IEEE Guide for the Design, Testing, and Application of Moisture-Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates

Sponsor

Insulated Conductors Committee
of the
IEEE Power Engineering Society

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IEEE Standards Board

Abstract: The user of underground cables is provided with information on the design, testing, and application of moisture-impervious, medium-voltage, solid dielectric power cable using metal-plastic laminates as moisture barriers. Information is also provided on selection of jacketing materials and installation practices. Other types of moisture barriers, such as extruded metal sheaths and bare metallic tapes with sealed seams, are beyond the scope of this guide.

Keywords: cable jackets, metal-plastic laminates, moisture-impervious cable, on-core moisture barrier, pulling tension calculations, semiconducting jackets, sidewall bearing pressure (SWBP) test, under-jacket moisture barrier, water blocking, water-swellable powders, water-swellable tapes, water treeing test

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Introduction

(This introduction is not a part of IEEE Std 1142-1995, IEEE Guide for the Design, Testing, and Application of Moisture-Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates.)

This guide was prepared by Working Group 6–23 of the Sheaths and Coverings Subcommittee (No. 6) of the Insulated Conductors Committee of the IEEE Power Engineering Society. Members of this working group represent a cross-section of the affected parties including cable users, consulting engineers, cable manufacturers, and suppliers of cable materials. The purpose is to provide users of underground medium-voltage cable with guidelines and considerations pertaining to moisture-impervious power cable design and application.

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IEEE Guide for the Design, Testing, and Application of Moisture-Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates

1. Overview

1.1 Scope

This guide will provide the user of underground cables with information on the design, testing, and application of moisture-impervious, medium-voltage, solid dielectric power cable using metal-plastic laminates as moisture barriers. References will be found in clause 2. A complete bibliography of pertinent technical papers together with patent and specification references relating to the content of this guide will be found in clause 8. The annexes provide information on selection of jacketing materials and installation practices. It is recognized that there are other types of moisture barriers available, such as extruded metal sheaths and bare metallic tapes with sealed seams (referred to in 1.5), that are beyond the scope of this guide. This guide should not be interpreted as precluding their use.

1.2 Concepts

In recent years, there have been widespread failures of polyethylene-insulated, medium-voltage cables in underground applications due to the water treeing phenomenon. These failures, mostly in underground residential distribution systems, have kindled a strong interest in measures to prevent water intrusion into cable cores. While metallic sheaths, such as lead and aluminum, have been effective in past years as barriers to moisture, their relative cost along with installation difficulties has tended to diminish their usage. Recently, thin metal-plastic laminates have found application as moisture barriers in medium-voltage power cables. Aluminum, copper, and lead substrates are used with polymeric compounds adhesively laminated on one or both sides. The tapes are usually applied longitudinally, with an overlapped and sealed seam, either directly over the core of the cable or under the jacket. In addition, other measures have been taken to block the longitudinal movement of moisture through the conductor and the shield interfaces so that water-impervious cables are now available. This guide will provide information on the use of such laminates in cable constructions as well as the use of other materials for longitudinal water blocking. Cable users should find this information of value in the selection, specification, installation, and testing of moisture-impervious, medium-voltage cables.

1.3 Development history

Thin metal-plastic laminates were first developed as moisture barriers for telephone cable in the early 1960s. They have been successfully utilized for many years in this application. These laminates have also been used for moisture barriers and shielding in many other types of low-voltage cables, such as control, coaxial, instrumentation, fiber optic, undersea, etc. Only in recent years have such laminates found application as moisture barriers for medium- and high-voltage power cable, where design parameters have been more restrictive. These restrictions and their solutions will be covered in this guide.

1.4 Utilization and trends

A number of power cable designs making use of such moisture barriers have been commercialized and there is an upward trend in their acceptance on a worldwide basis. Clause 8 provides further references to the many designs and the various countries, industries, and utilities that have selected, specified, and installed cable with moisture barriers and moisture-blocking materials.

1.5 Other designs

There are other means for providing radial moisture barriers in power cable designs, beyond the use of metal-plastic laminates, that are outside the scope of this guide. Extruded lead and aluminum sheaths can be used for this purpose and have been available for many years. Metal sheaths with welded seams and lateral corrugations have also been utilized in the past for this purpose. More recently, thin copper tapes, without plastic coatings, have been used as a combination moisture barrier and shield. Such tapes are applied longitudinally under the jacket, with an overlapped seam. The seam is sealed with an adhesive to block the entrance of moisture. Information on these designs should be obtained from other guides and standards or from manufacturers of such cable.

2. References

This guide shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

AEIC CS 5-94, Specifications for Cross-Linked Polyethylene Insulated Shielded Power Cables Rated 5 Through 46 kV, 10th ed.[1]

AEIC CS 6-87, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV, 5th ed.

ASTM B 736-92a, Specification for Aluminum, Aluminum Alloy, and Aluminum-Clad Steel Cable Shielding Stock.[2]

ASTM D 903-93, Test Method for Peel or Stripping Strength of Adhesive Bonds.

ASTM D 991-89, Test Method for Rubber Property—Volume Resistivity of Electrically Conductive and Antistatic Products.

ASTM D 1248-84 (Reaff 1989), Specification for Polyethylene Plastics Molding and Extrusion Materials.

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

ASTM D 1876-93, Test Method for Peel Resistance of Adhesives (T-Peel Test).

ASTM D 2861-87 (Reaff 1993), Test Methods for Flexible Composites of Copper Foil with Dielectric Film or Treated Fabrics.

ASTM D 4565-90a, Test Methods for Physical and Environmental Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable.

ASTM E 796-94, Test Method for Ductility Testing of Metallic Foil.

ICEA T-31-610-1989, Water Penetration Resistance Test, Sealed Conductor.[3]

IEEE Std 48-1990, IEEE Standard Test Procedures and Requirements for High-Voltage Alternating-Current Cable Terminations (ANSI).[4]

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

IEEE Std 404-1993, IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000–138 000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500–500 000 V (ANSI).

IEEE Std 422-1986 (W1994), IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations (ANSI).[5]

IEEE Std 525-1992, IEEE Guide for the Design and Installation of Cable Systems in Substations (ANSI).

IEEE Std 576-1989, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry (ANSI).

IEEE Std 690-1984 (W1994), IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations (ANSI).[6]

IEEE Std 930-1987 (W1994), IEEE Guide for the Statistical Analysis of Electrical Insulation Voltage Endurance Data (ANSI).[7]

IEEE Std 1202-1991, IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies (ANSI).

NEMA WC 7-1991 (ICEA S-66-524), Cross-Linked Polyethylene Insulated Wire and Cable for Transmission and Distribution of Electrical Energy.[8]

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

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[3] ICEA publications are available from ICEA, P.O. Box 411, South Yarmouth, MA 02664, USA.

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

[5] IEEE Std 422-1986 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

[6] IEEE Std 690-1984 has been withdrawn. It is available in the IEEE Nuclear Power Standards Collection (1990 Edition).

[7] IEEE Std 930-1987 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

[8] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Suite 300, Washington, DC 20037, USA.

3. Definitions

3.1 blocked conductor: A stranded conductor whose interstices are filled with a compound that prevents the migration of moisture along the interstices. *Syn:* strand-filled conductor.

3.2 cable core: The portion of a cable that includes the conductor, the conductor shield, the insulation, and the extruded insulation shield.

3.3 metal-plastic laminate: A tape made of aluminum, copper, lead, or other metal substrate that is laminated on one or both sides with a tightly adhering plastic film. The film used may consist of either an adhesive polyolefin copolymer that self-bonds to the metal substrate during the laminating process or another polymeric compound that is adhered through the use of a supplemental adhesive.

3.4 moisture barrier: A metal barrier that prevents moisture from permeating radially into the cable core.

3.5 moisture block: A means for preventing moisture from migrating longitudinally along the cable core, either through the conductor or within the space allowable between the extruded insulation shield and the jacket.

3.6 on-core type: A moisture barrier applied directly over the cable core.

3.7 swellable powder: A powder that swells upon contact with moisture. A jelly like material is formed to block the longitudinal transmission of moisture.

3.8 under-jacket type: A moisture barrier applied under the jacket and over the metallic shield or concentric neutral of a cable. Also, a combination moisture barrier and shield.

3.9 water-blocking tape: A nonwoven synthetic tape impregnated with a swellable powder. Also called a water-swellable tape. Such tapes may also provide cushioning to absorb expansion of the cable core and may also be semiconducting.

4. Cable designs utilizing moisture barriers

4.1 Cables with under-jacket moisture barriers

The under-jacket design incorporates a metallic moisture barrier directly under the jacket of a power cable intended for underground applications. The metallic moisture barrier is a laminate structure consisting of a metallic substrate coated on one or both sides with adhesive coatings. The laminate is overlapped longitudinally over the cable core. The coating on the laminate is bonded to the cable jacket by the heat transferred during the extrusion of the jacket. The extrusion process also provides heat to form a seal of the overlapped seam. The seam can be sealed by the adhesive coatings and/or a hot melt adhesive applied in the overlap. Specific types of adhesive coatings are required for adhesive compatibility with the various types of polyethylene (PE) jackets, and other types are required for compatibility with polyvinyl chloride (PVC) jackets. An illustration of this design is shown in figure 1.

Normally a mechanical stress relief layer is required under the metallic moisture barrier to allow for expansion and contraction of the core during thermal loading. In some cable designs, a layer of synthetic material is used that serves to cushion the expansion of the core. In other designs a special fluted construction for the insulation screen is utilized to absorb expansion. The screen flattens during thermal loading. In other designs, longitudinal corrugations are placed in the metal-plastic laminate to absorb thermal expansion and contraction.

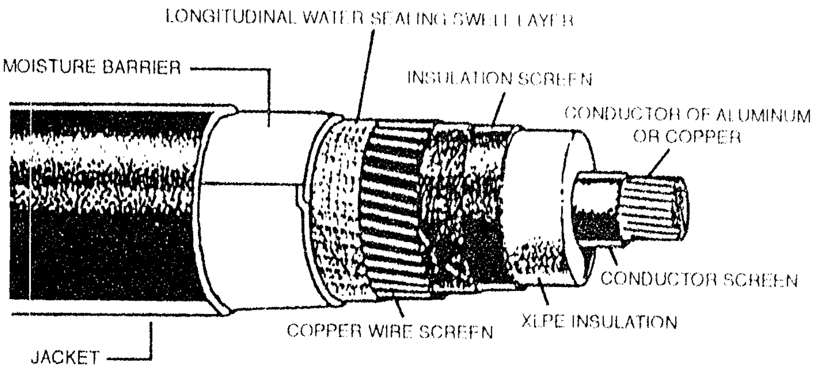

Figure 1—Under-jacket type with concentric neutrals

Another design consideration is that longitudinal water flow must be blocked in the interface between the moisture barrier and the core. Since the moisture barrier is separated from the core by the neutral wires and/or cushion layers, a moisture path is left in this interface. A fabric tape containing water-swellable powder is normally used for this purpose. Water-swellable yarns, as well as water-swellable powder alone, have also been utilized in certain designs. In any case, water flow is blocked by the gelling action of the powder in the event that water is present at a point of sheath rupture, or at an unsealed cable end. Water-blocking tapes can also function as cushion layers to absorb insulation expansion as described in 4.5.

The principal advantage of the under-jacket design is the use of metallic moisture barriers that are thick enough to ensure there are no pinholes and mechanically strong enough to withstand installation and use without rupture. With optimal combinations of jacket thickness and metal thickness, the under-jacket design can combine the flexibility of the plastic jacket with the strength of the metallic tape. The overall mechanical properties of the cable are improved over those that can be accomplished with the same materials unbonded. The bonded sheath has been shown to have increased hoop strength, which facilitates the installation process. The sheath has reduced shrinkback after installation. The longitudinally formed metallic tape with a sealed overlap is proven technology as a moisture barrier for cable as demonstrated by the many references to this construction listed in the bibliography (see clause 8).

The metallic moisture barrier can serve strictly as a moisture barrier over the wire neutral, or act as a shield either alone or to supplement the wire neutral. The choice depends on short-circuit requirements, cable design considerations, and economics. The choices of grounding techniques for these three constructions are detailed in 7.3. Even when the laminate is intended mainly as a moisture barrier, it is necessary to consider that it is going to form part of the shielding system of the cable, and that adequate contact with other metallic components of the insulation shield must be provided.

A more recent development of the under-jacket design combines the moisture barrier and the electrical shield or neutral into one common metallic layer. This design is illustrated in figure 2. A copper tape of sufficient thickness to safely carry fault or neutral currents is applied longitudinally with an overlapped and sealed seam. The tape is corrugated laterally for larger diameter cables to provide flexibility. The outer side of the tape is laminated to an adhesive film that bonds the laminate to the outer jacket of the cable. This provides improved mechanical properties and corrosion resistance. Semiconducting water-blocking tapes are used under the shield/moisture barrier to block longitudinal moisture transmission, to provide electrical continuity between the metallic shield and the semiconducting insulation shield, and to provide a cushioning layer for expansion control.

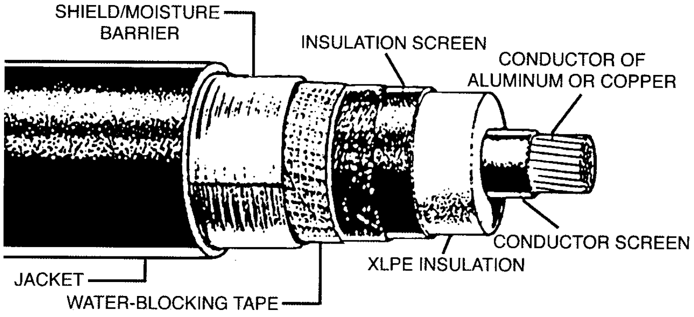

Figure 2—Under-jacket type with combined shield and moisture barrier

4.2 Cables with on-core moisture barriers

In the on-core construction, a laminate composed of a lead tape coated on both sides with a semiconducting adhesive copolymer is utilized. The lead is quite thin, about 2 mils (0.05 mm) thick and the laminate is designed to expand and contract with the cable core. The moisture barrier laminate is placed directly over the semiconducting screen. A semiconducting bedding tape is normally placed over the moisture barrier. The neutrals and a jacket are applied over the bedding tape. Most jacketing materials may be utilized. An illustration of the design is shown in figure 3. The sealed moisture barrier should not be applied in the manufacturing process until the extruded insulation has been degassed.

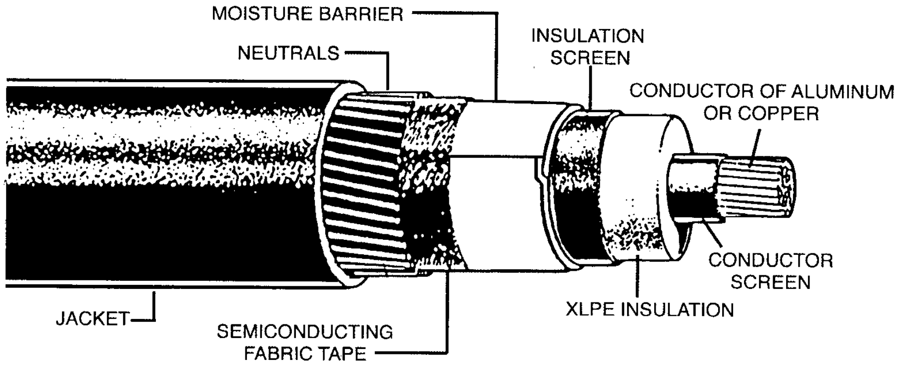

Figure 3—On core type

The primary function of the on-core moisture barrier is to prevent radial permeation of moisture. A primary advantage is that the moisture barrier is adhered directly to the core and thus guards against longitudinal water migration between the moisture barrier and the core. Another advantage of this design is that standard methods for splicing and terminating may be utilized. See 7.2 for further details. Since the on-core moisture barrier is directly adhered to the core, it must be able to expand and contract with the core under conditions of thermal loading. The bedding tape over the moisture barrier is required to prevent damage to the moisture barrier by the neutral wires when the core expands during thermal loading. The neutral wires and outer-jacket in turn mechanically protect the moisture barrier.

4.3 Selection of jacketing materials

4.3.1 Principles of jacket selection

Linear low-density polyethylene (LLDPE) may be chosen for the jacket, but where higher levels of abrasion resistance and temperature performance are required, either medium-density polyethylene (MDPE) or high-density polyethylene (HDPE) can be selected. ASTM D 1248-84[9] may be used as a baseline reference for PE jackets. A wide variety of PVC compounds may be chosen depending on the end-use requirements. PVC and chlorinated polyethylene (CPE) are generally used where ignition suppression properties are required in the cable. Specially compounded PE or copolymers of PE may be used where jackets with low levels of combustion emissions are required. Annex A provides an overview of jacketing materials in common use.

4.3.2 Under-jacket type

A key requirement for a jacket to be used with the under-jacket moisture barrier is that the jacket must be adhesively compatible with the coated metal used as the moisture barrier. The jacket choice, once adhesive requirements are met, will depend on mechanical and chemical considerations.

4.3.3 On-core type

Most types of CPE, PVC, or PE jackets may be selected for use with the on-core moisture barrier. Either semiconducting or insulating jackets may be utilized.

4.4 Use of synthetic tapes and powders for longitudinal water blocking

4.4.1 Powders

Swellable powders are available that expand upon contact with water and form a jelly-like material within a confined area to prevent longitudinal water penetration. Cable designs using a fluted semiconducting shield, swellable bedding tapes, or swellable yarns may be required to hold the powder in place depending on the type of moisture barrier selected. It is possible for the powder to migrate during cable handling and leave areas within the cable unprotected. It should be noted that the ability of swellable powders to swell in seawater is significantly reduced.

4.4.2 Nonmetallic water-blocking tapes for under-jacket constructions

4.4.2.1 Description

A water-blocking tape is usually a nonwoven, synthetic textile tape impregnated with, or otherwise containing, a swellable powder as described in 4.4.1.

4.4.2.2 Functions

The water-swellable tape functions as follows:

a) Upon contact with water, the powder swells into the cable interstices and forms a jelly-like longitudinal water-block.
b) The tape may act as a mechanical stress-relief layer for absorption of thermal expansion of the cable core.

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

c) The tape may act as cushioning for the metallic moisture barrier and/or as a bedding for neutrals.

d) The tape may be semiconductive to allow charge transfer from the insulation semiconducting shield to the metallic shield or wire neutrals.

4.4.2.3 Application

The tape may be applied either helically or longitudinally into areas of expected airspace, such as underneath a corrugated or smooth metal-plastic laminate or in the neutral area. Tapes used for power cables are omnidirectional and will swell on both sides upon contact with water. The factors affecting the ability of the tape to swell and fill the interface with gel are primarily dimensional. The space to be filled must be small enough so that sufficient pressure is built up in the gel to block the flow of water.

4.4.2.4 Tape selection criteria

4.4.2.4.1 Physical properties

The tape should have the following physical properties:

a) The tape should have sufficient mechanical strength, elongation, and flexibility to provide easy application and not impair cable flexibility.

b) The tape should have sufficient thickness to perform well as a mechanical stress-relief layer and for cushioning/bedding purposes.

4.4.2.4.2 Chemical properties

The tape should exhibit the following chemical properties:

a) The tape should have a balance of swellable height, speed, and gel strength to water-block the cable within a distance of 5.0 ft (1.52 m) from the point of entry.

b) The materials of construction for both the tape and the powder should be 100% synthetic to minimize bacterial degradation underground.

c) For power cable applications, the powder should be capable of swelling over repeated wet/dry cycles.

d) The tape should be stable over the temperature range associated with cable load cycling.

4.4.2.4.3 Electrical properties

Depending upon application, the tape should be either semiconductive or insulating.

4.5 Materials for expansion control

4.5.1 Under-jacket

The need for a specific layer of material for thermal expansion control is primarily with the under-jacket type of moisture barrier cable. There is need for some type of cushion that will buffer the difference in outer diameter of the core due to load cycling. The water-swellable tapes described in 4.4.2 are suitable as a cushion for accommodating the thermal expansion and contraction of the core. Semiconducting crepe papers are also available and have been used successfully in certain moisture barrier designs. Semiconducting foams have been used in experimental cable designs. The key to expansion control is to maintain the integrity of the moisture barrier during thermal cycling.

4.5.2 On-core

In general, the on-core design relies on the ability of the moisture barrier to expand and contract with the core. Semiconducting tapes are placed between the moisture barriers and the concentric neutral wires or shielding tape to buffer the expansion of the core. Such tapes also ensure electrical conductivity between the moisture barrier and the neutral wire or shielding tape, and provide protection to the moisture barrier.

The percent radial expansion of cross-linked polyethylene (XLPE) insulation is approximately 2% at a 90 °C (194 °F) conductor temperature and approximately 5% at 130 °C (264 °F). In the case of the on-core type of moisture barrier, the integrity of the laminate must be maintained during expansion and contraction of the core.

5. Metal-plastic laminates used for moisture barriers

5.1 Description

A laminate consists of a thin metal layer, usually 0.002–0.015 in (0.05–0.38 mm) in thickness, which is laminated on one or both sides with a plastic film with typical thicknesses of 0.002–0.004 in (0.05–0.10 mm). The film can be insulating or conductive. A strong adhesive bond must be formed between the film and the metal layer. Thus, a film should be selected that will not lose its properties after long-term exposure to heat and moisture cycling. In all cases, the metal layer must be pinhole free as such holes would entirely defeat its purpose as a moisture barrier.

5.2 Laminates for under-jacket designs

The type of metal chosen for a metal-plastic laminate depends on the cable design. Present choices include lead, copper, aluminum, and bronze. All of these metals can be coated or laminated with suitable plastics to achieve the desired composite structure. Laminates can be designed primarily for moisture barrier functions or for dual functions as both moisture barriers and metallic shields.

Each type of metal has distinct advantages and disadvantages for laminate use. In general, when lead is used as a moisture barrier in under-jacket designs there is a need to reinforce the metal with polymer layers to provide strength. A minimum lead thickness of 0.002 in (0.05 mm) is necessary to eliminate the possibility of pinholes. Copper is often used when maximum conductivity is required. This occurs when the metallic moisture barrier also performs as an electrical shield, either alone or to supplement wire neutrals. In splicing and terminating, copper has an advantage because it can be soldered or mechanically clamped more readily than other materials. For proper handling and forming, a minimum thickness of 0.004 in (0.1 mm) is needed when copper is used. Aluminum can also be utilized as a shield but is most often selected for moisture barrier purposes only. A minimum thickness of 0.006 in (0.15 mm) is needed for proper handling, forming about the cable core, and mechanical strength in the finished cable.

Two classes of metal-plastic laminates currently exist for use in the under-jacket designs. One class is adhesively compatible with PE, copolymers of PE, and CPE jackets. The other class is compatible with PVC-based jackets. ASTM B 736-92a can be used as a baseline reference for both types of laminates.

Plastic coatings or films exist for each class that will satisfactorily adhere to the metal substrate. The resulting laminate can then be used as an under-jacket moisture barrier in various cable constructions. The film may be applied to one or both sides of the metallic layer as the cable design dictates. Film laminated to the metal substrate on one side only permits electrical contact between the bare metal side and other metallic or semiconducting components of the cable. Splicing and termination are also facilitated. Film laminated to the metal substrate on both sides increases the corrosion resistance of the laminate and enhances seam sealing during the cable manufacturing process. Composites coated on one side and composites coated on both sides have found application in under-jacket cable designs.

The film used in such laminates may also be classed as either insulating or conductive. An insulating layer is generally used when a structure coated on only one side is bonded to an outer nonconductive jacket. Conductive layers of film are used when electrical contact between the metal substrate and other conducting components of the cable is required.

The plastic film or coating must meet the following requirements:

a) The plastic layer must adhere to itself or to the bare metal under the specified conditions of temperature, pressure, and time. The metal-film bond must not degrade upon exposure to water. The film must withstand the temperatures normally encountered in operating cables.
b) The film must exhibit a strong bond to the jacket. This bond must not diminish, to any appreciable extent, with extended water exposure and temperature cycling.

5.3 Laminates for on-core designs

The laminate for the on-core design utilizes lead foil about 2 mils (0.05 mm) thick. The lead is laminated on both sides with a semiconducting film approximately 4 mils (0.10 mm) thick. It has been found that the combination of lead and plastic film allows the lead to behave as a plastic material. The laminate is therefore capable of expanding and contracting with the cable core. Since the laminate is in the electrical field of the cable, the plastic film must be semiconducting. The film layers must also exhibit good adhesive strength to the metal, and be capable of sealing to the core, and to each other at the overlapped seam. The lead substrate must be free of pinholes and resistant to fatigue cracking from the load cycling of the cable core.

It has been found that metals other than lead, such as copper or aluminum foils, do not exhibit the same type of plastic behavior as does the lead laminate. During load cycling these metals may split and destroy the integrity of the moisture barrier. Thus, only the thin lead laminate with semiconducting film layers on both sides is used in the on-core design.

5.4 Optional seam adhesives

There are occasions when an additional adhesive may be necessary to enhance the bond strength and moisture barrier integrity of the overlap seam of the metal-plastic laminates. These occasions can be caused by improperly registered corrugations, as an example, or by soft or uneven underlaying cable surfaces, which prevent the proper heat sealing of the plastic coatings of the laminate. Hot-melt adhesives, extruded with proper application equipment into the overlap seam before it is closed, are recommended for this application. Their very fast set-up time and their excellent adhesion to the plastic film of the laminates, as well as to most metals and jacketing materials, contribute to their usefulness. Hot melts based on copolymers such as ethylene vinyl acetate (EVA) have been found adequate for medium-voltage cables. In the event of higher cable operating temperatures, polyamide-based hot melts are available that have softening points greater than 140 °C (284 °F).

5.5 Properties and testing of laminates

5.5.1 Film adhesion to metal substrates

The film adhesion between the plastic film and the metal substrate can be measured according to the ASTM B 736-92a and ASTM D 903-93 test procedures. The adhesion value should not show any substantial decrease when aged by temperature and heat cycling. Many factors affect the values obtained from the film adhesion test including the following:

a) Metal thickness
b) Film thickness
c) Test speed
d) Temperature

Such factors should be considered when evaluating different laminates.

5.5.2 Flexibility

The flexibility of the metal-plastic laminate plays a key role in the long-term life of the cable. If the laminate is required to expand and contract with the cable core, such as in the on-core designs, then it must possess excellent flexing and fatigue characteristics. These characteristics are not as important when under-jacket type designs are used since a mechanical stress-relief layer can be applied under the metal-plastic laminate.

5.5.3 Fatigue

It is essential that metal-plastic laminates for on-core constructions have the ability to resist fatigue from repetitive cycles of expansion and contraction. Laminates chosen for these types of designs are tested according to a procedure set forth in ASTM E 796-94.

5.5.4 Bond strength to jacket

For under-jacket metal-plastic laminates, a key performance criteria is jacket adhesion. This value can be measured with procedures patterned after ASTM D 4565-90a and ASTM D 1876-93. The metal-to-film bond as well as the film-to-jacket bond must be stable and show no significant loss after water and temperature aging.

5.5.5 Electrical properties of coatings

5.5.5.1 Insulating

Some metal-plastic laminates are coated with insulating plastic resins. These coatings do not conduct electricity and therefore cannot be used in applications where conductivity through the jacket or moisture barrier is required.

5.5.5.2 Conductive

For all on-core applications, the coating on the metal-plastic laminate must be conductive. Surface and volume resistivity are typically reported. These values are measured according to ASTM D 991-89. The electrical conduction properties must be maintained under all circumstances.

6. Cable performance criteria

6.1 General

Moisture-impervious cables are differentiated from other cable designs by their resistance to deterioration mechanisms associated with water. Metal-plastic laminates are used as radial moisture barriers on cables described in this guide.

Temperature ratings as described in AEIC CS 5-94 and AEIC CS 6-87 should be considered differently for cables with moisture barriers. In addition to maximum critical temperatures for operation in normal, emergency, and short-circuit modes, a cumulative number of temperature cycles should be considered at various temperatures to characterize the design in terms of fatiguing the laminate. Such temperature cycles can also show whether the design prevents accumulated set or deformation of the laminate due to thermal expansion and contraction of the core.

Other effects of the use of moisture barriers may include changes to chemical, fire, and/or corrosion resistance relative to more simple cable designs.

The following subclauses describe various qualification tests that can be used to determine the effectiveness and the operating parameters of moisture-impervious cable designs. Since cable core designs are similar in each case, AEIC CS 5-94 and AEIC CS 6-87 should be used, as appropriate, for qualification and production testing. The suggested changes to existing standards to accommodate the testing needs for moisture-impervious cable should not be interpreted as the initiation of such changes in those standards. Rather, the specifier and manufacturer of moisture-impervious cable should agree on such changes as supplemental to existing standards. The changes can then be incorporated into a supplemental customer specification as jointly determined.

6.2 Tests for the effects of moisture

Moisture can enter cables radially, during service, through the permeation process. Moisture can enter longitudinally at unsealed cable ends or at sheath defects. The continued presence of moisture at either the inner or outer surface of the insulation can initiate and propagate water treeing, which is a known mechanism of insulation degradation.

Moisture transmission into cables can be measured directly or indirectly. During testing, the cable's insulation and conductor are exposed to water, either in conduit or water tanks. Preconditioning of cables by thermal cycling and/or mechanical testing should be considered.

The direct method of determining moisture diffused into the insulation is by performing an analysis to measure insulation water content before and after exposure to the wet aging tests.

Indirect methods take into account the deterioration mechanisms of power cables associated with water in the presence of an electrical field. In some cases, energized cables subjected to water contaminated with various ions will lose dielectric strength as measured by an ac or impulse breakdown test, or experience a fault under the test conditions. Increasing voltage tends to accelerate deterioration in the presence of water and ions. Moisture-impervious cables, after such tests, demonstrate higher retained dielectric strength and increased life when compared to nonprotected designs using similar insulation materials.

6.2.1 Moisture content of insulation before and after aging

The presence of water in cable insulation can be analytically determined by several techniques including coulometric titration, Karl-Fisher titration, infrared spectroscopy, and differential scanning calorimetry. Caution should be exercised when interpreting results as they can be significantly affected by the following:

a) Water that is not homogeneously distributed in the cable insulation

b) Moisture measurement results, using commercial instruments, that may be erroneous due to the competing effects of various curing by-products

c) Sampling effects that can exceed the magnitude of the actual measurement

6.2.2 Comparison of dielectric strength before and after aging

The effectiveness of a moisture-impervious cable's moisture barriers can be determined by comparing the dielectric strength before and after aging a sample of the cable. An accelerated water treeing test as described in the qualification section of AEIC CS 5-94 and AEIC CS 6-87 can be performed with the results compared to ac and impulse breakdown tests performed on samples of new unaged cables and cables that have been dry aged. If truly moisture-impervious, cables with moisture barriers should experience little or no decline in properties when tested by these methods. The following modifications should be made to the accelerated water treeing test described in AEIC CS 5-94 and AEIC CS 6-87:

a) Because the preconditioning test is comparative, it is important to have identical cable core samples. In the cable sample without the moisture barrier, preconditioning may remove volatiles that provide some resistance to treeing. However, these volatiles would be unable to migrate past the metal laminate in a moisture-impervious design. If the samples are preconditioned, this effect should be given consideration.

b) An additional effect of preconditioning is the thermal/mechanical stress placed on the metal-plastic laminate. Care should be taken to factor out the effect preconditioning has on the integrity of the laminate.

c) Cable samples other than 15 kV, with 0.175 in (4.44 mm) insulation wall, may be tested since the test is comparative. It is recommended that the standard cable, as specified in AEIC CS 5-94 or AEIC CS 6-87, be used, if possible, since cross-comparisons can then be made.

d) The effect of moisture within the conductor strand has a detrimental effect on cable life. Testing a moisture-impervious cable in this manner may counteract any positive effect the moisture barrier had on cable life. It is recommended that the treeing test be conducted without water in the strand.

e) Removal of the jacket before testing may be detrimental to the thermal operation of the moisture barrier in a moisture-impervious design. It is recommended that the jackets not be removed when making these tests.

6.2.3 Cable life testing

A cable life test is similar to the test comparing dielectric strength before and after a period of aging. Rather than removing cables periodically and performing destructive tests, cables undergoing this type of test should remain energized until the test voltage produces failures. The considerations of 6.5 apply equally to this type of test. Typically, 5–20 samples of each design to be compared are used. Cables tested in this manner usually fail according to one of the extreme value distributions and are often plotted as Weibull or log-normal graphs. IEEE Std 930-1987 is useful in evaluating data from these tests.

6.3 Thermo-mechanical tests

Tests involving thermal cycling simulate the effect of load cycling on the metal-plastic laminate when used as a moisture barrier. The consequential effect on the physical and electrical integrity of the cable can then be determined. Consideration should be given to the fact that both ethylene propylene rubber (EPR) and XLPE insulation materials expand and contract during load cycling. However, XLPE requires special consideration due to its high coefficient of thermal expansion. In order to obtain a 130 °C (264 °F) emergency rating, a thermal expansion absorbing layer may be required.

As with other types of power cables, there should be stable and acceptable measurements of partial discharge, dissipation factor, and conductivity of the semiconducting components throughout the temperature operating range of the cable. In addition to these considerations, moisture barriers may be subject to fatigue cracking, bond separation, seam opening, and distortion or set in the metallic portion of the laminate. Tests and visual inspections to determine if any such deficiencies exist can be conducted without voltage applied to the cable sample during temperature load cycling.

6.3.1 Electrical properties during and after thermal cycling

The cyclic aging test described in AEIC CS 5-94 (or AEIC CS 6-87) is suitable for determining electrical property stability of cables with metal-plastic laminates, except that the jacket is not to be removed as required by this test procedure.

6.3.2 Determination of cable operating temperatures

The ability to withstand the temperature load cycles that a power cable endures is the most critical performance characteristic of a cable with a metal-plastic laminate used as a moisture barrier. The degree to which a laminate can be stressed during thermal cycling is dependent on the cable design. Such factors as the conductor size, the insulation and shield wall thickness, the provision of a thermal expansion absorbing layer, and the insulation and shield material types all have an impact. Users and manufacturers may wish to analyze proposed cable designs to determine the conditions under which the physical limitations of the laminate will be exceeded. While a laminate rupture may not result in a catastrophic cable fault, the effectiveness of the moisture barrier could be lost or at least reduced.

6.3.2.1 Thermal cycling to end of laminate life

This qualification test requires cable samples of sufficient length to allow thermal load cycling to the highest conductor temperature to which the cable may be subjected during operation. The test is continued (with or without voltage) until a laminate failure occurs. Dissection and visual examination should be performed at intervals or until sufficient cycles have been performed to satisfy the user that the design life has been obtained. This may require cycling under several time and temperature conditions. A curve showing the number of cycles to failure vs. cable temperature can then be established. Failure of the laminate is defined as splitting, seam opening, or bond rupture as determined by visual or microscopic examination.

A similar test should be applied to determine the short-circuit (current-time) performance of the metal laminate. If the cable construction does not allow the 250 °C (482 °F) rating, the cable may be derated to an appropriate temperature as determined by the user and the manufacturer.

6.4 Mechanical performance

Moisture-impervious cables, as with other cables, must withstand the mechanical stresses imposed during manufacture, shipping, and installation. The cable and moisture barrier must remain electrically and physically stable after being subjected to bending, twisting, and pulling through conduit systems. Visible mechanical damage is usually apparent before there is any compromise to electrical integrity.

The following three design or qualification tests are recommended for cable characterization:

a) Bend test
b) Twisting and bending test
c) Sidewall bearing pressure (SWBP) test

After each test, the cable should be dissected and visually examined for signs of cracking, wrinkling, or separation of the metallic laminate, or for damage to other portions of the cable.

6.4.1 Bend test

A bend test should consist of bending and reverse bending of the cable around a mandrel having a diameter some multiple of the cable outside diameter. Typically, 12 diameters are used with moisture barrier constructions in accordance with NEMA WC 7-1991 (ICEA S-66-524) or NEMA WC 8-1991 (ICEA S-68-516) recommendations for tape-shielded cable. A bending cycle consists of one bend and one reverse bend, 180 degrees around the mandrel, with the cable rotated 90 degrees before each cycle. After a specified number of cycles the moisture barrier should be examined for its integrity. ASTM D 4565-90a provides reference test procedures.

6.4.2 Twisting and bending test

During installation in conduit, cables are likely to twist as they are pulled. The cable size and design will play a role in the extent of twisting per unit length. When this consideration is important, a twisting test can be performed prior to the bend test. A given length of cable is merely twisted 90 degrees per desired unit length. It is unlikely that a cable will experience both twisting and reverse twisting. Therefore, twisting in only one direction is normal in this test.

6.4.3 Sidewall bearing pressure test

An SWBP test determines cable performance when a cable is pulled through duct bends and elbows. This information is used in determining maximum permissible pulling tensions during installation. EPRI Report RP 1519-01 [B91][10] and IEEE Std 525-1992 describe, in detail, test parameters and recommended maximum SWBP limits for various constructions. Refer to clause 7 and annex B of this guide for further information on methods for calculating pulling tensions and sidewall pressures. IEEE Std 422-1986, IEEE Std 576-1989, and IEEE Std 690-1984 also provide additional installation guidelines for specialized applications.

The test to determine maximum SWBP is performed by applying tension and back tension to the cable as it is pulled through an elbow. A pulling lubricant is applied to the cable prior to the test. The moisture barrier should be examined after pulling. Tests for adhesion can be used to establish the degree to which the integrity of the moisture barrier has been maintained. Since various moisture barrier cable designs may respond to this test differently, such qualification testing should be accomplished at several levels of SWBP. Limits of SWBP should be established by the cable manufacturer and the user. Maximum recommended limits for SWBP are generally at least 10% lower than the damage threshold level.

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[10] The numbers in brackets correspond to those in the bibliography in clause 8.

6.5 Testing for moisture transmission

6.5.1 Considerations

Certain additional qualification test considerations are necessary to fully characterize a moisture barrier cable. The user should first delineate cable with only a radial moisture barrier (water from the outside) from a moisture-impervious cable (water from outside and/or longitudinally through the conductor or other interfaces within the cable). It has been shown that water in the conductor can initiate the treeing phenomenon more quickly than water from the outside. Therefore, separate tests are required to properly distinguish between the effects of water in the conductor vs. water from the outside. Also, since under-jacket moisture barrier cables usually have a water-blocking layer under the moisture barrier to prevent longitudinal flow of water, additional consideration should be given to a test for this property. Jackets also affect results and their presence should be taken into consideration as a control. It follows that appropriate tests should be designed to provide an accurate comparison of the performance of these barriers in preventing moisture from reaching insulation surfaces within the cable.

6.5.2 Effect of water in the conductor

A cable with an outer moisture barrier will normally employ some means of retarding water ingress through the conductor. This may be accomplished through either

a) The use of a solid conductor where conductor size permits
b) In the case of stranded conductors, the use of a filled/blocked strand
c) The use of a metal-plastic laminate around the conductor

The literature reflects that water in the strands of test cables contributes substantially to insulation degradation. Thus, comparisons to cables tested with water in the strand should be avoided unless appropriate control samples are utilized to separate the effects of water in the conductor from the effects of water entering radially. Testing for water-blocking performance of the conductor involves placing a reservoir of water at the upper end of a vertical 3 ft (0.91 m) section of cable and applying pressure. Typically, the application of 3–15 psi (0.02–0.11 Pa) for 1 h has been used. ICEA T-31-610-1989 covers this test. Cable that does not have a filled and blocked strand must be manufactured in such a manner as to prevent water entrapment in the conductor.

6.5.3 Effect of jackets

An overall jacket is an integral component of any moisture-impervious cable design. A jacket is also the first line of defense against radial permeation of moisture and will usually contribute to the performance of a cable in wet environments. Different jacket materials will vary in their moisture vapor transmission rate. With PE, for example, the higher the density, the lower the transmission rate.

6.5.4 Preconditioning

Thermal and/or mechanical preconditioning of cables prior to a water treeing test can serve several purposes. In cables without moisture barriers, one intent of thermal treatment is to remove any volatiles that may, in the short term, provide some resistance to treeing during an accelerated test. In cables with moisture barriers, preconditioning may change the moisture resistance characteristics of the metal-plastic laminate. This could result in fatigue cracking of the laminate, opening of the overlap seam, and/or bond deterioration of the laminate to other cable components. The selection of a preconditioning treatment will vary with cable size, design, and intended use. Some suggested methods are included in the mechanical and electrical testing portions of this guide. See 6.4 and 6.6 for further information.

6.5.5 Longitudinal water transmission in sheath interfaces

Longitudinal water migration under the jacket of cables can have an adverse effect on the insulation, the insulation shield, the neutral wires because of corrosion, and the cable terminations and splices. Longitudinal water migration should therefore be minimized. This can be accomplished through the use of water-swellable powders and/or water-swellable tapes in the interface between the jacket and the shield. In the case of under-jacket moisture barriers, a water-blocking tape is usually placed under the moisture barrier and over the shield. Semiconductive water-blocking tapes are applied when an electrical contact is required between the insulation shield and the moisture barrier.

The two basic types of longitudinal water propagation testing are

- Testing the full cross-sectional area of the cable
- Testing the interface between the sheath/shield and the jacket (T-type)

Testing for longitudinal water blockage can follow either or both of the following:

- ICEA T-31-610-1989 (with modifications)
- Electricite de France (EDF) specification HN 33-S-23 [B87]

The ICEA T-31-610-1989 test subjects the entire cable cross-section area to water pressure and is suitable as a production test or a qualification test. The EDF HN 33-S-23 [B87] test subjects only the interface between the sheath/shield and the jacket. The EDF HN 33-S-23 [B87] test procedure is suitable for use as a qualification test only. It is recommended that either test procedure be used to qualify a new cable design and that the ICEA T-31-610-1989 test be required for production testing.

The ICEA T-31-610-1989 test should be performed as a qualification test (60 min) and as a production test (15 min) while the EDF HN 33-S-23 [B87] test covers a period of 104 h (the last 80 h in combination with 10 load cycles) and is performed as part of a qualification test only.

Suggested modifications to ICEA T-31-610-1989: This standard is intended to evaluate sealed conductors for longitudinal water penetration. As such, it is necessary that the testing procedure be modified before an evaluation of the sheath/shield to jacket interface can be made. The following changes should be considered:

- The preconditioning air oven temperature of cables with thermoplastic jackets should be lowered to 90 °C (194 °F). This should approximate the temperature of the jacket with a conductor temperature of 130 °C (264 °F).
- The test should be conducted with the jacket in place.
- The test pressure should be 5 psig (0.35 bar).

Suggested modifications to EDF HN 33-S-23 [B87]: The water penetration test is part of this EDF specification, which covers construction and testing of XLPE insulated cable of 12–20 kV. The following changes should be considered:

- During each heating cycle, the conductor should reach a temperature of 130 °C (264 °F).
- The water pressure should be 5 psig (0.35 bar).

6.5.6 Longitudinal water transmission from moisture barrier damage

The possibility exists that the moisture barrier could be damaged, thus allowing water to contact the insulation screen. It is possible for damage to be simulated by using a controlled experiment to examine water penetration due to moisture barrier faults. However, no industry standards or guides are known to exist at this time with regard to this defect type, size, or frequency.

6.6 Electrical

The cable core consisting of semiconducting shields and insulation should meet the electrical tests as required by AEIC CS 5-94 or AEIC CS 6-87. In conducting such tests, the test parameters for moisture barrier only vs. moisture-impervious cables should be determined. The standard test procedure requires water in the conductor. See 6.5.2 of this guide.

6.6.1 Accelerated water treeing test

The AEIC accelerated water treeing test may not be suitable for use on the water-impervious cable designs due to the moisture barrier over the cable core and the longitudinal blocking measures utilized in this type of construction. If there is doubt about the suitability of the cable core, then the outer moisture barrier, in the case of the under-jacket design, should be removed from the cable and the core should be subjected to the full AEIC CS 5-94 or AEIC CS 6-87 accelerated water treeing tests. In the case of on-core type water-impervious designs, the moisture barrier over the insulation shield should be removed in order to perform this test. This would interfere with the insulation shield. Thus, the test would not be feasible in this instance. One school of thought is to assume that the moisture-impervious designs are an effective means for preventing moisture intrusion to the insulation surfaces and therefore an accelerated water treeing test is meaningless.

Another school of thought holds that the standard water treeing test procedure could be performed on completed moisture-impervious cables as a means of evaluating performance of various designs. In this instance, cable samples should be subjected to thermo-mechanical test procedures in order to stress the moisture barriers prior to subjecting the cable to the accelerated water treeing test. Based on this hypothesis, the following modifications to test procedures specified in AEIC CS 5-94 or AEIC CS 6-87 are suggested.

6.6.1.1 Thermo-mechanical test prior to treeing test

a) Increase the number of test cycles from 14 to a minimum of 30.

b) As an option, it may be possible to decrease the cycle duration to 2 h on and 4 h off, or as appropriate for the size of the cable under test, as long as there is enough time for the cable to achieve steady-state conditions.

c) The metal-plastic laminate should experience at least 0.5 h at 90 °C (194 °F) during the on period and 0.5 h at 35 °C (158 °F) during the off period.

d) Tests for adhesion can be used to establish the integrity of the moisture barrier.

6.6.1.2 Accelerated water treeing test considerations

a) The considerations stated in 6.5 should be taken into account in applying this test to completed moisture-impervious cables.

b) The conductor size and insulation thickness of a complete cable shall be as required by AEIC CS 5-94 or AEIC CS 6-87 for the thermo-mechanical procedure.

c) The duration of the aging test should be sufficiently increased to allow sufficient progress in the growth of trees in a cable whose barrier may have been damaged during the mechanical and or thermo-mechanical tests.

d) Attempts should be made to run at least one set of samples until failure to establish aging data.

e) Tests for adhesion can be used to establish the integrity of the moisture barriers.

6.7 Special environmental considerations

Moisture-impervious power cables may be exposed to unusual environmental conditions that require special material or design considerations. The following comments should be considered in such instances. These conditions may include chemical and corrosive environments or exposure to fire.

6.7.1 Chemical resistance

The chemical resistance of any cable is a function of many parameters. The first line of defense against chemical attack is the overall outer jacket. The selection of a jacketing compound should be made to suit the chemical environment in which the cable will be required to operate. In special cases an additional chemical barrier or sheath may be required. Refer to annex A for further discussion of jacketing materials.

6.7.2 Corrosion protection

Metal-plastic laminates, when used as moisture barriers on the cables described in this guide, are not necessarily intended to provide corrosion protection. Generally, metal-plastic laminates are very stable against groundwater and chemicals that may exist around buried cable installations. In the under-jacket design, the laminate also serves to protect underlying neutral wires. A combination of special jacket material and metal-plastic moisture barriers may be necessary to control corrosion in certain environments. References to applicable technical papers on this subject are listed in the bibliography (see 8.1).

6.7.3 Fire propagation and emissions

Fire propagation and gaseous emissions are a concern where cables are installed indoors. The user may wish to specify limits on propagation and emission properties.

6.7.3.1 Fire propagation testing

The degree of fire retarding properties required should be determined by the user. The test method most often specified is the IEEE Std 383-1974 vertical tray flame test. A more recently developed test for fire propagation may be found in IEEE Std 1202-1991.

6.7.3.2 Gaseous emission testing

Gaseous emissions that occur during burning are a function of the cable insulation, shielding, and jacketing materials. The amount and types of these emissions can be controlled by compound formulation. Various test methods are under development.

7. Cable installation

7.1 General criteria

Most moisture-impervious cable designs incorporate solid-dielectric cores and metal-plastic laminates as moisture barriers. In general, handling and installation procedures for such cables will not change from those used on non-moisture-impervious cables. Likewise, most standard premolded and shrinkable accessories are readily adaptable.

7.1.1 Minimum bending radius

The mechanical reinforcement provided by the bonded sheath greatly enhances the bend performance of under-jacket moisture barrier cables. The minimum recommended bending radius for cables with moisture barriers is 12 times cable diameter.

7.1.2 Attachment of pulling devices

Compression-type pulling eyes are often employed with aluminum and copper conductor cables in both the under-jacket and on-core designs. Some reports indicate that compression pulling eyes on aluminum conductors may fail before maximum allowable pulling tensions are reached. Epoxy-filled pulling eyes can overcome this limitation. Other pulling eyes can be installed over the jacket and compressed in concentric bands to maximize pulling strength.

Basket-weave pulling grips may also be used in some instances but can result in jacket or sheath damage since the pulling tension is usually applied to the outer surface of the jacket. Under-jacket moisture barriers can be stretched with this type of pulling device, especially if there is a loose fit over the cable core. Because moisture barriers for on-core constructions are placed on the insulation shield, any pulling device that is typically employed with standard jacketed cable can be used without concern for the moisture barrier.

7.1.3 End seals

The use of end seals is normally considered mandatory for any medium-voltage cable during storage and pulling, and while awaiting accessory installation. However, with moisture-impervious cable, utilizing solid or strand-blocked conductor, the inherent longitudinal blockage of moisture diminishes the need for end caps. Nevertheless, the use of end caps during storage and installation is recommended for any medium-voltage cable. Procedures relative to the use of end caps should be determined by the cable manufacturer and the cable user.

7.1.4 Pulling tension

Maximum allowable pulling tension should be commensurate with the cable diameter and sheath design. Annex B outlines procedures for calculating pulling tension.

7.1.5 Maximum allowable SWBP

SWBP is the radial force exerted on the insulation and sheath of a cable at a bend point when the cable is under tension. The SWBP acting upon a cable at any bend may be calculated from the procedures outlined in annex B.

7.1.6 Other considerations

7.1.6.1 Temperature

The minimum temperature at which cable can be pulled will depend on the type of insulation and the jacket or sheath. If installation is made at temperatures below 5 °C (40 °F), then care should be taken to prevent fracture upon impact, sharp bending, or kinking. Refer to annex A for further information.

7.1.6.2 Lubrication

Lubricants should be compatible with cable jackets, insulations, and the environment. They should not set-up or harden during the installation period. The coefficient of friction can vary from 0.15 (for well lubricated cables pulled into new smooth wall conduits) to 0.85 (for lubricated cables pulled into rough or dirty conduit or ducts). Typical values are 0.3–0.5.

7.1.6.3 Protection of cable

Before pulling cables, the raceways, conduit, or ducts should be thoroughly inspected and cleaned. Pulling a mandrel through the raceways is recommended. Any abrasions or sharp edges that might cause damage to cable sheaths or jackets during the pulling operations should be removed. Once cable pulling operations have started, a determination should be made as to which cable pulls are susceptible to damage, and adequate precautions should be taken to protect the cables. After cable installation has started, cable raceways should be periodically cleaned as necessary to prevent the accumulation of debris. Cables being installed in cable trays, conduit, ducts, or trenches should not be pulled around corners or obstructions without the use of cable sheaves of the proper radius.

7.2 Terminating and jointing

A joint or termination for a cable with an integral moisture barrier must provide adequate provision for grounding the moisture barrier and provide continuity of the moisture barrier over the joint. The technique to accomplish this will vary, depending on the cable design. With some designs, the under-jacket moisture barrier may also function as the system neutral or the metallic shield. In such instances, grounds are connected at terminations in a conventional manner. For other designs, such as those utilizing the on-core moisture barrier, the metal-plastic laminate functions as an integral part of the insulation shield. Those designs accommodate grounding and sealing of the moisture barrier into their design characteristics.

7.2.1 Terminations

In order to terminate cables with moisture barriers, the outer jacket and other cable components must be removed to expose the insulation shield and insulation of the cable. Standard techniques may then be used to provide a nontracking outdoor insulation over the external creepage distance. As with any cable construction, the termination should be designed and installed so as to reduce and/or eliminate air spaces or voids within the termination. Low-moisture vapor transmission rate materials should be used where possible. Environmental conditions of the cable installation should be considered when selecting appropriate termination practices.

With under-jacket designs it may be necessary to electrically ground the barrier layer (see 7.3). The termination should accommodate this requirement. The termination should provide an outer insulation surface that is fully sealed to the conductor terminal lug and to the cable jacket, thereby meeting the requirements of a Class I termination according to IEEE Std 48-1990.

Termination designs should incorporate positive sealant components using nontracking adhesives and sealants plus moisture-blocked or solid-ground leads.

7.2.2 Joints

Joints for moisture-impervious cable should meet the performance requirements of IEEE Std 404-1993. The joint should accommodate the various constructions of moisture-impervious cable that manufacturers may provide.

With under-jacket designs, provision must always be made to ground the moisture barrier layer. The sealant system must accommodate conditions where neutral wires or tape-shield layers have formed indentations in an extruded insulation shield layer.

The moisture-barrier layer may be reconstructed across the joint using any technique that provides a moisture/vapor-proof barrier. Heat shrinkable or cold shrink components with an integral metal foil, aluminum foil and polymer laminated components, or devices combining the moisture/vapor barrier and the outer jacket may be used. In all cases, it is desirable to construct the joint so as to reduce abrupt changes in geometry, minimize internal air spaces or voids, and use a low-moisture/vapor transmission rate material where possible. These procedures should help eliminate the ingress and migration of moisture, both longitudinally and radially.

The joint should be provided with a one-piece outer jacket component that is positively sealed onto the cable jacket. A heat or cold shrinkable sleeve uniformly precoated with an adhesive or mastic is recommended.

In addition to certified test evidence that the joint designs meet the requirements of IEEE Std 404-1993, manufacturers should provide test data demonstrating the efficacy of their moisture barrier joint.

7.3 Grounding

With on-core construction, neutral wires are grounded in the same manner as for conventional jacketed neutral cable. Since the moisture barrier in this construction is an integral part of the insulation shield, separate grounding of the moisture barrier is not required.

With under-jacket construction, there are additional considerations with respect to grounding the moisture barrier. If a copper metallic tape coated on only one side is used as both shield and barrier, then the moisture barrier may be terminated by soldering or clamping techniques similar to those used with spirally wrapped or longitudinally folded copper tapes. If neutrals are under the barrier, then barrier-to-neutral contact through the semiconducting cushion tape may preclude grounding of the barrier when the neutrals are grounded by standard procedures. Use of a semiconducting coating on the side of the moisture barrier facing the insulation screen/neutrals may also preclude grounding of the screen. If an insulating coating is used on the side of the barrier tape facing the core, the tape can then be terminated using standard connectors developed for such tapes. These connectors utilize teeth that penetrate the coating to form metal-to-metal contact. An appropriately sized grounding wire and a sufficient number of connectors must be utilized to provide the ground connection with sufficient current-carrying capacity. If the jacket can be stripped from the moisture barrier (this is normally difficult), standard termination kits may be used.

8. Bibliography

8.1 Technical papers

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Annex A

(informative)

Overview of commonly used outer jackets for use on moisture-impervious cable

A.1 Introduction

The selection of a suitable jacketing material for moisture-impervious cable is dependent upon several factors. Each type of jacketing material has its advantages and disadvantages, as will be pointed out in the discussion that follows. In most instances, environmental and mechanical considerations will have the most influence on the selection. However, caution should also be exercised in selecting a compound that, with proper extrusion conditions, will pass the thermo-mechanical test as specified in AEIC CS 5-94 or AEIC CS 6-87.

A.2 Polyvinyl chloride (PVC)

Two important properties of PVC are its good resistance to oil and ignition. However, the decomposition of PVC under heat or burning leads to the emission of chlorine and hydrochloric acid. These general-purpose compounds have excellent resistance to weather 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 properties (flexibility) of PVC jackets should be treated with some caution.

A.3 Polyethylene (PE)

The PE jacketing materials used for moisture barrier power cable applications can have a broad range of molecular weights, and are compounded with the addition of stabilizers, carbon black, or coloring matter. PEs are specified by the range of densities within which they fall (see ASTM D 1248-84). As density increases, thermal deformation resistance increases. Melt temperature, abrasion resistance, and cut-through resistance all improve with density. Tensile yield increases with density so cable stiffness also will increase with density. This may be objectionable in some installations. Stress crack resistance is excellent for these properly formulated jacketing compounds. PEs have excellent chemical resistance to acids and bases, less to oils, and are not recommended for contact with hydrocarbons that may swell the polymer. PEs have excellent low-temperature properties.

A.4 Chlorinated polyethylene (CPE)

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 also excellent. Both thermoplastic and thermoset CPE compounds are available. The thermoset compounds can be formulated to meet medium-duty, heavy-duty or extra-heavy-duty requirements. However, the thermoplastic compounds are most often used for medium-voltage power cable. CPE has intermediate low-temperature flexibility and some caution should be used in low-temperature applications.

A.5 Zero-halogen thermoplastic

Copolymers of PE and vinyl acetate, ethyl acrylate, and/or acrylic acid have found applications in jacket formulations where oil or other chemical resistance, moisture resistance, and toughness are requirements. While PE has no inherent flame resistance, these polymers can be compounded with nonhalogen flame-retardant additives to meet a broad range of flame resistance requirements. These materials have been used in cable applications requiring reduced combustion emissions.

A.6 Semiconducting jackets

Semiconducting compounds are used as the protective jacket and bedding for the concentric wires. The compound may be of the following types:

a) *Thermoplastic copolymers of PE.* These materials are not as tough and deformation resistant at elevated temperatures as conventional PE jackets.

b) *Deformation resistant thermoplastic (DRT) compounds.* DRT compounds, such as those utilizing CPE, have chemical resistance and low-temperature properties similar to the base resins chosen to formulate the compounds.

c) *Thermoplastic PE.* A new class of semiconducting thermoplastic compounds, based on PE, has been developed specifically for use as a jacketing material. This material is characterized by improved low-temperature properties along with deformation resistance equal to insulating jackets. Mechanical properties, such as toughness and abrasion resistance, are reported to be similar to those of a PE insulating jacket.

Annex B

(informative)

Calculation of pulling tensions and sidewall bearing pressures

B.1 Calculation of pulling tensions (per IEEE Std 525-1992 and [B91])

Instead of attempting to directly calculate the maximum length of cable that can be pulled through a duct or conduit, it is usually easier to select a length and find the tension that will be developed. For a straight run of cable, the tension is given by equation (B.1).

$$T = Lwfc \tag{B.1}$$

where

T is pulling tension (lb)
L is length of straight run of cable (ft)
w is weight of cable (lb/ft)
f is coefficient of friction between cable(s) and duct or conduit surface
c is weight correction factor

The coefficient of friction, f, has been found to vary between 0.35 and 0.5 depending on the cable, jacket, lubrication, and the duct or conduit material.

For a run with bends, the tension is obtained by a cumulative process using equation (B.2).

$$T_0 = T_1 e^{(fca)} \tag{B.2}$$

where

T_0 is tension out of bend, in lb
T_1 is tension accumulated into start of bend (accumulated from the feeding end) (lb)
e is base of natural or Naperian logarithms
a is bend angle (rad)
45° = 0.79
90° = 1.57

Three single cables in cradled configuration are given by equation (B.3).

$$c = 1 + \frac{4}{3}\left[\frac{d}{D - d}\right]^2 \tag{B.3}$$

where

c is weight correction factor

Three single cables in triangular configuration are given by equation (B.4).

$$c = \frac{1}{\sqrt{1 - \left[\frac{d}{D - d}\right]^2}} \tag{B.4}$$

Four single cables in diamond configuration are given by equation (B.5).

$$c = 1 + 2\left[\frac{d}{D - d}\right]^2 \tag{B.5}$$

where

d is outside diameter of a single cable
D is conduit inside diameter

B.2 Calculation of SWBP (per IEEE Std 525-1992)

SWBP is equal to:

$$P = \sqrt{(T/R)^2 + w^2} \tag{B.6}$$

If there is one cable per duct or conduit, and T is 10 times, or higher, than the value of w, then the following formula should be used:

$$P = \frac{T_0}{R} \tag{B.7}$$

where

P is SWBP (lb/ft)
T_0 is pulling tension out of bend (lb)
R is inside radius of bend (ft)

For three cables in cradle configuration where the center cable presses hardest against the conduit:

$$P = \frac{(3C - 2)T_0}{3R} \tag{B.8}$$

For three cables in triangular configuration where the pressure is divided between the two bottom cables:

$$P = \frac{CT_0}{2R} \tag{B.9}$$

For cables in diamond configuration where the bottom cable is subjected to the greatest crushing force:

$$P = \frac{(C - 1)T_0}{2R} \tag{B.10}$$

The maximum allowable SWBP that may be exerted on the insulation or sheath varies with the cable design and material. The cable manufacturer should be consulted for the permissible SWBP and pulling tension for a particular design.

Normally, the maximum SWBP will occur at the last bend of the duct system (i.e., the bend nearest the pulling end). This may not be true if there is a bend of relatively short radius elsewhere in the system.

SWBP in bends should also be taken into consideration in the design of the conduit or duct system. The radius of bends must be such that the maximum allowable SWBP is not exceeded during cable pulling. The maximum allowable SWBP for any cable is also directly related to the maximum tensile force.

IEEE Std 576-1989 contains considerable information on cable installation that is useful for both industrial and utility installations.