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(Revision of IEEE Std 532-1982)

IEEE Guide for Selecting and Testing Jackets for Underground Cables

Sponsor

Insulated Conductors Committee
of the
IEEE Power Engineering Society

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Abstract: This guide covers corrosion protection, properties of commonly used jackets, electrical characteristics of jackets, physical requirements for jackets referenced in industry standards, and selection and testing of jackets. It is written for those responsible for optimizing underground cable installations. 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 shun the highly technical language and theory commonly used by electrical engineers, corrosion engineers, and chemists to discuss the more detailed application of jackets.
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Introduction

(This introduction is not a part of IEEE Std 532-1993, IEEE Guide for Selecting and Testing Jackets for Underground Cables.)

This guide is concerned with jackets as they are defined in IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (“A thermoplastic or thermosetting 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 for the many persons with responsibilities for optimizing underground cable installations. The purpose of the guide 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 shun the highly technical language and theory commonly used by electrical engineers, corrosion engineers, and chemists to discuss the more detailed application of jackets. This implies that the various topics covered in this guide are not necessarily exhaustive in every respect.

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.

This guide represents the work of the Sheaths and Coverings Subcommittee No. 6 of the IEEE Insulated Conductors Committee. Grateful acknowledgment is given to the many individuals who prepared material for this guide, and in particular the members of Task Group 6-3.

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CLAUSE PAGE

IEEE Guide for Selecting and Testing Jackets for Underground Cables

1. Overview

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 without danger to the user or surroundings.

2. References

This guide shall be used in conjunction with the following references.

AEIC CS1-90, Specifications for Impregnated-Paper-Insulated Metallic Sheathed Cable, Solid Type, 11th ed., Oct. 1990.[1]

AEIC CS4-93, Specifications for Impregnated-Paper-Insulated Low and Medium Pressure Self Contained Liquid Filled Cable, 8th ed., Jan. 1993.

ANSI/ICEA S-56-434-1983 (Reaff 1991), Polyolefin-Insulated Communication Cables For Outdoor Use.[2]

ASTM D1248-84 (Reaff 1989), Specification for Polyethylene Plastics Molding and Extrusion Materials.[3]

ICEA S-19-81 (NEMA WC 3-1992), Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

ICEA S-61-402 (NEMA WC 5-1992), Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

ICEA S-66-524 (NEMA WC 7-1991), Cross-Linked-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

ICEA S-68-516 (NEMA WC 8-1991), Ethylene-Propylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

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[1] AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P.O. Box 2641, Birmingham, AL 35291-0992, USA.

[2] ICEA publications are available from the Insulated Cable Engineers Association, Inc., P.O. Box 440, South Yarmouth, MA 02664, USA.

[3] ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

ICEA T-25-425, Guide for Establishing Stability of Volume Resistivity for Conducting Polymeric Components of Power Cables (Revised Feb. 1981).

IEC 331-1970, Fire-resisting characteristics of electric cables.[4]

IEC 332-1979, Tests on electric cables under fire conditions.

IEEE Std 383-1974 (Reaff 1992), IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations (ANSI).[5]

IEEE Std 575-1988, IEEE Guide for the Application of Sheath-Bonding Methods for Single-Conductor Cables and the Calculation of Induced Voltages and Currents in Cable Sheaths (ANSI).

UL 44-1991, Rubber-Insulated Wires and Cables.[6]

UL 83-1991, Thermoplastic-Insulated Wires and Cables.

UL 854-1991, Service-Entrance Cables.

UL 1072-1986, Medium-Voltage Power Cables.

UL 1277-1989, Electrical Power and Control Tray Cables With Optional Optical-Fiber Members.

UL 1569-1983, Metal-Clad Cables.

3. Abbreviations

The following abbreviations are used in this guide:

CPE	chlorinated polyethylene
CSPE	chlorosulfonated polyethylene
DRTP	deformation-resistant thermoplastic
EPR	Ethylene propylene rubber
HDPE	high-density polyethylene
LDPE	low-density polyethylene
MDPE	medium-density polyethylene
NBR	nitrile butadiene rubber
PVC	polyvinyl chloride
UD-CN	underground distribution concentric neutral
URD	underground residential distribution

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[4] IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[5] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[6] UL publications are available from Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, USA.

4. Jacket characteristics

Jackets furnish mechanical protection for cables during installation and heat cycling. Jackets retard the ingress of water and environmental chemicals into the underlying core. Jackets over metallic shields, sheaths, and concentric neutral wires also provide protection against corrosion.

Evaluation criteria 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. Note that certain jackets can be modified by the addition of fillers, plasticizers, activators, inhibitors, etc., to enhance particular physical characteristics.

a) Toughness, tear, and abrasion resistance
b) Sufficient flexibility to facilitate cable installation
c) Flexibility at abnormally low temperatures
d) 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 terminal]
e) Resistance to heat aging for the operating conditions of the cable
f) Resistance to deformation for the operating conditions of the cable
g) Sufficient insulating value to prevent excessive surface leakage at conductor terminations of low-voltage power and control cables
h) Sufficient insulating value to isolate the metallic shield from ground. This will facilitate single-point grounding and special bonding systems to minimize shield-circulating current losses
i) Electrical conductivity when required to function as an insulation shield or as a jacket on a shielded cable buried in the earth and required to be grounded along its entire length
j) Resistance to electrical discharge likely to be experienced on unshielded power cables
k) Adequate dielectric strength to withstand voltage surges caused by power line switching and power system faults, and induced surges from similar transients
l) Resistance to abnormal concentrations of inorganic chemicals, especially those that promote corrosion and oxidation of cable shielding materials
m) Resistance to abnormal concentrations of organic chemicals, especially for conductive shields and jackets
n) Resistance to ozone concentrations higher than normally encountered in the atmosphere
o) Low moisture absorption
p) Flame resistance
q) Oil resistance
r) Resistance to sunlight and weather
s) Reliability for extra-heavy-duty service such as required of portable power cables

5. Corrosion protection

Cable jackets can greatly retard and sometimes prevent corrosion of cable shielding and sheathing materials. Corrosion of metals is often a very complex process. The annex provides a simplified description of some pertinent corrosion mechanisms.

5.1 Cable-jacket or cable-shield configurations

Some of the designs of the cable-jacket or cable-shield configuration are as follows. Each of these interacts 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 semiconducting 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 an insulating (nonconductive) protective jacket.

5.2 Protective jackets

Protective jackets can have the following beneficial effects:

a) *Mechanical and electrical protection*. Protective jackets provide mechanical protection, especially during installation of the cable, and electrical protection during system disturbances when a metallic sheath or metallic shield may carry high-fault current.
b) *Corrosion protection*. Corrosion of the metallic sheath or metallic shield can be prevented or greatly reduced by the use of an insulating 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 a number of ways including:
    1) Mechanical damage due to 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.
    2) Electrical puncture after installation due to excessive voltage on the sheath or shield or by ground currents due to lightning. Methods of preventing voltages high enough to puncture insulating jackets are discussed in clause 7.
    3) Damage by rodents or insects.
    4) Degradation due to aging, chemical action, or bacterial action.

5.3 Insulating and semiconducting protective jackets

Insulating protective jackets insulate 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 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 prevents concentrated corrosive damage. The effects of corrosion due to 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.

Semiconducting 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.

6. Properties of commonly used jackets

6.1 Neoprene

Neoprene is the generic name for elastomeric polymers derived from the polymerization of chloroprene. Typical compositions contain 40–60% by weight of the neoprene polymer. A treatment is required to cross-link the polymer and thereby 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, results in embrittlement and 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 have considerable resistance to flame propagation. 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.

6.2 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, is fairly linear in structure with approximately 5–10% 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, when compounded with stabilizers, plasticizers, fillers, and other ingredients, is suitable for general-purpose cable jacket application. It retains these features in either black or colors. Physical properties such as tensile strength, elongation, and abrasion resistance are good; tear resistance is fair. Two properties widely utilized are its good resistance to oil and flame. These general-purpose compounds are low in water absorption, have excellent resistance to weather and soil environments, and are highly resistant to inorganic acids, alkaline solutions, and aliphatic hydrocarbons, but are attacked by aromatic hydrocarbons, ketones, esters, and chlorinated hydrocarbons.

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 the rate of bending, cable construction, intensity of shock or impact, and other factors. It is, therefore, usually recommended that cables with general-purpose PVC jackets be installed at temperatures above –10 °C. PVC, like other polymeric materials, can be compounded for special-purpose applications.

6.3 Polyethylene

Polyethylene is a thermoplastic, semicrystalline hydrocarbon. The polyethylene jacketing materials used for power cable have a broad range of molecular weights, and are compounded with the addition of stabilizers, carbon black, or coloring matter. When properly cross-linked, polyethylene becomes a thermoset material.

The amount and degree of branching in the polymer chain greatly affects the physical properties of polyethylene. As branching decreases, the crystallinity, hardness, density, and melting point increase; in this respect, polyethylenes are specified by the range of densities within which they fall (see type 10 in ASTM D1248-84).[7] 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 melt index (see ASTM D1248-84). 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.

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[7] Information on references can be found in clause 2.

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. This 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.

Polyethylene can be compounded with other materials to become a deformation-resistant thermoplastic (DRTP). DRTPs are, as the name implies, higher temperature thermoplastics that do not deform as severely at temperatures of the order of 121 °C as do conventional polyethylenes.

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.

While polyethylene has no inherent flame resistance, it can be compounded with halogen or non-halogen flame retardant additives to meet a broad range of flame resistance requirements. These materials have been used in cable applications requiring reduced combustion emissions.

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

6.4 Chlorinated polyethylene (CPE)

CPE is produced by either solution or slurry reaction of polyethylene with chlorine. Semicrystalline or amorphous polymers can be produced. (These polymers are randomly chlorinated.) The semicrystalline polymers are typically thermoplastic in nature while the amorphous polymers are elastomeric. The unmodified polymers contain 25–46% chlorine.

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 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 resistance. 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.

6.5 Chlorosulfonated polyethylene (CSPE)

CSPE is produced by reactions of polyethylene with chlorine and sulfur dioxide. Semicrystalline or amorphous polymers having chlorine and sulfonyl chloride (SO_2Cl) side chains can be produced.

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 most acids, alkalies, and many chemicals. They are also resistant to petroleum oils.

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

NBR/PVC is a blend of acrylonitrile butadiene rubber and PVC. This thermosetting material is compounded and cross-linked. This material is available in black and in colors. Colors are stable to ultraviolet degradation.

NBR/PVC initially became popular through its usage in the mining industry because of its colorability. NBR/PVC, when properly compounded, provides excellent mechanical properties, abrasion resistance, toughness, and flame resistance in both black and colored jacket compounds. The main usage of NBR/PVC jacket is on cables used in the mining industry primarily in surface mining operations.

NBR/PVC, through compounding, exhibits excellent resistance to chemicals, oil, ozone, and weathering for both black and colored jackets. These jackets, when properly compounded, exhibit good mechanical properties and abrasion resistance for both black and colors. NBR/PVC can be compounded to meet heavy-duty or extra-heavy-duty requirements in accordance with applicable ICEA specifications.

6.7 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 °C.

6.8 Thermoplastic rubber

Thermoplastic rubber jacketing compound is the only “rubber-like” thermoplastic material available. It may be a form of crystalline polyethylene but can be 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 resistance
b) Low temperature performance
c) Abrasion resistance
d) Low-temperature flexibility
e) Oil resistance

6.9 Summary of physical properties

The commonly used jacket materials are either thermoplastic or thermoset (cross-linked) material. The minimum cold bend test temperature can be as low as –40 °C depending upon the formulation, but the cable should not be installed when its temperature is below –10 °C.

Thermoplastic materials are available for operating temperatures up to 90 °C and a maximum short-circuit temperature rating of 200 °C. Their typical tensile strength is 9 653 kPa (1 400 lb/in^2), while some compounds may reach 18 616 kPa (2 700 lb/in^2).

Thermoset materials have a normal operating temperature of up to 90 °C and a maximum short-circuit temperature rating of 350 °C. Their typical tensile strength is 10 342 kPa (1 500 lb/in^2), while some compounds may reach 20 684 kPa (3 000 lb/in^2).

As a result of their halogen content and proper compounding techniques, neoprene, PVC, NBR/PVC, CSPE, and CPE compounds do not support combustion. However, the decomposition of these materials when burning may lead to emission of chlorine and hydrochloric acid. Flame retardant additives can be combined with copolymers of polyethylene to achieve similar resistance to flame when compared to halogenated materials. When cables are jacketed with properly compounded polymers for a degree of flame retardance, cables can withstand the vertical tray flame test described in IEEE Std 383-1974.

Cable jackets meeting flame test requirements are usually based on the chlorine-containing polymers (neoprene, PVC, CPE, CSPE, and NBR/PVC) or other polymers compounded with halogen additives.

6.10 Semiconducting jackets

Materials such as polyethylene, deformation-resistant polyethylene, copolymers, EPR, CSPE, CPE, and thermoplastic elastomers can be made semiconducting 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 quite high. The jackets may be either thermoplastic or thermoset and must be compatible with any material in direct contact.

Operating and emergency temperatures of semiconducting jackets are the same as those for the base material.

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

A serious possible environmental effect is that some fluids (e.g., transformer oils and creosote) may swell semiconducting jackets; some compounds can become substantially insulating with such contact.

When subjected to sufficiently high electrical stress, conductive compounds fail by overheating so that the breakdown stress depends upon 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.

7. Electrical characteristics of jackets

7.1 Insulating jackets

7.1.1 General

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 effectively isolate 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.

7.1.2 Factors that influenced improvement of jackets for cable sheaths/shields

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 which, by their nature, involve induced voltages on the sheath/shield (see [B6], [B9]).[8] 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 [B7], [B8], [B11]); under transient conditions these voltages may be substantial.

7.1.3 Sources of electrical stress imposed upon jackets

7.1.3.1 Galvanic cells and stray currents

An insulating 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 sheath to corrosive influences. Jacket punctures may also result from other reasons prior to, during, or after installation.

The purpose of a semiconducting covering is to provide a low-resistance path between the metallic sheath/shield and earth. Since the semiconducting covering prevents direct contact between the electrolytes and the metallic sheath/shield of the cable, corrosion and loss of metal should be minor.

7.1.3.2 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 575-1988.

The use of single-conductor cable circuits with long cable lengths between sheath insulators results in high induced standing sheath potentials. The advantages derived from fewer splices and longer spans in the cable sheath are made possible by the availability of reliable extruded insulating polymeric materials for jackets.

Jackets with high-quality insulating 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, sealing of bonding leads, and the desirability of a withstand acceptance test on the jacket to prove its electrical integrity.

7.1.3.3 Transient overvoltages

It has been shown (see [B6], [B9], [B10], [B12]) that transient overvoltages of different origins are responsible for damaged cable sheath jackets, sheath insulators, and sheath bonding leads. It is essential that the expected life of the insulating jackets match that of the cable.

Transient overvoltages are caused by:

a) Switching surges
b) Short-circuit currents (system faults)
c) Dielectric breakdown

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[8] The numbers in brackets, when preceded by the letter “B,” correspond to the bibliographical entries in clause 10.

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 high magnitude.

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

Sheath-to-ground voltage caused by short-circuit currents depends upon magnitude of 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 sheath during the flow of fault current. Overvoltages due to the flow of fault current in the sheath happen less frequently than switching surges and are lower in magnitude.

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

Dielectric breakdown of cable insulation will initiate a voltage surge in the 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 due to 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 1569-1983). The magnitude of the incident wave is largely determined by the overvoltage control provided for the circuit. In general, the incident surge on the conductor will be the protective level of the surge arrestor or 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.

7.1.4 Discussion and conclusion

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 [B9], [B12]) dealing with power systems rated 230 kV have indicated that extruded polymeric jackets with 110–120 mil (2.8–3.05 mm) thickness are a practical means of protecting the sheath.
c) Industry standards (see ICEA S-61-402) usually specify protective jacket thickness as related to the diameter of the cable.
d) Integrity of protective jackets is established by factory ac or dc tests and may be verified by dc field tests of appropriate values. The more commonly used extruded protective jacket materials at this time are polyethylene 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.
e) Investigators (see [B9], [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 [B2], [B3]).

7.2 Semiconducting jackets

7.2.1 Insulation shield

The most common usage of semiconducting extruded polymeric materials is in the form of adherent shields at either boundary of the cable insulation. In this guide, consideration is given to the insulation shield for the special case where it also serves as the outermost jacket, as in some underground distribution concentric neutral (UD-CN) cable designs. This shield serves to conduct the charging current of the insulation, both radially and in the plane of the jacket, to the concentric neutral wires that are the outermost cable component and that may be in only intermittent contact with the shield. Stability of electrical resistance is important (see ICEA T-25-425).

The electrical resistivity and the boundary resistance must be sufficiently low to avoid two effects:

a) The development of excessive voltages at any part of the insulation shield between points of contact with the metallic shield. These voltages might lead to partial discharges in cavities between the two elements.
b) The development of excessive losses is indicated by an increase in the effective dissipation factor of the cable. These losses might make an appreciable contribution to the heat generated in the cable.

Both of these effects are dependent upon the spacing of contacts between the insulation shield and the metallic shield and upon the effectiveness of these contacts. They will vary with the cable design.

7.2.2 Corrosion protection

Semiconducting 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.

7.2.3 Surge protection

Semiconducting 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 due to lightning. A compound of low electrical resistivity is desirable for this application.

7.2.4 Operating precautions

Significant voltages to ground may be present on the concentric neutral wires of single-phase cables due to return current flow, or they may be induced in the shield (concentric) of single-conductor cables comprising a three-phase circuit when the shields are grounded at a single point or in the case of long, asymmetrically spaced cables. The leakage currents due to these voltages will generate heat in an outer semiconducting jacket in contact with ground and, in certain circumstances, could cause failure of the jacket. A semiconducting jacket of low electrical resistivity, stable with temperature, is desirable for this application. The steady-state voltage to ground across a semiconducting jacket preferably should not exceed 10 V.

8. Physical requirements for jackets referenced in industry standards

It is strongly recommended that copies of the standards cited in clause 2 be procured so that the engineering information in its entirety will be readily at hand.

8.1 Jacket requirements—Cables without sheaths

Tables 1 and 2 are included to assist the user in determining the applicable standards for thermoplastic and thermoset materials when used as jackets on solid dielectric insulated cables. Table 3 is included to assist the user in determining the applicable standards for jacket thicknesses for solid dielectric cables.

Table 1—Thermoplastic materials

Material type	Industry standards
PVC	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Low-density black polyethylene (LDPE)	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Medium-density black polyethylene (MDPE)	ICEA S-61-402
High-density black polyethylene (HDPE)	ICEA S-61-402
CPE	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Semiconducting insulation shield/jacket materials	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516

Table 2—Thermoset materials (cross-linked)

Material type	Industry standards
Neoprene: General purpose, heavy-duty, or extra-heavy-duty	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
CSPE: General purpose, heavy-duty, or extra-heavy-duty	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
NBR/PVC: General purpose, heavy-duty, or extra-heavy-duty	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
CPE: General purpose, heavy-duty, or extra-heavy-duty	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Semiconducting insulation shield/jacket materials	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516

Table 3—Jacket thickness—Cables without sheaths

Material type	Industry standard
Single-conductor nonshielded cables; for all uses: conduit, trays, troughs, underground duct, aerial, and direct-buried	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Single-conductor metallic shielded cables; for all uses: conduit, trays, troughs, underground duct, aerial, and direct-buried	
2 001–15 000 V	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
15 001–35 000 V	ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Multiconductor cables; for all uses and voltages	
Jackets for individual conductors	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Common overall jacket	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Common overall jacket for flat twin cables	ICEA S-19-81
Single- and multiconductor wire and cable; for all uses except communication and portable cables and portable cords	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516

8.2 Jacket requirements—Metallic-sheathed cables

Table 4 is included to assist the user in determining the applicable standards for commonly used jacket materials on lead and aluminum sheathed cables.

Table 4—Commonly used jacket materials

Material type	Industry standard
Reinforced neoprene	AEIC CS1-90, AEIC CS4-93
LDPE	AEIC CS1-90, AEIC CS4-93, ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
PVC	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
CPE	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516

Table 5 is included to assist the user in determining the applicable standards for jacket thicknesses for lead- and aluminum-sheathed cables.

Table 5—Jacket thickness—Metallic-sheathed cables

Material type	Industry standard
Neoprene: Combination of treated fibrous reinforcing tapes and neoprene jacket compound. Combination of fibrous reinforcing tapes and a continuous wall of neoprene compound. The outer layer of the jacket shall be fibrous tape.	ICEA S-19-81, ICEA S-66-524, ICEA S-68-516 AEIC CS1-90, AEIC CS4-93
Thermoplastic	ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516
Polyethylene	AEIC CS1-90, AEIC CS4-93

8.3 Special requirements

8.3.1 Discharge resistance

Single-conductor nonshielded cables rated at 2 001–5 000 V are required by industry standards (ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516) 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.

8.3.2 Flame resistance

When underground cables are to be brought indoors aboveground they may be required to have a flame-resisting jacket, unless they are to be coated with flame-resisting material. A number of industry standards include flame tests. Such tests do not indicate resistance to an actual fire situation, but rather give a relative indication of the flame resistance of various materials and cable designs.

The various cable flame tests are discussed in ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516, and other newer tests are discussed in IEEE Std 383-1974, IEC 331-1970, IEC 332-1979, UL 44-1991, UL 83-1991, UL 854-1991, and [B4]). A special test, [B4], is used for the approval of cables for use in underground mines.

9. Discussion on the selection and testing of jackets

9.1 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 this 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 quite 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 chlorine into the polymer structure is one method of imparting a measure of fire retardance to the material. On the other hand, chlorine and hydrochloric acid are often emitted in substantial amounts should a fire occur. These can cause significant damage to nearby structures and involve hazards to life.

The minimum installation temperature for jacketed power cables is an important consideration for many users. The industry standards (AEIC CS1-90, AEIC CS4-93, ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516) establish temperature values and qualifying tests for PVC, polyethylene, and NBR/PVC at –10 °C, –40 °C, and –25 °C, respectively. Refer to the supplier for minimum installation temperatures for neoprene, CSPE, CPE, and semiconducting 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.

9.2 Jackets for metallic-sheathed cable

The first jacket 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.

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 lead sheath is important if the reinforced neoprene jacket is to perform its function successfully.

A high molecular weight, low-density, thermoplastic, polyethylene jacket has been employed more recently 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. Bentonite-based pulling compounds are normally employed.

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 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.

9.3 Jackets for cables without sheaths

9.3.1 General

Polychloroprene (neoprene), CSPE, NBR/PVC, and CPE are all tough, abrasion resistant, and typically flame retardant. Of these four compounds, neoprene, CSPE, and NBR/PVC are thermoset while CPE can be manufactured either thermoset or thermoplastic. Copolymers of polyethylene have the ability to accept large amounts of fillers including halogen and non-halogen flame retardants. Halogen additives include chlorine and/or bromine while hydrated mineral fillers are normally used for non-halogen 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 rated 90 °C.

Although all of these compound types can have various properties altered by careful formulation, certain characteristics are predominant in certain compounds. Neoprene, NBR/PVC, and CSPE are typically resilient and flexible. CPE in a thermoplastic form is typically less flexible and somewhat harder. When compounded as a thermoset material, CPE exhibits elastomeric characteristics similar to neoprene, NBR/PVC, and CSPE. Typically, CPE, CSPE, and polyethylene are more moisture resistant than either neoprene or NBR/PVC.

All of these materials depend to a significant degree on chlorine in the base polymer for their flame retardance. Chlorine and/or bromine containing chemicals can be added to these materials to enhance their flame retardance.

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 in the jacket material.

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.

9.3.2 PVC jackets

PVC jacket compounds are tough and abrasion resistant. PVC can be distinguished from low- and high-density polyethylenes by its inherently better flame resistance. This property can be enhanced by the addition of flame retardants. It should therefore find application over a thermoplastic cable core where flame resistance 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 PVC jackets for cables to be employed in generating plants, substations, and similar applications because of concern over the liberation of hydrochloric acid fumes when PVC jackets burn.

Where PVC is selected as a jacket for power and control cable for installation aboveground, 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 the colder locations and good deformation resistance at elevated temperatures for installation in the warmer locations. (Since these materials are thermoplastic in nature, they tend to soften and deform at elevated temperatures.)

9.3.3 Polyethylene jackets

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 in order to achieve a stable structure that will not become brittle and crack in service.

9.4 Semiconducting jackets

Semiconducting polymeric compounds are used over the insulation as insulation shield and, in the case of UD-CN and underground residential distribution (URD) cables, also function as the protective jacket and bedding for the concentric wires.

The compound may be of several types:

a) *Thermoplastic polyethylene*. This is not as tough and deformation resistant at high temperatures as low-density polyethylene cable insulation.
b) *DRTP compounds*. These are used for insulation shields for cross-linked polyethylene and other insulations.
c) *Cross-linked semiconducting compound*. This is sometimes used over cross-linked polyethylene insulation. Its physical properties and resistance to deformation at high temperatures more closely resemble those of the cross-linked polyethylene insulation. Difficulty may be experienced when stripping the shield from the insulation at splices and terminations.

The choice of compound may affect the emergency operating temperature of the cable. As noted earlier, the electrical resistivity will be increased by any swelling of the base polymer. 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. The cross-linked material is not affected to quite the same degree and appears to be more compatible with the tapes commonly used for sealing purposes at joints and terminations.

A semiconducting jacket may sometimes be used on direct buried cable to provide a low-resistance covering between shield, concentric wires, or sheath and earth. It should be recognized that such a jacket can become thermally unstable with relatively low voltages across it, leading to electrical breakdown. Such voltages may arise on a single-phase circuit where the concentric conductor carries the return current. A similar situation occurs on a three-phase circuit using spaced single-conductor cables where the shields or sheaths are operated with only one end grounded so as to eliminate losses due to shield-circulating currents. Voltages will also appear on the shields of spaced single-conductor cables in three-phase circuits if their disposition is not symmetrical or if the electrical load is unbalanced. This limitation of a semiconducting jacket should be given serious consideration when its use over a shield or sheath is contemplated.

9.5 Testing of jackets

Jackets are required to be tested by industry standards. AEIC CS1-90, AEIC CS4-93, ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516 are to be used for compliance with the applicable physical and thickness requirements indicated in clause 9 of this guide. 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 for the time listed in ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516, and ICEA T-25-425. The spark-test voltages, as set forth in the respective industry standards, are indicated in the following:

a) Spark-test voltage for thermoplastic jacket: see AEIC CS1-90, AEIC CS4-93, ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516.
b) Spark-test voltage for polyethylene jacket: see AEIC CS1-90, AEIC CS4-93, and ICEA S-61-402.
c) Spark-test voltage for neoprene jacket: see AEIC CS1-90 and AEIC CS4-93.

ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, and ICEA S-68-516 require a spark-test for a jacket applied over metallic shield or for a neoprene jacket over metallic sheath.

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 semiconducting 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 utilities' 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 semiconducting coating also facilitates voltage testing of the protective jacket after cable installation and periodically thereafter to verify the integrity of the jacket. As an alternate to the graphite coating, the cable may be immersed in a water tank to check the integrity of the jacket.

9.6 Jacket shrinkback

There have been reports, both from utilities and industrials, of failures of medium-voltage cable due to 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 extrusions 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 there is a restraint 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 there is a reasonably tight extrusion. Wire shields are somewhat better since the jacket can adhere more tightly to the conductive layer unless cabling tapes are utilized. There must be some compromise in bending flexibility vs. restraint of the jacket from longitudinal movement. Longitudinal corrugated shields may offer some restraint to jacket movement without sacrifice in flexibility provided that the end of the shield is restrained.

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

Where there has been adverse experience with shrinkback, most engineers have resorted to mechanical restraints at terminations and splices. Hose clamps have been widely used to tightly grip the jacket and 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. Likewise, shrink terminations are effective in restraining the jacket and preventing openings that might allow entrance of moisture.

The only test method currently being utilized to evaluate shrinkback potential is contained in ANSI/ICEA S-56-434-1983. This involves the removal of a 0.127 m (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 extrusion conditions and does not involve the overall cable design.

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Annex A
Fundamentals of corrosion and methods of corrosion control with protective jackets

(informative)

Corrosion is the destruction of metal because of reaction with its environment [A3].[1] In general, when a metal is placed in the earth, it has the tendency to revert to a lower energy level and the more stable state of its oxide. Conditions external to the metal can have a great influence on the corrosion process. It is the role of the jacket to prevent contact of electrolyte with metal and thus prevent corrosion. While polymeric coverings are permeable to water vapor molecules, they are much less permeable to electrolytes.

The classification of corrosion into types or forms can be handled in several ways [A1]. Some sources classify according to the appearance or form of corroded metal such as pitting, general, crevice, and stress corrosion. Other sources classify according to causative agents such as caustic, sulfide, oxygen concentration, and hydrogen embrittlement corrosion. It must also be remembered that each metal and alloy displays a particular corrosion behavior in each particular environment. For the purpose of this guide, corrosion will be classified as chemical, electrolytic, and biochemical. These classifications recognize that the rate of corrosion is influenced by chemical composition of the environment, electric potential, and certain bacteria. All are electrochemical in nature because the corrosion of metallic cable sheaths/shields involves chemical reactions and the flow of electric charges. It requires a conducting medium (electrolyte) in contact with the metal to complete the circuit between the anode and the cathode of the corrosion cell [A2].

A.1 Chemical corrosion

Chemical corrosion is caused by direct contact with soil waters that are acidic or alkaline in nature. Organic acids resulting from sewage, decaying wood and vegetation, and wastes from industrial plants are common offenders. Inorganic acids generated from inorganic fertilizers used on lawns and gardens have been reported to cause corrosion on the copper concentric neutral wires of underground distribution cables.

Alkalis can present particular corrosion hazards for the amphoteric metals, aluminum and lead, which are extensively used for underground cable sheaths. The principal sources of alkalis are as follows:

a) Lime-containing soils.
b) Highly cathodic areas on the cable sheath where the pH of the environment rises.
c) Concrete may cause alkaline corrosion (light etching) during curing and after curing if kept wet with chloride salts present. The chlorides may be present as additives in the concrete for fast curing or may permeate from exterior moisture.

Electrolytes containing chloride, sulfide, and ammonium ions can lead to accelerated corrosion. Most chemical corrosion occurs in conjunction with electrolytic corrosion where it encourages local cell action and contributes to the creation of dissimilar environments along the cable sheath. Chemical corrosion can be reduced by a continuous (free of holes) jacket made of a material relatively impermeable to the molecules of chemical compounds that promote destructive corrosion.

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[1] The numbers in brackets, when preceded by the letter “A,” correspond to the bibliographical entries in A.8.

A.2 Corrosion due to electrolysis

Two types of electrolysis are as follows:

a) *Natural electrolysis*. Occurs where the electric current, which is part of the corrosion process, is self-generated by the potentials of the cell(s) involved. These are galvanic cells and are set up in the following situations:
    1) Interconnection of dissimilar metals that are in the same electrolyte
    2) Dissimilar electrolytes in contact with a single-cable sheath
    3) Local cell action due to anodic and cathodic areas on the surface of a single metal, such as a scratched or new (shiny) lead sheath connected to an old (dull) lead sheath
b) *Electrolytic or stray current corrosion*. Occurs where the anode(s) and cathode(s) of the corrosion process are caused or influenced by current imposed on the cable sheath by an external source. These electrolytic cells are set up in underground cable when the sheath provides an electrical path for stray dc currents.

In both types of electrolysis, anodes and cathodes exist. The electrochemistry indicates that

- At the anode, oxidation proceeds and metallic ions go into solution; i.e., the anode dissolves (corrodes).
- At the cathode, reduction proceeds and may include deposition of a metal, liberation of hydrogen, or formation of an alkaline substance; i.e., the cathode is protected. However, it is the formation of this alkaline substance that, for some metals, contributes the cathodic corrosion.

The electrolytic corrosion of underground cables is caused by the interchange of electric current between the surface of the sheath and its environment. When the corrosion current is unidirectional away from the cable, the metallic sheath/shield is anodic to its surroundings and will suffer anodic corrosion. When the corrosion current is unidirectional towards the cable, the metallic sheath/shield is cathodic to its surroundings and may be protected from corrosion while certain metals such as aluminum, zinc, lead, etc., may suffer cathodic corrosion. Both types may occur on the same length of cable because the current may flow onto the cable sheath at one location and off at another.

A.3 Biochemical corrosion or bacterial corrosion

Biochemical corrosion or bacterial corrosion results from the activity of bacteria. This type of corrosion may occur on unprotected metal of cable or pipes buried in poorly aerated, wet soil containing sulfates and organic matter. This type of corrosion is well known to the pipeline operator using bare steel pipe, but cases are being reported more frequently in duct and manhole systems of the power industry. An account of the mechanism of anaerobic bacterial corrosion and the role of various jacket materials has been given by E. S. Penkhurst [A4].

Bacteria are not likely to exist if the environment has an alkaline pH greater than 9.0; therefore, an excess of cathodic protection may raise the pH sufficiently to stop bacterial corrosion. Bacterial attack can be controlled by an impervious, continuous jacket though certain ingredients (plasticizers) in certain jackets may themselves be subject to bacterial attack.

A.4 Anodic corrosion

A.4.1 Corrosion from stray currents

Anodic corrosion is the most prevalent type of corrosion. When current flows away from the sheath into the surrounding moist soil or electrolyte in the duct, the resulting corrosion is known as anodic corrosion. This unidirectional current (dc) may be caused to flow from a cable sheath/shield by stray currents and galvanic cells.

Stray currents come from rectifiers, rotary converters, and dc generators in transit systems, electric furnaces, cathodic protection systems, and welding operations. The stray currents are forced into the earth by faulty rail bonds, inadequate connections, and inadvertent connections. The current flows through the earth on its way back to the source by the path of least resistance. If a bare metallic cable sheath or a poorly jacketed sheath is in this path, current will flow onto the sheath and leave the sheath near the ground of the negative pole of the source. At this point metal will be removed in direct proportion to the product of the amperes and hours. For example, theoretical penetration per year of the usual sheath materials with 0.155 mA/cm^2 of current discharge is as follows:

Aluminum	1.64 mm
Steel	1.80 mm
Lead	4.62 mm
Copper	3.60 mm

It is obvious that such a condition would be disastrous to a cable sheath. Anodic corrosion may be eliminated by preventing the current from discharging from the sheath into the electrolyte formed by the surrounding moist soil or duct. This is accomplished by connecting low-resistance conductors between the cable sheath near the point where the current is leaving and the structure the current is trying to reach. This applies to existing cables. If cables with undamaged jackets are installed, the sheath is prevented from collecting and discharging current.

A.4.2 Corrosion from galvanic cell current

Current from galvanic cells is another source of anodic corrosion. When two dissimilar metals are immersed in an electrolyte, a potential difference may exist between them. For example, lead is usually anodic to copper and may corrode if an electrical connection is made between them; however, potential difference alone will not indicate the rate nor the magnitude of corrosion which will occur between two dissimilar metals. This is a difficult situation to control especially at electric stations and substations where all structures are connected together and grounded for safety reasons. One remedy is to install a cathodic protection system of sacrificial anodes of a material more anodic than the cable sheath to be protected or to supply current from an anode bed with a rectifier. This system is adjusted to force current to the sheath in the current amount and at the critical locations to counteract the current flowing off the sheath and thus prevent corrosion. This protective system is called cathodic protection. Cathodic protection is effective, but it is difficult to design so that other pipes, cables, and structures are not corroded by the protective current. It is, however, the best expedient to use on an existing cable system that requires protection. On new installations, galvanic cells can be minimized by the use of a continuous jacket on the cable.

Still another type of galvanic corrosion cell is that formed by dissimilar environments in contact with the cable sheath. This condition may set up oxygen concentration cells or differential aeration cells that are one of the most common mechanisms involved in corrosion in soils.

An example of this type of corrosion is the familiar ground line corrosion where the metal (especially true of steel) just below the ground has a deficiency of oxygen in comparison with the metal just at and above ground. The area lacking in oxygen becomes anodic to the area rich in oxygen and is subject to corrosion. Similarly, where water or mud is in contact with cable lying in the duct, the condition for differential aeration cells exists.

Cathodic protection is required on existing systems to prevent this type of corrosion. Cable with a continuous protective jacket is highly resistant to corrosion from these cells. A damaged jacket, however, may help create differential aeration cells. The soil water at the site of damage will be relatively rich in oxygen when compared to water entering this site and penetrating under the jacket. A galvanic cell is created and corrosion proceeds under the jacket at a rate determined by the relative differences in oxygen concentration.

A.4.3 Corrosion of underground distribution concentric neutral (UD-CN) cables

A galvanic cell is created when unjacketed UD-CN cable is installed in a duct bank containing bare lead sheath cables. The exposed copper concentric neutral wires on the outside of UD-CN cable create a cell that will corrode lead sheaths. Tinning these concentric neutral wires helps to reduce the amount of current from the lead sheaths but will not completely prevent it from flowing because the tin may be removed by the abrasion caused by pulling the cable into the duct.

Such cells can be eliminated by the use of a jacket over the concentric neutral wires of the UD-CN cable. When the UD-CN cable is buried in normal soil, the exposed copper concentric neutral wires may be subject to corrosion where sulfur is present in soils that contain chemical waste or cinders. Also, differential aeration cells occur in moist sandy soils. Some cases of such corrosion may also occur on the copper concentric neutral wires of UD-CN cable pulled into the duct due to the non-uniform accumulation of mud and sand around the cable.

A.5 Cathodic corrosion

Cathodic corrosion may occur on amphoteric metals such as lead and aluminum if the current density at the sheath is too high. The cathodic current causes a highly alkaline condition at the surface of the sheath which will attack such metals. These high cathodic current densities may be found where:

a) Pinholes and punctures occur in jackets
b) High-potential cathodic protection systems are working adjacent to underground cables

Cathodic currents, where the current flows from the surrounding electrolyte to the metals (the surroundings are negative to the cable sheath), are used to provide cathodic protection (to control corrosion) for nearly all metals. In the case of amphoteric metals such as lead and aluminum, too much cathodic current (overprotection) can cause an alkaline buildup at the metal surface which will dissolve the normally protective oxide allowing corrosion to proceed at an accelerated rate.

Overprotection can be avoided by careful design of cathodic protection systems to ensure that potentials no more negative than –1.2 V vs. the $Cu/CuSO_4$ half-cell will occur.

A.6 AC corrosion

AC corrosion is the result of high-density ac at the surface of the cable’s sheath or neutral wires flowing between it and the surrounding environments.

French’s paper [A6] explains the mechanics of ac corrosion as it applies to aluminum. Schick's paper [A11] discusses ac corrosion of tinned copper neutral wires on buried cables. F. E. Kulman [A8] gives a summary of ac corrosion up to 1960 and concludes that ac can cause corrosion but at a lower rate than dc of equal current density.

Other investigators [A5], [A7], [A12], [A13] have studied the effect of ac on various metals buried underground. These studies have shown generally that:

a) The metal loss resulting from ac corrosion is a function of the density of the current leaving (or entering) and is also time-dependent. High-current densities (fault conditions) can be sustained for short periods of time while lower current densities can be sustained for longer durations without extensive damage.
b) Each metal has a threshold or critical ac density below which no ac corrosion will occur.

A.7 Fundamentals of corrosion controls

The usual means for controlling corrosion are those that control the corroding current. Several choices are available to the underground cable engineer:

a) Judiciously apply an external dc to cancel out the effects of the corroding dc. This is known as cathodic protection. Recommended procedures and practices for controlling corrosion with cathodic protection are given in [A9] and [A10].
b) Judiciously apply dc current by appropriate galvanic coupling. The use of the sacrificial anode to make the metallic cable sheath/shield more cathodic to its environment is a form of cathodic protection.
c) Judiciously use bonding leads to conduct current from the cable sheath rather than allow current to flow directly from the sheath to the soil.
d) Eliminate the corrosion current by insulating the cable sheath from its environment with a pinhole-free jacket of a material impervious to electrolytic solutions.
e) Design the surface area of the cable's sheath, shield, or neutral sufficient to maintain the density of ac leaving (or entering) below the critical current density.

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