions of the cable

3.4 Electrical characteristics of non-conducting jackets

For shielded insulated conductors, non-conducting jackets should pass the appropriate electrical tests in industry standards to isolate the metallic shield effectively from the environment. This isolation is required on bonding schemes, which include single-point grounded systems and cross-bonding schemes to minimize shield-circulating current losses. Non-conducting jackets provide a level of isolation between the metallic sheath and the system ground during short-circuit operation.

For unshielded insulated conductors, non-conducting jackets provide resistance to electrical discharge likely to be experienced on power cables and prevent excessive surface leakage at conductor terminations of unshielded power and control cables.

3.5 Electrical conductivity of semi-conducting jacket

Semi-conducting jackets are used most often in areas of high lightning incidents where it is considered desirable to have a relatively low resistance between the concentric neutral wires or shield and the earth. Semi-conducting jackets are rarely used on control and instrumentation cable. The general properties of importance include:

- Electrical conductivity when required to function as an insulation shield or as a jacket on a shielded cable buried in the earth and when required to be grounded along its entire length
- Resistance to abnormal concentrations of organic chemicals, which could increase the resistivity of conductive shields and jackets

3.6 Flame retardance

This jacket material is capable of resisting, retarding, or minimizing the propagation of flame. The flame retardance is accomplished with additives or is inherent in the chemical composition of the material (such as in halogenated polymers). Different applications (such as cable tray, riser, and plenum) require different levels of flame retardancy. Riser and plenum applications often have additional requirements such as low heat generation, low smoke, and low toxicity. Flame-retardant materials are not the same as fire-resistant or fire-rated materials that are used in cables designed to withstand a high-temperature fire and continue to operate during the fire for a period of time.

4. Corrosion protection

An overall cable jacket provides a barrier between the metallic shield or sheath and the local environment, which interrupts the dc corrosion cell. See IEEE Std 1617™ [B21] for more information on corrosion mechanisms.

Some cable-jacket or cable-shield configuration designs discussed in 5.1 interact with a corrosive environment in its own way.

- a) The metallic sheath or concentric neutral wires may be left bare for direct contact with ducts or earth, or both.
- b) The metallic sheath, metallic shield, or concentric neutral may be covered with a semi-conducting protective jacket for electrical contact with the ground.

- c) The metallic components may be insulated from contact with ducts or earth, or both, by the use of a non-conducting protective jacket.

Corrosion of the metallic sheath or metallic shield can be prevented or greatly reduced by the use of a non-conducting or semi-conducting jacket. The jacket must be continuous, without punctures, to prevent accelerated corrosion that may occur at a discontinuity. The continuity of the jacket may be destroyed in several ways, including:

- Mechanical damage resulting from poor design of manholes and duct entrances; imperfections or foreign abrasive material in duct and manhole systems; inadequate feeding, exit, and pulling equipment; or poorly trained, or inexperienced, personnel. Similar hazards exist for direct buried cable, particularly when plowing methods are used.
- Electrical puncture after installation resulting from excessive voltage on the sheath or shield or by ground currents from lightning. Methods of preventing voltages high enough to puncture non-conducting jackets are discussed in Clause 7.
- Damage caused by rodents or insects.
- Degradation caused by aging, chemical action, or bacterial action.

4.1 Corrosion protection of semi-conducting jackets on underground distribution concentric neutral cables

Semi-conducting jackets have also been employed over the concentric neutral wires of UD-CN cables for protection against corrosion where the soil conditions are known to be corrosive to exposed copper and where it is considered desirable to have a relatively low resistance between the concentric neutral wires and the earth. Semi-conducting jackets would not be recommended in the vicinity of pipeline cathodic protection systems.

5. Protective jackets

Protective jackets can have beneficial effects besides corrosion protection. They can provide mechanical protection, especially during installation of the cable, and some degree of electrical isolation during system disturbances when a metallic sheath or metallic shield may carry high-fault current.

5.1 Jacket design configurations for shielded power cable

5.1.1 Overlaying jacket design

The conventional overlaying (sleeved) jacket design uses a layer of polymer film over the metallic shields, and the jacket is extruded over the polymer film. This approach provides a cable that has (1) no or minimum [less than 0.125 mm (5 mils)] indentation into the insulation shield; (2) easy jacket removal that can be facilitated even more by incorporation of rip cords, reducing even more the need for cutting tools; and (3) flexibility because the wires have some mobility to allow less force to be required for bending.

A potential problem with overlaying jackets is that water can gain entrance to the cable at open ends or from jacket faults and can freely flow within the void spaces between the jacket and the metallic shield. For applications where water ingress is an issue, this deficiency can be overcome by water-blocking systems.

The sleeved jacket design allows for easy incorporation of a variety of longitudinal water-blocking materials. Most commonly, water-swellaable tapes are applied over the metallic shield.

The use of a polyester tape or water-swellaable tape over the metallic shield also has the benefit of limiting jacket irregularities resulting from the presence of the shield. To get a smooth cylindrical jacket, some support is needed during extrusion, and these tapes can provide that support.

5.1.2 Extruded-to-fill jacket design for concentric neutral cables

For concentric neutral cables, an extruded-to-fill (encapsulated) jacket is a design option that can be used to mitigate water ingress (Marciano and Cinquemani [B28]). In this design, the jacket is extruded in such a manner as to fill the spaces over and between the neutral wires. Current challenges in the use of this design in order of importance are as follows: indentation of the insulation shield by the neutral wires, difficulty in stripping the jacket, and cable flexibility.

The specifications for underground distribution cable have requirements on the depth of the indentations of the neutral wires into the semi-conducting insulation shield of the cable. The concerns are that (1) the indents could have electrical implications for cable operations; (2) they potentially make it more difficult to strip the insulation shield during termination or splicing operations; and (3) they may serve as a circumferential trough for water propagation. Since jackets can be extruded at high temperatures, a concern exists about concentric neutral wire indentations when the jacket is applied directly over this neutral design.

The stripping of the jacket is complicated by the encapsulating effect of the filling of the spaces between and around the wires. The mechanical resistance imposed by the jacket makes stripping of the jacket from around the wires a more difficult operation.

The neutral wires are restricted from motion by the jacket. During bending operations, in particular, the lack of movement of the wires translates into a less flexible cable. Thus, positioning the cable for splicing and terminating may be more difficult. For medium-voltage concentric neutral cables, extruded-to-fill jackets do a better job of restraining wire movement during ground fault current flow than do overlaying jackets.

5.2 Jacket design configurations for low-voltage power, control, and instrumentation cables

A conventional extruded, overlaying (sleeved) jacket design is normally used on low-voltage power, control, and instrumentation cables. The jacket is applied directly over a longitudinally applied or helically wrapped cable tape. In this type of extrusion, the jacket usually follows the contour of the cable core. Generally, the cable core binder is a polyester film tape, a coated fabric tape, or a binder string. The most commonly used jacket material on these cables is PVC. The requirements for these jackets can be found in ICEA S-95-658 [B78] and ICEA S-73-532 [B76]. A ripcord is sometimes incorporated into the design beneath the jacket to assist in its removal. Low-voltage power, control, and especially instrumentation cable jackets can be extruded directly over a metallic or metalized polyester shielding tape.

A less common design used on low-voltage power, control, and instrumentation cables is an extruded-to-fill or pressure-extruded jacket. The jacket is pressure extruded into the interstices of the troughed taped cable core and results in a round outer surface. This type of jacket will make for a more rugged design but also creates difficulty with regard to variations in jacket thickness. The jacket will be thicker in those areas where it fills the interstices of the core. Jacket removal becomes more difficult because of the thickness of the layer in these interstices. This extra thickness or web causes increased mechanical resistance. A ripcord placed under this type of extruded jacket may not have the strength to tear through the web of a thicker and tougher jacket material.

A CPE jacket is most often used with shielded power or instrument cable having a bonded sheath as described in UL 13 [B90] and UL 1277 [B101]. The CPE jacket will bond adhesively to the coating on the overall shield. The overall shielded cable is used when lightning or moisture protection is a field requirement.

Water-swellaible tapes are generally not used in these types of cable. However, a user may want to consider one in applications where the cable will be continuously wet.

5.3 Non-conducting protective jackets

Control and instrumentation cables generally use non-conductive protective jackets.

Non-conducting protective jackets isolate the metallic sheath or shield from ground and permit the use of sheath or shield bonding schemes to control the magnitude of the induced voltage on the sheath or shield of single-conductor cable circuits. Cable joints and accessories electrically connected to cables must be covered with insulating tape or isolated from electrolytes common to the sheath or shield and ground. This protection keeps any current leaving the sheath or shield from being concentrated at the cable joint, fittings, oil-feed pipes, reservoirs, or adjacent cables, and thereby it prevents concentrated corrosive damage. The effects of corrosion caused by dissimilar metals in the sheath or shields and accessories can also be reduced. Shield isolation of separable connectors is complicated. When separable connectors are used, the manufacturer should be consulted.

Many nonmetallic shielded control and instrumentation cables use jackets for physical and environmental protection. See 7.3 for more detail on nonmetallic cable sheaths.

5.4 Semi-conducting protective jackets

Semi-conducting protective jackets isolate the metallic sheath or shield from its corrosive surroundings while providing a uniform conduction path for the entire system and limiting overvoltages between the shield and the earth. Semi-conducting protective jackets, when used, are typically on power cables.

Materials such as PE, DRTP, EBA, EEA, EVA, EPR, CSPE, CPE, and TPE can be made semi-conducting by the addition of suitable carbon blacks. Typical compounds have an electrical resistivity of less than 500 Ωm at 90 °C. The temperature coefficient of resistivity varies from compound to compound and may, in some cases, be high. The jackets may be either thermoplastic or thermoset and must be compatible with any material in direct contact.

Because of the nature of these semi-conductive materials, invariably a substantial boundary resistance occurs where contact is made with a metallic conductor. Special precautions should, therefore, be taken in making electrical measurements.

When subjected to sufficiently high electrical stress, conductive compounds fail by overheating so that the breakdown stress depends on the electrical resistivity, the time of application of the voltage, and the form of the specimen. Permissible operating stresses for sustained voltage are normally very low.

A possible environmental effect is that some fluids (e.g., transformer oils and creosote) may swell semi-conducting jackets; some compounds can become substantially non-conducting with such contact. Care must therefore be exercised in controlling contact with oils, pulling compounds containing oils or other active ingredients, and plasticizers that may be a component of rubber-like or PVC tapes. A cross-linked material is not affected to the same degree and seems to be more compatible with the tapes commonly used for sealing purposes at joints and terminations.

A semi-conducting jacket is used most often in direct burial cable applications to provide a low-resistance covering between metallic shield, concentric wires, or sheath and earth. It is necessary to recognize that voltages appear on the neutrals of cables carrying return currents or as a result of magnetic induction from the phase currents into the shields of cables in a three-phase operation. It should be kept in mind in situations that might concentrate current flow through the jacket at specific locations, such as (but not limited to) contact with well-grounded objects or the possibility of puncture at contacts, including adjacent cables under surge events. A situation almost certainly to be avoided is the use of semi-conducting jackets in the case of single-point grounded applications discussed in 5.4.2.

5.4.1 Semi-conductive jackets when used for surge protection

Semi-conducting jackets have also been used experimentally as the outermost covering over a metallic shield to provide continuous grounding of the cable shield in the presence of lightning-caused ground currents and to prevent puncture of the jacket from lightning. A compound of low electrical resistivity is desirable for this application.

5.4.2 Operating precautions for semi-conductive jackets

Semi-conducting jackets are not recommended for single-point grounded applications, whether cross bonded or not. The purpose of single-point grounding is to avoid the flow of sheath currents. A semi-conducting jacket will allow current flow through the jacket resulting in some flow of sheath currents and in somewhat defeating the purpose of single-point grounding.

5.5 Jackets on cables operating at cable emergency temperature rating

Operating and emergency temperature rating of jackets are the same for non-conducting and semi-conducting materials. The matter of adequate test temperature should be considered here in view of 105 °C normal/140 °C emergency operation. LLDPE/VLDPE-based and EPR-based semi-conducting jackets pass ICEA thermomechanical requirements for 90 °C and 105 °C rated medium-voltage cables. The ICEA thermomechanical test is conducted on single cable lengths. Some studies report LLDPE non-conducting jackets melt and deform during thermomechanical tests conducted on bundled cables at 130 °C, and although LDPE/VLDPE-based semi-conducting jackets were not tested in these studies, it is anticipated they would behave similarly to the LLDPE non-conducting jackets.

6. Electrical characteristics of jackets

6.1 Sources of electrical stress imposed on jackets

6.1.1 Galvanic cells and stray currents

A non-conducting jacket will eliminate the sheath/shield as one pole of a galvanic cell, isolate the sheath/shield from ground, and eliminate the parallel low-resistance path for pickup and transfer of stray dc current. It may be assumed that jackets suitable for withstanding induced sheath voltages and transient sheath overvoltages will meet the electrical requirement for a jacket to afford corrosion protection. Jacket puncture resulting from transient overvoltages may result in exposure of the metallic sheath to corrosive influences. Jacket punctures may also result from other sources such as mechanical damage caused by construction or wildlife attack before, during, or after installation.

The purpose of a semi-conducting covering is to provide a low-resistance path between the metallic sheath/shield and the earth. Since the semi-conducting covering prevents direct contact between the electrolytes and the metallic sheath/shield of the cable, corrosion and loss of metal should be minor. Field experience on cables with semi-conducting jackets over the past years indicates no reports of cable failures caused by galvanic corrosion with any adjacent equipment.

6.1.2 Standing sheath/shield voltage induced by load current

Methods for calculating sheath voltages and currents and descriptions for sheath bonding systems are described in IEEE Std 575™ [B83]. Methods for handling shielding in low-voltage cables are described in IEEE Std 525™ [B82] and IEEE Std 1143™ [B84].

The use of single-conductor cable circuits with long cable lengths between sheath or shield sectionalizing points may result in induced standing sheath/shield potentials that are above the safety limits explained in various documents (reference IEEE Std 575 [B83]). However, the advantages derived from fewer splices and longer spans in the cable sheath/shield are made possible by the use of reliable extruded non-conducting polymeric materials for jackets. The user will need to ensure that adequate safety procedures are in force for workers who may be within touch potential to the cable.

Jackets with high-quality non-conducting properties make operation with high sheath standing voltages feasible. This mode of operation places emphasis on the need for careful installation of the cable, thoroughness in field application of joint sleeve coverings, and sealing of bonding leads.

6.1.3 Transient overvoltages

It has been shown (see Eaton and Issa [B6], Kellam [B9], Kuwahara and Doench [B10], and Wollaston and Kidd [B12]) that transient overvoltages of different origins are responsible for damaged cable sheath jackets, sheath insulators, and sheath bonding leads.

Transient overvoltages are caused by:

- a) Switching surges
- b) Short-circuit currents (system faults)
- c) Dielectric breakdown
- d) Overhead line or termination flashover
- e) Lightning

The influence of system disturbances is a complex event that, theoretically, may result in sheath voltages of a high magnitude.

Sheath-to-ground voltage caused by switching surges depends on power system configuration, type of interrupting device, and bonding arrangement of the cable. Sheath-to-ground potentials of high values have been reported (see Watson and Erven [B11] and Wollaston and Kidd [B12]) for 115 kV and 230 kV three-phase, single-conductor underground power cables. The voltage across sheath insulators may approach double the sheath-to-ground value.

Sheath-to-ground voltage caused by short-circuit currents depends on the magnitude of the short-circuit current, length of cable, sheath bonding arrangement, and sheath material. Wollaston and Kidd [B12] have provided a means for calculating this (60 Hz) voltage that can appear on the metallic sheath during the flow

of fault current. Overvoltages caused by the flow of fault current in the sheath happen less frequently than do switching surges and are lower in magnitude.

Jacket puncture resulting from transient overvoltages may result in exposure of the metallic component of the sheath to corrosive influences.

Dielectric breakdown of cable insulation will initiate a voltage surge in the metallic sheath enhanced by the discontinuity produced by the sheath insulator. Watson and Erven [B11] have shown that a sheath-to-ground voltage of 28.5 kV could appear on the sheath of a 230 kV system cable.

Disturbances caused by lightning, cable termination flashover, and overhead line insulation flashover will, in general, cause the most severe sheath-to-ground voltage. A portion of the incident surge on the cable conductor will appear on the sheath as a result of the discontinuity produced by the sheath insulator (see UL 1569 [B104]). The magnitude of the incident wave is determined largely by the overvoltage control provided for the circuit. In general, the incident surge on the conductor will be the protective level of the surge arrester or the coordinating gaps at the cable termination. For a typical 115 kV system, the portion of the incident surge that may appear on the sheath could be approximately 30 kV.

Semi-conducting jackets provide effective grounding to cables during lightning strikes and faults. Tests have shown that cables with non-conducting jackets are prone to lightning punctures of the jacket. Puncture thresholds of 150 kV to 160 kV for 1.27 mm (50 mil) jackets and 155 kV to 170 kV for 2.03 mm (80 mil) non-conducting jackets have been reported. On cables with semi-conducting jackets, the neutral-to-ground voltages remained less than 50 kV. Semi-conducting jackets reduce the neutral-to-ground impulse voltage by improving grounding efficiencies.

6.1.4 Additional electrical considerations

Some additional electrical considerations are as follows:

- a) Experience and analysis have shown that the sheath and sheath bonding accessories for three-phase, single-conductor cable systems are subject to steady-state ac potentials and occasionally to transient potentials of high value. As a consequence, protective jackets for underground cables should have the dielectric strength to withstand these conditions.
- b) Investigators (see Kellam [B9] and Wollaston and Kidd [B12]) dealing with power systems rated 230 kV have indicated that extruded polymeric jackets with 2.8 mm to 3.05 mm (110 mil to 120 mil) thickness are a practical means of protecting the metallic sheath.
- c) Integrity of protective jackets with a metallic layer can be established by factory ac or dc tests. For cables above 46 kV, where a semi-conducting coating is applied over the jacket, the integrity may be verified by dc field tests of appropriate values. The more commonly used extruded protective jacket materials at this time are PE and PVC polymeric compounds. These materials have high withstand capability to short-duration, surge-type voltage, which is an advantage when these materials are used for protective jackets.
- d) Investigators (see Kellam [B9] and Wollaston and Kidd [B12]) point out that a system to limit the overvoltages should be considered where it is not practical to provide a withstand dielectric strength to cover the predicted overvoltages that may appear on the cable sheath and across sheath insulators or protective devices (see CIGRE [B2], [B3]).

7. Discussion on the selection and testing of jackets

7.1 General

The first choice in the selection of a jacket is concerned with the type of material to be used: thermoplastic or thermosetting. In some cases, the material choice is determined by the nature of the core that has to be covered. Apart from the elimination of a melting point, thermosetting materials can be formulated so as to be soft and flexible at room temperature and yet retain adequate strength at the maximum temperatures likely to be encountered.

Another consideration relates to flammability. The introduction of halogen into the polymer structure is one method of imparting a measure of flame retardance to the material. On the other hand, halogens and halogen acids are often emitted in substantial amounts should a fire occur. These acids can cause significant damage to nearby structures and personnel, depending on the level of exposure. These risks should be considered when using these jacket materials.

The minimum installation temperature for jacketed power cables is an important consideration for many users. Industry standards typically establish minimum temperature values and qualifying tests. Generally, for PVC, polyethylene, and NBR/PVC jackets, these temperatures are $-10\text{ }^{\circ}\text{C}$, $-40\text{ }^{\circ}\text{C}$, and $-25\text{ }^{\circ}\text{C}$, respectively. The cable user should refer to the supplier for minimum installation temperatures for neoprene, CSPE, CPE, and semi-conducting compounds. However, all polymeric jacket materials may be specially compounded for lower minimum installation temperatures. When special low-temperature compounds are required, the purchase specification should designate the bending or impact test to be used for qualification.

Jacketing materials vary somewhat in their ability to withstand sunlight and weathering. To ensure a long and satisfactory life when exposed outdoors, it is recommended that the compound include a sufficient quantity of well-dispersed carbon black or other suitable ultraviolet light inhibitor (see 7.7.3).

7.2 Jackets for metallic sheathed cable

The main purpose of the jacket is to maintain the integrity of the sheath when the cable is installed in corrosive environments. A tight bond between the jacket and the metallic sheath is important if the jacket is to perform its function successfully. Both thermoplastic and thermoset jacket materials can be used on metallic sheathed cables.

The first polymeric jacket material employed over paper-insulated lead-sheathed cable for installation in ducts was a composite neoprene jacket consisting of fibrous neoprene-filled cloth tapes and neoprene compound tapes vulcanized together for firm cohesion between its components and firm adhesion to the underlying lead sheath.

A high-molecular-weight, low-density, thermoplastic, polyethylene jacket has also been used as a protective covering over paper-insulated metallic-sheathed cable. Care should be exercised in the selection of pulling compounds for polyethylene-covered cable to minimize the risk of environmental stress cracking. Reference IEEE Std 1210™ [B86] for more information on pulling compounds.

Based on economic considerations, the ease with which the jacket can be removed when splicing and terminating the cable, the low coefficient of friction, and physical properties (including toughness, resistance to abrasion, and damage during installation), high-molecular-weight polyethylene is commonly used as the jacket for cable sheathed with lead, aluminum, or other metals. In paper cable designs, and particularly when the cables are installed in wet locations, a protective flooding compound between the metallic sheath and the jacket is recommended to prevent water migration. The flooding compound should

have a suitable brittleness temperature and softening point to retain a seal during reeling, shipment, and cable installation.

7.3 Jackets for cables without metallic sheaths

7.3.1 General

Both thermoplastic and thermoset jacket materials can be used on cables without metallic sheaths. In applications that do not require flame retardance, PE, PE copolymers, PP, and TPE can be used as the outer jacket.

In applications that require flame retardance, jackets based on compounds containing polychloroprene (neoprene), CSPE, PVC, NBR/PVC, and CPE can be used. These materials are all tough, abrasion resistant, and typically flame retardant. The flame-retardant characteristics of neoprene, CPE, CSPE, PVC, and NBR/PVC depend to a significant degree on the chlorine content in the base polymer. Improvements in the flame retardance of these materials can be achieved in several ways, including the addition of chlorine-containing or bromine-containing chemicals to the compound and/or through the addition of appropriate hydrated mineral fillers. Of these four compounds, neoprene, CSPE, and NBR/PVC are thermoset jackets, whereas CPE jackets can be manufactured either as a thermoset or thermoplastic. All of these materials can be formulated for special low-temperature applications, but the manufacturer should be apprised of such requirements so that the necessary compounding variations can be implemented into the jacket material.

Flame-retardant jackets can be based on polyethylene copolymers because these materials have the ability to accept large amounts of fillers, including halogen and nonhalogen flame retardants. Halogen additives include chlorine and/or bromine, whereas hydrated mineral fillers are normally used for nonhalogen formulations when reduced combustion emissions are required. These polyethylene compounds can also be manufactured as thermosetting or thermoplastic materials. All of these materials are compounds and can have certain desirable characteristics enhanced by careful formulations and mixing. When properly compounded, these compounds are suitable for use as jackets on cables.

Although all of these compound types can have various properties altered by careful formulation, certain characteristics are predominant in certain compounds. Neoprene, NBR/PVC, CPE, and CSPE are typically tough, resilient, and flexible. CPE in a thermoplastic form is typically less flexible and has a somewhat higher hardness. Consequently, the surface of the cable is usually smoother and typically exhibits a lower coefficient of friction. Typically, CPE, CSPE, and polyethylene are more moisture resistant than either neoprene or NBR/PVC.

Examples of applications where this feature may be of importance are wiring in generating plants involving many connections to motors and switchgear and installation of cables in a system of undersized ducts and small-size manholes. Portable power cables may require a neoprene, CPE, or CSPE jacket because of the high degree of resilience, flexibility, and physical stability over a broad range of ambient and operating temperatures provided by these compounds.

7.4 Testing of jackets

Jackets are required to be tested by industry standards. Table A.1 outlines the relevant industry standards to be used for compliance with the applicable physical and thickness requirements. In addition, a thermoplastic jacket applied over a metallic sheath of an extruded dielectric cable and a thermoplastic or thermosetting protective jacket applied over a metallic sheath of a laminar dielectric cable are required to be spark-tested to ensure the integrity of the jacket. The voltage is required to be applied between an

electrode at the outside surface of the jacket and the metallic sheath. The spark-test voltages are set forth in the respective industry standards (see A.7).

Care should be exercised in the selection of pulling compounds for cables to minimize the risk of environmental stress cracking and other potential interactions between the lubricant and jacket material. Reference IEEE Std 1210 [B86] for more information on pulling compounds.

Where the jacket is used to support a sheath (or shield) voltage as in single-point grounded or cross-bonded systems, it is recommended that a semi-conducting graphite base coating be applied over the jacket subsequent to the application of the spark-test voltage and that the finished cable on the reel withstand an appropriate dc test voltage (based on the specific manufacturer's recommendation or the utility's standard practice) applied for a prescribed period of time between the metallic sheath and a grounded electrode on the outside surface of the jacket. The semi-conducting coating also facilitates voltage testing of the protective jacket after cable installation and periodically thereafter to verify the integrity of the jacket. An alternative method to a graphite coating is to extrude a thin layer of semi-conducting protective layer over the non-conducting jacket.

7.5 Jacket shrinkback

There have been reports, from both utilities and industrial users, of failures of medium-voltage cable caused by shrinkback of jackets. Under certain conditions, jacket movement and ultimate shrinkback at splices and terminations may allow entry of moisture and contaminants, thus precipitating an insulation failure. Such jacket movement can also disrupt the insulation shielding system, thereby creating points of high dielectric stress that can also cause insulation failures.

Factors that contribute to jacket shrinkback include:

- a) The type of polymer and the makeup of the jacket compound.
- b) Jacket extrusion equipment and conditions.
- c) The type of shielding system and the tightness of the jacket extrusion.
- d) Seasonal and intermittent temperature swings to which the cable is subjected.
- e) The high coefficient of thermal expansion of some materials may be significant.

Jacket extrusion conditions are important in minimizing shrinkback. Factors most often involved are drawdown and cooling. Within polymer or compound limitations, minimization of internal stresses or memory is an important factor.

Jacket movement is minimized when a restraint exists at the interface between the jacket and the metal shield as well as between the shield and the conductive layer that is normally bonded to the outer surface of the insulation. A loose extrusion permits unrestrained movement. Concentric tape shields do little to restrain the jacket even if a reasonably tight extrusion exists. Wire shields are somewhat better since the jacket can adhere more tightly to the conductive layer unless cabling tapes are used. Some compromise must take place in bending flexibility versus restraint of the jacket from longitudinal movement. Longitudinally applied corrugated tapes will offer some restraint to jacket movement without sacrifice in flexibility provided that the end of the tape is restrained.

Climates where large temperature swings from summer to winter occur tend to accelerate jacket shrinkback. This acceleration is probably caused by the ratcheting effect associated with the expansion and contraction cycles. Obviously, aerial cables exposed to sunlight are subject to higher temperature swings than are underground cables.

Where adverse experience with shrinkback has occurred, most engineers have resorted to mechanical restraints at terminations and splices. Hose clamps have been used widely to grip tightly the jacket and to transmit pressure to the underlying cable core. Grips with teeth have also been devised to clamp the jacket over a larger area and to minimize slippage under the clamp. Some terminating devices have built-in clamps to restrain the jacket. During emergency overload conditions, these mechanical restraints will restrict the radial expansion of the cable. Likewise, shrink terminations or sleeves are effective in restraining the jacket and in preventing openings that might allow entrance of moisture.

A test method currently being used to evaluate shrinkback potential in communication cables is contained in ANSI/ICEA S-56-434 [B34]. This test method is used for telecommunication cables; however, this test has not been shown to be applicable to other types of cables. It involves the removal of a 12.5 mm (0.5 in) wide strip from the jacket, which is measured in length before and after oven conditioning at 100 °C for 24 h. The percentage of shrinkage is then calculated from these measurements. Of course, this test relates only to the jacket materials and to the extrusion conditions and does not involve the overall cable design.

7.6 Jacket thicknesses

Refer to the industry standards as listed in Table A.1.

7.7 Special requirements

7.7.1 Discharge resistance

Single-conductor nonshielded cables rated at 2001 V to 5000 V are required by industry standards to comply with the U-bend discharge and surface resistivity tests. The purpose of these tests is to demonstrate that the insulation/jacket combination or jacket itself, where a separate insulation is applied, is resistant to electrical discharge and that the cable will perform satisfactorily under the prescribed installation and environmental conditions.

7.7.2 Flame retardance

When underground cables are to be brought indoors aboveground, they may be required to have a flame-retardant jacket, unless they are to be coated with flame-retardant material. Several industry standards include flame tests. Such tests do not indicate the cable's ability to withstand an actual fire situation, but they give a relative indication of the flame retardance of various materials and cable designs.

The various industry cable flame-retardance tests range from a single wire test to cable tests. The single wire test (as outlined in UL 1581 [B105]) evaluates the flame retardance of the insulated wire in horizontal and vertical positions. The cable tests evaluate the performance of cables in an industrial cable tray configuration (as outlined in IEEE Std 1202™ [B85]), a building riser configuration (as outlined in UL 1666 [B106]) and a plenum cable design (as outlined in NFPA 262 [B88]). A special test, see CFR 30 [B4], is used for the approval of cables for use in underground mines.

7.7.3 Sunlight resistance

Cables are exposed to sunlight either by design—airial cables, riser sections of underground cables, etc.—or casually during storage.

7.7.3.1 Effect of sunlight on polymers

Sunlight, and more particularly ultraviolet (UV) radiation, degrades the physical properties of the polymers commonly used as jacketing materials. The degradation is observed initially as discoloration followed by surface crazing and finally as embrittlement. For insufficiently protected polymers, the degradation can become so severe that the jacket can no longer perform its design function.

7.7.3.2 Protection from the effects of sunlight

One of the most effective and most commonly used means to protect polymers from the effects of exposure to sunlight is to add a minimum of 2% by weight of an ASTM D 1765 [B41] type N.110 carbon black.

There are some jacket applications for which a minimum of 2% carbon black cannot be used. Obviously, carbon black cannot be used for jackets or jacket stripes where colors other than black are required. For track-resistant jackets such as those used for fiber optic cables, a maximum of about 0.5% by weight of carbon black can be used before the anti-tracking properties are compromised.

In such cases, UV protection is afforded by the use of additives commonly known as light stabilizers or UV stabilizers. The general classes of such additives that are commonly used in cable jacketing compounds are as follows:

- a) UV screeners: They are typified by minerals such as calcium carbonate, magnesium oxide, and the rutile form of titanium dioxide. UV screeners act by absorbing incident UV radiation and dissipating it harmlessly, usually as heat. (Carbon black is also a UV screener.)
- b) UV absorbers: They are complex organic molecules, such as the commonly used benzotriazoles, that dissipate incident UV radiation as heat.
- c) Antioxidants: Since photo-oxidation plays a major role in the degradation of polymers exposed to sunlight, it is not surprising that certain antioxidants are effective. The most widely used are the hindered amine light stabilizers. As in thermal oxidation, thioester antioxidants can act as synergists.

7.7.3.3 Tests for sunlight resistance

The testing protocols for sunlight resistance range from simple tests on film samples to complex testing on cables. The former is typified by ASTM D 3349 [B42] that measures the UV absorption coefficient of a thin film. Typical of the latter are the tests required by UL in order to print "Sunlight Resistant" on cable jackets. Such tests measure the degradation of physical properties after exposure to UV radiation generated by a Xenon arc or Carbon arc light source and with the addition of a periodic water spray. For additional information on the topic of sunlight resistance, see UL 1581 [B105], ASTM D 3349 [B42], ASTM G 151 [B43], and ASTM G 155 [B44].

7.7.4 Nuclear applications

In nuclear power plant applications, important consideration needs to be given to the radiation service conditions and nuclear power accident service conditions. For guidance on specifying and testing electric cable jacketing for safety application use in nuclear power plant environments, refer to IEEE Std 323TM [B81] or the current version.

Another important consideration is the impact of the bond between the jacket and the insulation. Improper bonding can result in catastrophic failure of both the jacket and the underlying insulation. This concern is identified in U.S. Nuclear Regulatory Commission Information Notice 92-81 [B108].

8. Properties of commonly used jackets

The commonly used jacket materials are either thermoplastic or thermoset (cross-linked) material. The most common jacketing materials are thermoplastic. These materials can be extruded onto the core (shielded or not shielded) by the cable manufacturer. As polymeric materials, they exhibit many of the good properties that are expected from polymers, such as physical properties and dimensional stability.

In some cases you want to improve the heat deformation resistance even more by cross-linking the polymer. Additionally by cross-linking, there is an improvement in solvent resistance. The cross-linking process is an extra step after extrusion that can be done in vulcanization tubes, by irradiation or by moisture cross-linking. The effect is that the polymer is converted from a thermoplastic to a thermoset such that its resistance to flow is increased and it can no longer be remelted.

Jackets are generally used for the mechanical protection of the cable core such that the toughness required of the jacket should be considered in selecting the jacket material for the application. Toughness is generally characterized by mechanical properties, abrasion resistance, and hardness.

The environment, including cable temperature rating, needs to be considered when selecting a jacket material since the jacket will likely be exposed to a variety of temperature environments. The jacket material can have a minimum cold bend test temperature of as low as -40 °C. However, when the installation temperature is below -10 °C, it is recommended that the cable not be installed without the concurrence of the cable manufacturer. In high-temperature applications, the cable temperature rating should be considered when selecting a jacket material. Some jackets listed in this guide will perform better at higher temperatures than will others.

As a result of their halogen content and proper compounding techniques, neoprene, PVC, NBR/PVC, CSPE, and CPE compounds retard combustion. However, the decomposition of these materials when burning may lead to emission of chlorine and hydrochloric acid. These risks should be considered when using these jacket materials. Flame-retardant additives can be combined with other polymers to achieve similar resistance to flame when compared with the halogen polymers. When cables are jacketed with properly compounded polymers for a degree of flame retardance, cables can withstand the applicable flame test.

8.1 Summary of physical properties of commonly used jacket materials

Table 1 and Table 2 outline the typical relative physical performance characteristics of commonly used jacket materials and their relative chemical resistance when exposed to different chemicals. The performance of the jacket materials in the actual field installation may be different than those listed in these tables, and it is recommended the user refer to the actual cable standard. This information is being provided so the guide user can easily compare these properties among different jacket materials.

Table 1—Typical jacket material physical property table

	Weathering	Heat aging	Heat distortion	Low temperature	Abrasion	Flexibility	Flame retardance
Neoprene	E	F-G	E	E	E	E	G-E
PVC	E	F-E	P-F	F-G	G	E	G
PE-TP	E	E	P-G	E	P-E	P-G	P
XLPE	E	E	E	E	G	F	P-G
CPE-TP	E	E	G	G	G	G	G
CPE-XL	E	E	E	E	G	E	G
CSPE	E	G	E	G	G	E	G
NBR/PVC	E	P-F	P	G	F-G	E	G
Polypropylene	E	E	F-G	F-E	E	F	P-G
EPR	E	E	E	G	G	E	F-G
Polyamide 6	F-G	F-G	E	G	E	F	F-G
Fluoropolymer	E	E	E	E	E	E	E
TPE	E	G-E	F-G	E	P-F	E	P-G

NOTE—The above chart is intended to provide a basic comparison of black jacketing materials and their suitability in certain adverse environments. This information is based on testing performed at approximately 23 °C. A material's rating typically changes dramatically when subjected to elevated temperatures. Cable and/or material manufacturers should be contacted for more specific information in determining the suitability of a material for a cable jacket application.²

E—Excellent.
G—Good.
F—Fair.
P—Poor.

² Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

Table 2—Typical jacket materials chemical resistance property table

	Naphtha	Gasoline/Kerosene	Diesel fuel	Acetone	Ethylene glycol	IRM oils	Mineral oil	Silicone oil	Acid	Base
Neoprene	G-E	G-E	G-E	G-E	G-E	G-E	G-E	E	E	E
PVC	NR	NR	NR	NR	G	NR	E	E	E	E
PE-TP	G	G	G	E	E	G	G	E	E	E
XLPE	G	G	G	E	E	G	E	E	E	E
CPE-TP	G	G	G	G	G	NR	G	E	E	E
CPE-XL	G	G	G	G	G	G	G	E	E	E
CSPE	G	G	G	G	G	G	G	E	E	E
NBR/PVC	G	G	G	G	G	G	G	E	E	E
EPR	G	G	G	E	E	G	E	E	E	E
Polypropylene	G	G	G	E	E	G	E	E	E	E
Polyamide 6	E	E	E	E	E	E	E	E	NR	NR
Fluoropolymer	E	E	E	E	E	E	E	E	E	E
TPE	NR	NR	NR	G	G	NR	E	E	E	E

NOTE—The above chart is intended to provide a basic comparison of jacketing materials and their suitability in certain adverse environments. This information is based on testing performed at approximately 23 °C. The affect of chemicals on jacketing materials is dependent on the type of chemical, its concentration, and the temperature at which it is tested. Specific chemical resistance should be checked with the cable or material manufacturer for a cable jacket.

E—Excellent, virtually not affected.

G—Good, slightly affected.

NR—Not recommended, significantly attacked and unsuitable for the environment.

8.2 Characteristics of polymeric jacket materials

It is strongly recommended that copies of the standards cited in Table A.1 be referenced so that the engineering information in its entirety will be readily at hand.

In 8.3 through 8.15, the characteristics of the different polymeric jacket materials that are currently in common use are discussed and their typical properties in various performance categories that are deemed applicable for jackets are outlined.

8.3 Neoprene

Neoprene (i.e., polychloroprene) is the generic name for elastomeric polymers derived from the polymerization of chloroprene. Typical jacket compounds contain 40% to 60% by weight of the neoprene

polymer. A treatment is required to cross-link the polymer and thereby to impart its thermoset characteristics.

Physical properties such as tear strength, resistance to compressive flow, and abrasion resistance are typically of a high order.

Prolonged exposure to elevated temperatures, however, can result in embrittlement and in a loss of elongation. The temperature-related properties are sensitive to compound formulation, and the manufacturer should be consulted for specific information.

Neoprene compositions have excellent resistance to chemicals, sunlight and weathering, aging, and ozone (depending on the formulation), and they have considerable resistance to flame propagation. Since neoprene contains chlorine, the risks associated with these materials when burning should be considered when using these jackets. This combination of properties has been responsible for its major uses. There is a lack of overall industry standards for water permeability and water absorption, and the manufacturer should be consulted for specific information.

In general, neoprene compositions have excellent resistance to aliphatic hydrocarbons, aliphatic hydroxyl compounds, animal and vegetable oils and fats, fluorinated hydrocarbons, dilute mineral acids, alkaline solutions, and all salts except those of a strong oxidizing nature. The manufacturer should be consulted for specific information.

8.4 Polyvinyl chloride (PVC)

PVC, a thermoplastic material, belongs to a group of polymers broadly referred to as vinyls. The unmodified polymer, which contains 57% chlorine by weight, is fairly linear in structure with approximately 5% to 10% crystallinity, is brittle at room temperatures, and must be plasticized to make it flexible.

Thermal degradation during processing and in service is retarded by the addition of stabilizers, which, for cable applications, are predominantly lead salts. PVC jackets with non-lead stabilizers are also being used today. PVC, when compounded with stabilizers, plasticizers, fillers, and other ingredients, is suitable for general-purpose cable jacket application in either black or other colors. Physical properties such as tensile strength, elongation, and abrasion resistance are good; tear resistance is fair. These general-purpose compounds are tough and abrasion resistant, are low in water absorption, have excellent resistance to soil environments, and are highly resistant to inorganic acids and alkaline solutions, but they can be attacked by some hydrocarbons, ketones, esters, and chlorinated hydrocarbons. UV inhibitors, including a black color additive, can be added to provide excellent weather resistance. Care should be taken when extruding PVC jackets directly over semi-conducting polymer systems, as the plasticizers and other ingredients in the PVC can affect the conductive properties of the semi-conducting layers.

The low-temperature flexibility of these materials must be treated with some caution. The temperature at which fracture occurs is a function not only of the bending radius-cable diameter ratio but also of the rate of bending, cable construction, intensity of shock or impact, and other factors. It is usually recommended that cables with general-purpose PVC jackets be installed at temperatures above $-10\text{ }^{\circ}\text{C}$. PVC, like other polymeric materials, can be compounded for special-purpose applications, including lower temperature use and better resistance to oil and hydrocarbons.

One way PVC can be distinguished from low- and high-density polyethylenes is by its inherently better flame retardance. This property can be enhanced even more by the addition of flame-retardant additives. It should therefore find application over a cable core where flame retardance is of importance and where a less expensive cable is desired as compared with a neoprene or CSPE jacketed cable. In recent years, there has been a trend away from halogen-containing jackets such as PVC, CPE, CSPE, and neoprene for cables to be employed in generating plants, substations, and similar applications because of concern over the

liberation of halogen acid fumes when these jackets burn. The risks associated with halogen acid fumes during burning should be considered when using these jacket materials.

Where PVC is selected as a jacket for power and control cable for installation above ground, in underground ducts, and direct buried in the earth, care should be exercised in selecting a suitable compound. It should have good low-temperature properties for installation in colder locations and good deformation resistance at elevated temperatures for installation in warmer locations. (Since these materials are thermoplastic in nature, they tend to soften and deform at elevated temperatures.)

8.5 Polyethylene

Polyethylene is a thermoplastic, semicrystalline hydrocarbon. The polyethylene materials used for cable jackets have a broad range of molecular weights, and they may be compounded with the addition of stabilizers, carbon black, flame retardants, UV protectors, or coloring pigments. When properly cross-linked, polyethylene becomes a thermoset material.

8.5.1 Thermoplastic PE

The amount and degree of branching in the polymer greatly affects the physical properties of polyethylene. As branching decreases, the crystallinity, hardness, density, and softening point increase; in this respect, polyethylenes are specified by the range of densities within which they fall (reference ASTM D 1248 [B40]). The density ranges are commonly classified as VLDPE, LLDPE/LDPE, MDPE, and HDPE and are outlined in Table 3. Table 3 also contains the typical softening range of these polyethylenes. The average molecular weight, or length of the polymer chains, also influences the physical properties, particularly at high temperatures. This quality is defined as an inverse molecular weight criterion called the melt index (see ASTM D 1248 [B40]). The melt index is a measure of the fluidity of the polymer at an elevated temperature (190 °C) and under specified conditions that control the shear stress; in general, a low melt index indicates a high-molecular-weight material. Molecular weight distribution is important since it influences the processing and property values of a polymer of a given melt index.

Table 3—Density ranges for polyethylene

Polyethylene type	Density range (gm/cm ³)	Softening range (°C)
VLDPE	<0.910	90 to 115
LDPE	0.910 to 0.925	105 to 112
LLDPE	0.910 to 0.925	115 to 120
MDPE	0.925 to 0.940	120 to 130
HDPE	0.940 to 0.960	127 to 138

Low- and high-density polyethylene jackets exhibit excellent dielectric strength, low moisture absorption, good low-temperature properties, a high degree of toughness and abrasion resistance at normal installation temperatures, and physical stability over the specified temperature range.

High-density polyethylene jackets are particularly well suited for direct earth burial cable because of their exceptional toughness, abrasion resistance, and high degree of resistance to permeation by hydrogen sulfide and other earth chemicals. The added stiffness imparted to the cable by this jacket compound should not be objectionable in this type of installation. The selection of a high-quality, high-density polyethylene jacket compound and its proper application to the cable core are extremely important to achieve a stable structure that will not become brittle and crack in service.

VLDPE jackets are the most flexible of all PE jackets. They are also the most recent additions to the PE family. In many cable standards, VLDPE may either fall under the LLDPE group or not be covered at all.

The mechanical properties of a polyethylene jacket will be impaired by contact with any liquid that swells the polymer. In addition, contact with certain liquid polar materials such as soaps and detergents can lead to brittle failure under conditions of biaxial mechanical stress, which means that care must be taken to ensure the compatibility of the pulling compounds and the jackets. Clay-filled compounds are generally compatible with most jacketing materials and may be used as pulling compounds. Jacketing materials are chemically formulated so that troubles from these causes will not be encountered under normal circumstances. Users should contact the manufacturer to verify that the jacketing material is compatible with the pulling lubricant.

Care should be exercised in the selection of polyethylene jackets for high-temperature cable applications. The local cable temperature environment should be considered since it is possible the local temperature may approach the softening temperature of a thermoplastic jacket (see Table 3).

Polyethylene can be mixed with other materials to become a DRTP. These thermoplastics are typically semi-conductive compounds. DRTPs are, as the name implies, higher temperature thermoplastics that do not deform as severely at temperatures of the order of 121 °C as does conventional polyethylene.

Polyethylene jackets are typically compounded with well-dispersed carbon black of small particle size to protect against ultraviolet light and a stabilizer to protect against possible thermal degradation caused by processing and operating conditions.

Although polyethylene has no inherent flame retardance, it can be compounded with halogen or non-halogen flame-retardant additives to meet a broad range of flame-retardant requirements. These materials have been used in cable applications requiring reduced combustion emissions. Adding flame-retardant fillers to the polyethylene will affect its physical properties and electrical properties. Typically, the physical properties (such as tensile and elongation) are reduced.

Copolymers of ethylene and vinyl acetate, ethyl/butyl acrylate, and/or acrylic acid have also found applications in jacket formulations where oil or other chemical resistance, moisture resistance, and toughness are required.

8.5.2 Cross-linked polyethylene

Cable operation at higher temperatures or in more aggressive chemical environments may require cross-linking the polyethylene jacket. It is also sometimes necessary to cross-link the polyethylene jacket when a highly filled compound is used to retain the polymer's physical properties. Several types of materials exist, which differ in density and cross-linking method.

What has been said above about thermoplastic PE also applies to cross-linked material. The exception is that the material cannot be remelted again.

8.6 Chlorinated polyethylene (CPE)

CPE is produced by the controlled chlorination of polyethylene in either solution or slurry reaction media and has been in commercial production since the 1970s. The CPE process provides an opportunity to make a range of products. The most common CPE product variations are (1) molecular weight, i.e., Mooney Viscosity; (2) chlorine content (today's materials typically contain ~25 wt.% to 42 wt.% chlorine); and

(3) level of residual polyethylene crystallinity. Depending on the end-use application, the compounding chemist can choose a CPE product that is most suitable for end-use performance.

The saturated backbone of CPE, i.e., no double bonds in the polymer chain, imparts outstanding ozone, oxidative, and heat resistance to a compound's performance. In addition, the chlorine content of the base CPE resin plays a significant role in determining the performance characteristics of the CPE compound. The presence of chlorine on the polyethylene backbone increases the polarity of the molecule and thereby affects its properties. For example, higher chlorine content will increase oil and flame retardance, but it will decrease the low-temperature flexibility of the compound. Compounders can choose an appropriate chlorine content to help provide the desired degree of performance in the finished cable jacket. Since CPE contains chlorine, the risks associated with these materials when burning should be considered when using these jackets

When used as a cable jacket, CPE is used both with cross-linking (thermosetting) and without cross-linking (thermoplastic). CPE, when compounded with antioxidants, plasticizers, fillers, curatives (cross-linking agents), and other ingredients, is suitable for general-purpose, heavy-duty, and extra-heavy-duty jackets on portable cables and for jackets on cables used in nuclear plants.

Thermoplastic cable jackets containing CPE are typically referred to as deformation resistant. These deformation-resistant materials are suitable for jackets on instrumentation, control and power cables in power generating stations, and fiber optic cables.

CPE, when properly compounded, provides excellent mechanical properties, abrasion resistance, toughness, and flame retardance. The resistance to chemicals, oil, ozone, corona discharge, moisture, and weathering of properly compounded CPE is excellent for both black and colored jacket compounds. CPE can be compounded to meet medium-duty, heavy-duty, or extra-heavy-duty requirements in accordance with applicable ICEA specifications.

The base polymers of CPE and CSPE are chemically similar and can often be used for the same jacket applications. The ability to use one or the other often can depend on specific performance factors that may be met more easily with one polymer versus the other.

8.7 Chlorosulfonated polyethylene (CPSE)

CSPE is produced by reactions of polyethylene with chlorine and sulfur dioxide. The chlorosulfonation process can be controlled to produce a range of products. The most common variables are (1) molecular weight (Mooney Viscosity); (2) chlorine content (today's materials typically contain ~25 wt.% to 42 wt.% chlorine); (3) level of residual crystallinity; and (4) sulfur content. One can see that there are many similarities between CPE and CSPE. One major difference is the presence of sulfur in CSPE in the form of pendant SO_2Cl functionalities. The SO_2Cl group provides an alternative route to cross-linking the CSPE polymer. Since CSPE contains chlorine, the risks associated with these materials when burning should be considered when using these jackets

When used as a cable jacket, CSPE is usually cross-linked and is therefore thermosetting. When compounded with antioxidants, plasticizers, fillers, and other ingredients, CSPE is suitable for general-purpose cable applications. In addition, CSPE may be compounded for extra-heavy-duty jackets on portable cables and for jackets on cables used in nuclear plants.

The weather and moisture resistance of properly compounded CSPE is excellent. The absence of double bonds in their molecular structure makes CSPE-based compounds very resistant to ozone attack and oxidation. CSPE compounds are resistant to most acids, alkalies, and many chemicals. They are also resistant to petroleum oils. The cable manufacturer should be contacted regarding specific resistance data.

The base polymers of CPE and CSPE are chemically similar and can often be used for the same jacket applications. The ability to use one or the other often can depend on specific performance factors that may be met more easily with one polymer versus the other.

8.8 Nitrile butadiene rubber/polyvinyl chloride (NBR/PVC)

NBR/PVC is a blend of acrylonitrile butadiene (Nitrile) rubber and PVC. Blends of comparable amounts of nitrile rubber and PVC can be used as thermoplastic elastomers or can be vulcanized/cured to form thermoset elastomers. The thermoset elastomer is generally used for cable jackets. The addition of Nitrile rubber provides a rubber-like feel to PVC and results in improved abrasion resistance, compression set, tensile strength, tear resistance, and flex fatigue properties. The NBR/PVC compound for cable jackets initially became popular through its usage in the mining industry because of its excellent colorability characteristics. These jackets, when properly compounded, exhibit good mechanical properties and abrasion resistance in both black and colored products. NBR/PVC can be compounded to meet heavy-duty or extra-heavy-duty requirements in accordance with applicable ICEA specifications. Since this material contains chlorine, the risks associated with these materials when burning should be considered when using these jackets.

8.9 Ethylene propylene rubber (EPR)

The EPR compound typically used for cable jackets is a modified form of the EPR insulating compound. This material can be thermoset (cross-linked) and in its usual form has extremely good abrasion resistance but only fair solvent resistance. It has a cold bend performance of at least $-40\text{ }^{\circ}\text{C}$.

8.10 Polypropylene

Polypropylene is a thermoplastic, semicrystalline hydrocarbon and can be either a homopolymer or a random copolymer. Polypropylene is used on cables with a $105\text{ }^{\circ}\text{C}$ rating because of its high melting point that translates into good deformation resistance in a temperature range of $105\text{ }^{\circ}\text{C}$ to $140\text{ }^{\circ}\text{C}$. Polypropylene jackets, with melting points ranging from $115\text{ }^{\circ}\text{C}$ to $150\text{ }^{\circ}\text{C}$, depending on the type of polypropylene used, are well suited to withstand the higher $105\text{ }^{\circ}\text{C}$ insulation temperature requirements. This increase in temperature performance is required particularly in URD duct installations brought about by increased energy (ampacity) demand.

The low-temperature performance of polypropylene depends on the polymer structure. Polypropylene homopolymer has good low-temperature performance down to $-25\text{ }^{\circ}\text{C}$, whereas polypropylene random copolymers have good low temperature performance down to $-50\text{ }^{\circ}\text{C}$.

Both homopolymer and random copolymer polypropylene demonstrate excellent environmental stress crack resistance as well as chemical and oil resistance. Polypropylene jackets also show good moisture permeation resistance.

Polypropylene jackets are tough materials demonstrating high secant moduli. Secant moduli of polypropylene copolymer and homopolymers typically range from 150 000 psi to 180 000 psi. This high modulus of polypropylene translates into good toughness that has enabled wall thickness reductions for particular duct installations.

Polypropylene jackets are typically produced by blending a weathering grade of carbon black masterbatch with the polypropylene to achieve an absorption coefficient of 320 as measured per ASTM D 3349 [B42].

The polypropylene jackets currently used for 105 °C rated cables are based on a polypropylene random copolymer (with a melting point above 125 °C). These materials are mixed with a carbon black masterbatch to achieve an acceptable carbon black loading for good weathering performance.

8.11 Polyamide 6 (PA6)

Polyamides are polymeric resins formed by the condensation of dibasic organic acids with diamines into linear chains containing amide groups. The superior mechanical properties and processing ease of polyamide 6 resulted in its preference as the jacket of wire constructions. Polyamide 6 is manufactured by the polymerization of E-Caprolactam, which is a cyclic lactam of amino caproic acid. The outstanding features of polyamide 6 include high strength and toughness, abrasion resistance, low coefficient of friction, and chemical and thermal resistance. Nylon 6 is the generic term for polyamide 6 resins.

Polyamide 6 is commonly used in building wire and cable construction as a jacketing material over primary insulation. The electrical properties of polyamide 6 are generally not adequate for use as a primary insulation material. In wire jacketing applications, the polyamide 6 is typically a medium viscosity, heat-stabilized homopolymer with an internal lubricant for improved resin extrusion.

The main function of polyamide 6 jacketing is to provide mechanical protection for the insulation. The polyamide has excellent cut-through and abrasion resistance. The low coefficient of friction of polyamide 6 permits easier installation of jacketed conductors in new or existing conduit. Polyamide 6 also has excellent chemical resistance. Polyamide 6 jacketing is often employed where electrical conductors are exposed to gasoline, oil, and other hydrocarbon solvents.

Heat-stabilized polyamide 6 grades are suitable for continuous use up to 120 °C and short-term (less than 15 min) exposure of temperatures up to 185 °C. Prolonged exposure to sunlight and weathering may require the addition of UV additives or pigment systems. The manufacturer should be consulted for specific information.

8.12 Fluoropolymer

The fluoropolymers used in the cable industry for jackets can be of three types: FEP, ECTFE, and PVDF. Typically, FEP is used for insulation, either solid or foamed, in fire alarm cables or high-frequency data cables made according to the category system. It is also used less frequently for jacketing in the same applications. Fluorinated ethylene propylene is used as an insulating material and less frequently as a jacketing material. It has a melting point of 290 °C. Ethylene chlorotrifluoroethylene is used as a sheathing material for industrial control cables and nuclear plant cables. It has a melting point of 150 °C. Polyvinylidene fluoride is used exclusively as a sheathing material and can also be cross-linked by irradiation. Cross-linked polyvinylidene fluoride is used as a sheathing material in demanding industrial cable applications. It has a melting point of 171 °C. Fluoropolymers have high-temperature properties that lend themselves to applications where resistance to external or environmental heat sources is required. The fluoropolymers have the ability to consistently meet the requirements of the horizontal flame test (Steiner Tunnel Test). They do not emit smoke during the flame tests, thereby meeting the requirements for low smoke and low corrosivity required for safety cables. They do, however, emit some toxic by-products in small quantities such as hydrogen fluoride. Overall, fluoropolymer jackets have low coefficients of friction, high levels of hardness, tensile strength, and chemical resistance as compared to other jackets. They require special extrusion techniques.

8.13 Thermoplastic elastomer

The thermoplastic elastomer jacketing compound is the only “rubber-like” thermoplastic material available. It may be a form of crystalline polyethylene but can block copolymers from a variety of different monomers. It comes in various forms with a combination of the following properties, all of which may be achieved in any one compound:

- a) Flame retardance
- b) Low-temperature performance
- c) Low-temperature flexibility
- d) Oil resistance

The thermoplastic elastomer (TPE) has properties similar to those of vulcanized (thermosetting) rubbers. However, TPEs describe materials whose durometer hardness can range between 55 A and 95 A. TPEs are blends of thermoplastic polyolefins and EPR or EPDM polymers, which combine the flexibility and impact resistance of thermoset rubbers with the strength and convenient processability of thermoplastics. TPEs are multiphase compositions in which the polyolefinic phase and rubber phases are dispersed intimately. At least one phase consists of a material that is hard at room temperature but fluid on heating. The other phase consists of the softer, rubber material that is rubbery-like at room temperature. In many cases, the phases are chemically bonded by block or graft copolymerization. In others, a fine dispersion is sufficient.

Like many conventional rubber materials, TPE is highly resistant to oils, chemicals, ozone, and other environmental factors. It has low water absorption, has low coefficient of friction, has excellent electrical properties, and is very flexible. TPE can be processed on widely used cable extrusion and jacketing equipment. TPE is used in a variety of cable jacketing applications.

8.14 Low-smoke/flame-retardant jacketing

One class of jacketing materials used in the manufacture of cables is low-smoke/halogen-free flame-retardant compounds. These materials are generally referred to as LSHF-FR or LSZH. This type of jacketing material is typically used in applications where smoke, toxicity, corrosivity, and flame propagation are concerns for public or individual safety. Applications include cables for tunnels, underground public transit systems, shipboards, and enclosed or confined spaces.

Compared with halogenated flame-retardant systems and resins, LSHF-FR systems produce much less smoke and toxic gases and, generally, no corrosive gases upon burning. These factors are important as most injuries in cases of fire can be caused by disorientation from heavy smoke and irritants (HCl, HBr, HF, SO₂, NO₂, etc.). The smoke density with LSHF materials can be much lower and take longer to reach its peak than halogen-containing systems. The lack of corrosive gases decreases the secondary effect of a fire as the risks for damaging electrical equipment, machines, and so on are reduced.

These materials are generally based on polyolefins, but other resins can be used based on the desired cable performance requirements. LSHF-FR compounds can be either thermoplastic or cross-linked. Some materials are developed with excellent flame retardancy and can meet some vertical flame test requirements. One type of flame-retardant system can be based on metal hydrates, such as aluminium and magnesium hydroxides, which act as flame retarders and smoke suppressants. Other flame-retardant systems can include char formers based generally on melamine and/or phosphorus. Jackets with good flame retardancy may also assist in boosting the overall flame rating of a completed cable construction. Cross-linked jacket materials are used when increased resistance to mechanical, thermal, and chemical abuse is required over those of thermoplastic materials. These LSHF-FR materials can be black compounds or natural to allow for coloration with standard wire and cable color concentrates.

Selection of LSHF-FR jacketing materials will be dependent on the end-use application and industry requirements.

8.15 Identifiable jackets

Many methods have been used to identify underground power cables and ducts. They range from marker tapes, raised ridges, indent printing, as well as colored and striped jackets. The 1993 National Electrical Safety Code® (NESC®) (Accredited Standards Committee C-2) [B29] adopted rule 350G, which applies to all direct buried jacketed supply cable meeting rule 350B and all direct buried communication cables. NESC rule 350G stipulates a lightning bolt be indented or embossed in the outermost cable jacket of supply cable or duct at a repeating frequency of not more than 1 m (40 in). The symbol may be sequentially combined with other data or symbols, or both, printed on the jacket, but it shall be separated as indicated in Figure 350-1 of the NESC. Some utilities are using additional identification, such as red stripes or raised ridges, to supplement the NESC requirement. IEEE Std 1235™ [B87] was issued June 20, 2000 to establish a guide for identification markings of jacketed underground power cables and ducts. Included in IEEE Std 1235 [B87] are various methods of identifying underground power cables and ducts and the visual, chemical, and mechanical properties of the identification materials and/or methods, as well as their impact on the properties of the overall jacket or conduit and installation practices.

Annex A

(informative)

Bibliography

A.1 Non-conducting jacket compounds

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³ Federal regulations are available from the Government Printing Office, 732 N. Capitol Street NE, Washington, DC 20401, USA.

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A.3 Corrosion protection

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⁶ The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

A.7 Informative references

Use the latest edition or revision of the standards listed as follows:

- [B29] Accredited Standards Committee C-2, National Electrical Safety Code[®] (NESC[®]).⁷
- [B30] AEIC CS1, Specifications for Impregnated Paper-Insulated Metallic Sheathed Cable, Solid Type.⁸
- [B31] AEIC CS4, Specifications for Impregnated-Paper-Insulated Low and Medium Pressure Self-Contained Liquid Filled Cable.
- [B32] AEIC CS8, Specification for Extruded Dielectric, Shielded Power Cables Rated 5 Through 46 kV.
- [B33] AEIC CS9, Specification for Extruded Insulation Power Cables and Their Accessories Rated Above 46 kV through 345 kVac.
- [B34] ANSI/ICEA S-56-434, Standard for Polyolefin Insulated Communications Cables For Outdoor Use.⁹
- [B35] ANSI/ICEA S-81-570, Standard for 600 Volt Rated Cables of Ruggedized Design for Direct Burial Installations as Single Conductors or Assemblies of Single Conductors.
- [B36] ANSI/ICEA S-86-634, Standard for Buried Telecommunications Wire Filled, Polyolefin Insulated, Copper Conductor Technical Requirements.
- [B37] ANSI/ICEA S-94-649, Standard for Concentric Neutral Cables Rated 5 Through 46 kV.
- [B38] ANSI/ICEA S-97-682, Standard for Utility Shielded Power Cables 5–46 kV.
- [B39] ANSI/ICEA S-105-692, Standard for 600 Volt Single Layer Thermoset Insulated Utility Underground Distribution Cables.
- [B40] ASTM D 1248, Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable.
- [B41] ASTM D 1765, Standard Classification System for Carbon Blacks Used in Rubber Products.¹⁰
- [B42] ASTM D 3349, Standard Test Method for Absorption Coefficient of Ethylene Polymer Material Pigmented with Carbon Black.
- [B43] ASTM G 151, Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices That Use Laboratory Light Sources.
- [B44] ASTM G 155, Standard Practice for Operating Xenon-Arc Light Apparatus for Exposure of Nonmetallic Materials.
- [B45] CAN/CSA-C22.2 No. 38, Thermoset-Insulated Wires and Cables.¹¹
- [B46] CAN/CSA-C22.2 No. 48, Nonmetallic Sheathed Cable.
- [B47] CAN/CSA-C22.2 No. 49, Flexible Cords and Cables.
- [B48] CAN/CSA-C22.2 No. 51, Armoured Cables.
- [B49] CAN/CSA-C22.2 No. 52, Underground Service-Entrance Cables.
- [B50] CAN/CSA-C22.2 No. 75, Thermoplastic-Insulated Wires and Cables.

⁷ The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards/ieee.org/>).

⁸ AEIC publications are available from Association of Edison Illuminating Companies, P.O. Box 2641, Birmingham, AL 35291, USA (<http://www.aeic.org/>).

⁹ ANSI/ICEA publications are available from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA (<http://global.ihs.com/>).

¹⁰ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

¹¹ CAN/CSA publications are available from the Standards Council of Canada, 270 Albert Street, Suite 200, Ottawa, Ontario, K1P 6N7, Canada (<http://www.scc.ca/en/>).

- [B51] CAN/CSA-C22.2 No. 96, Portable Power Cables.
- [B52] CAN/CSA-C22.2 No. 96.1, Mine Power Feeder Cables.
- [B53] CAN/CSA-C22.2 No. 123, Aluminum Sheathed Cables.
- [B54] CAN/CSA-C22.2 No. 124, Mineral-Insulated Cable.
- [B55] CAN/CSA-C22.2 No. 127, Equipment and Lead Wires.
- [B56] CAN/CSA-C22.2 No. 129, Neutral Supported Cables.
- [B57] CAN/CSA-C22.2 No. 131, Type TECK 90 Cable.
- [B58] CAN/CSA-C22.2 No. 179, Airport Series Lighting Cables.
- [B59] CAN/CSA-C22.2 No. 208, Fire Alarm and Signal Cable.
- [B60] CAN/CSA-C22.2 No. 210.2, Appliance Wiring Material Products.
- [B61] CAN/CSA-C22.2 No. 214, Communications Cables.
- [B62] CAN/CSA-C22.2 No. 230, Tray Cables.
- [B63] CAN/CSA-C22.2 No. 232, Optical Fiber Cables.
- [B64] CAN/CSA-C22.2 No. 233, Cords and Cord Sets for Communication Systems.
- [B65] CAN/CSA-C22.2 No. 239, Control and Instrumentation Cables.
- [B66] CAN/CSA-C22.2 No. 245, Marine Shipboard Cable.
- [B67] CAN/CSA-C22.2 No. 262, Optical Fiber Cable and Communication Cable Raceway Systems.
- [B68] CAN/CSA-C22.2 No. 2556, Wire and Cable Test Methods.
- [B69] CAN/CSA-C68.1, Specifications for Impregnated Paper-Insulated Metallic-Sheathed Cable.
- [B70] CAN/CSA-C68.5, Primary and Shielded Concentric Neutral Cable for Distribution Utilities.
- [B71] CAN/CSA-C68.10, Shielded Power Cable for Industrial and Commercial Applications.
- [B72] CSA-C22.2 No. 0.3, Test Methods for Electrical Wires and Cables.
- [B73] CSA-C22.2 No. 21, Cord Sets and Power Supply Cords.
- [B74] CSA-C22.2 No. 35, Extra-Low-Voltage Control Circuit Cables, Low-Energy Control.
- [B75] ICEA T-33-655 Low Smoke, Halogen-Free Polymeric Jackets.¹²
- [B76] ICEA S-73-532 (NEMA WC57), Standard for Control, Thermocouple Extension and Instrumentation Cables.
- [B77] ICEA S-75-381 (NEMA WC58), Standard for Portable & Mine Power Feeder Cables.
- [B78] ICEA S-95-658 (NEMA WC70), Standard for Non-Shielded Power Cables Rated 2000 V or Less.
- [B79] ICEA S-96-659 (NEMA WC71), Standard for Non-Shielded Power Cables Rated 2001-5000 V.
- [B80] ICEA S-93-639 (NEMA WC74), Standard for Shielded Power Cables 5,000-46,000 V.
- [B81] IEEE Std 323™, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.
- [B82] IEEE Std 525™, IEEE Guide for the Design and Installation of Cable Systems in Substations.
- [B83] IEEE Std 575™, IEEE Guide for the Application of Sheath-Bonding Methods for Single-Conductor Cables and the Calculation of Induced Voltages and Currents in Cable Sheaths (withdrawn).¹³

¹² ICEA publications are available from the Insulated Cable Engineer's Association, Inc., P.O. Box 1568, Carrollton, GA 30112, USA (<http://www.icea.net>).

- [B84] IEEE Std 1143™, IEEE Guide on Shielding Practice for Low Voltage Cables.
- [B85] IEEE Std 1202™, IEEE Standard for Flame-Propagation Testing of Wire and Cable.
- [B86] IEEE Std 1210™, IEEE Standard Tests for Determining Compatibility of Cable-Pulling Lubricants With Wire and Cable.
- [B87] IEEE Std 1235™, IEEE Guide for the Properties of Identifiable Jackets for Underground Power Cables and Ducts.
- [B88] NFPA 262 Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces.¹⁴
- [B89] UL 4, Standard for Armored Cable.¹⁵
- [B90] UL 13, Standard for Tray Cable.
- [B91] UL 44, Standard for Thermoset-Insulated Cables.
- [B92] UL 62, Standard for Flexible Cord and Fixture Wire.
- [B93] UL 83, Standard for Thermoplastic-Insulated Wires and Cables.
- [B94] UL 493, Standard for Thermoplastic-Insulated Underground Feeder and Branch-Circuit Cables.
- [B95] UL 719, Standard for Nonmetallic-Sheathed Cables.
- [B96] UL 758, Standard for Appliance Wiring Material.
- [B97] UL 814, Standard for Gas-Tube-Sign Cable.
- [B98] UL 854, Standard for Service Entrance Cables.
- [B99] UL 1063, Standard for Machine-Tool Wires and Cable.
- [B100] UL 1072, Standard for Medium-Voltage Power Cables.
- [B101] UL 1277, Standard for Electrical Power and Control Tray Cables with Optional Optical-Fiber Members.
- [B102] UL 1309, Standard for Marine Shipboard Cable.
- [B103] UL 1426, Standard for Electrical Cables for Boats.
- [B104] UL 1569, Standard for Metal-Clad Cables.
- [B105] UL 1581, Reference Standard for Electrical Wires, Cables, and Flexible Cords.
- [B106] UL 1666, Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts.
- [B107] UL 2250, Standard for ITC Tray Cable.
- [B108] U.S. Nuclear Regulatory Commission Information Notice 92-81, Potential Deficiency of Electrical Cables With Bonded Hypalon Jackets.

Table A.1 provides a breakdown of industry standards according to type of power cable.

¹³ IEEE Std 575 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

¹⁴ NFPA publications are available from Publication Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://nfpa.org/codes/index.html>).

¹⁵ UL publications are available from Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, USA. Standards information is available at <http://ulstandardsinfonet.ul.com>. Publications are available at <http://global.ihs.com>.

Table A.1—Industry standards for industrial, utility, control, instrumentation, and portable power cables

Industrial power cables	
Standard	Description
NEMA WC70/ICEA S-95-658 [B78] CAN/CSA-C22.2 No. 38 [B45] CAN/CSA-C22.2 No. 51[B48] CAN/CSA-C22.2 No. 75 [B50] CAN/CSA-C22.2 No. 123[B53] CAN/CSA-C22.2 No. 124 [B54] CAN/CSA-C22.2 No. 131 [B57] CAN/CSA-C22.2 No. 230 [B62]	Nonshielded Power Cables Rated 2000 Volts or Less Thermoset-Insulated Wires and Cables Armoured Cables Thermoplastic-Insulated Wires and Cables Aluminum Sheathed Cables Mineral-Insulated Cable Type TECK 90 Cable Tray Cables
NEMA WC71/ICEA S-96-659 [B79] CAN/CSA-C22.2 No. 38 [B45] CAN/CSA-C22.2 No. 123 [B53] CAN/CSA-C22.2 No. 131 [B57] CAN/CSA-C22.2 No. 230 [B62]	Nonshielded Cables Rated 2001-5000 Volts for Use in the Distribution of Electric Energy Thermoset-Insulated Wires and Cables Aluminum Sheathed Cables Type TECK 90 Cable Tray Cables
NEMA WC74/ICEA S-93-639 [B80] CAN/CSA C68.10 [B71]	5–46 kV Shielded Power Cable for Use in the Transmission & Distribution of Electric Energy Shielded Power Cable for Industrial and Commercial and Applications
Utility power cables	
Standard	Description
ANSI/ICEA S-94-649 [B37] CAN/CSA C68.5 [B70]	Concentric Neutral Cables Rated 5 Through 46 kV Primary and Shielded Concentric Neutral Cable for Distribution Utilities
ANSI/ICEA S-97-682 [B38] CAN/CSA C68.5 [B70]	Utility Shielded Power Cables Rated 5000–46,000 Volts Primary and Shielded Concentric Neutral Cable for Distribution Utilities
Control and instrumentation cables	
Standard	Description
NEMA WC57/ICEA S-73-532 [B76] CAN/CSA-C22.2 No. 239 [B65]	Standard for Control, Thermocouple Extension, and Instrumentation Cables Control and Instrumentation Cables
Portable power cables	
Standard	Description
NEMA WC58/ICEA S-75-381 [B77] CAN/CSA-C22.2 No. 96 [B51] CAN/CSA-C22.2 No. 96.1 [B52]	Portable and Power Feeder Cables for Use in Mines and Similar Applications Portable Power Cables Mine Power Feeder Cables