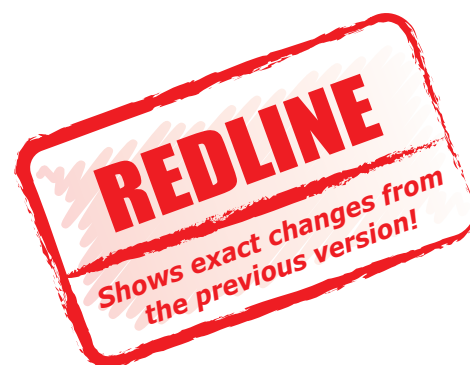




IEEE Guide for the Selection, Testing, Application, and Installation of Cables having Radial-Moisture Barriers and/or Longitudinal Water Blocking

IEEE Power & Energy Society

Sponsored by the
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IEEE Power & Energy Society

Approved 9 December 2009

IEEE-SA Standards Board

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Abstract: Detailed information relating to the design, testing, application and installation of various types of electrical cables in order to prevent the deleterious effect of moisture and chemical ingress and resultant failures in service is provided in this guide. This includes single and multi-conductor cables over a complete range of voltage ratings. Testing criteria and installation methods covered along with many technical references.

Keywords: laminate sheaths, longitudinal water blocking, moisture impervious, powders, radial-moisture barriers, sealed overlap, water-swellable tapes, yarns

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Introduction

This introduction is not part of IEEE Std 1142-2009, IEEE Guide for the Selection, Testing, Application, and Installation of Cables having Radial-Moisture Barriers and/or Longitudinal Water Blocking.

This guide is an update of previously published IEEE Guide 1142-1995. When that guide was circulated for a renewal ballot it was found that many revisions were needed to reflect changes in technology and to incorporate additional types of cables along with other means of preventing moisture/chemical ingress into cable cores. The objective still remains to supply complete information for utility and industrial cable users on ways and means to protect cables from the deleterious effects of moisture and chemical ingress to cable insulation as well as protection from unfavorable environmental and installation conditions. Much information has been derived from reported global experience as well as the many technical papers that have been presented in recent years on these topics. The bibliography has been updated to cover many new informative references.

This guide will be most useful to those users who wish to maximize cable life and minimize cable faults that cause interruptions in critical circuits.

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IEEE Guide for the ~~Design~~ Selection, Testing, Application, and Installation of ~~Impervious, Solid Dielectric, 5–35 kV Power~~ ~~Cable Using Metal–Plastic Laminates~~ Cables having Radial-Moisture Barriers and/or Longitudinal Water Blocking

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1. Overview

1.1 Scope

This guide ~~will provide the user of underground cables~~ provides cable manufacturers and users with extensive information on the design, testing, ~~and application of moisture impervious~~ and installation of low, medium-voltage, solid dielectric power cable using and high-voltage power cables, as well as communication, control and instrument cables that make use of metal-plastic laminates as radial-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.~~ This guide addresses additional means of protecting cables from the entrance of moisture through the use of polymeric super absorbent materials for longitudinal water blocking of stranded conductors and other spaces within cables. 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 alternate use of~~ extruded metal sheaths or bare, longitudinally applied, 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~~ will likewise be addressed.

1.2 Purpose Concepts

While metallic sheaths, such as lead and aluminum, have been effective in past years as barriers to moisture, their relative cost, environmental concerns along with installation difficulties ~~has tended to diminish their usage. Recently have led to the search for alternatives. 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.~~ Alternatively, thin metal-plastic ~~laminates have found~~ foils are finding application as moisture barriers in low, medium, high, and extra-high voltage power cables. Aluminum, copper, or lead substrates are coated with polymeric ~~compounds adhesively laminated~~ coatings on one or both sides and adhesively bonded to the cable jacket or over sheath. The tapes are usually applied longitudinally, with an overlap, or seam, ~~either directly that is adhesively sealed~~ over the core of the cable and 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 coated metals~~ 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 having radial-~~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~~ /or longitudinal water-blocking systems.

There is an extensive amount of information in this guide that refers to IEC Standards, British Standards and CIGRE study group recommendations. These organizations, and others, have developed recommendations, standards and specifications that are pertinent to cables with radial-moisture barriers and longitudinal water blocking. Inclusion of a discussion of these documents presents the user of the guide with a more complete picture of the degree to which cables with radial and longitudinal moisture protection have developed. The technology has matured greatly since this guide was first published and inclusion of all pertinent information not only serves to better inform the user of the guide but also documents how extensive and prevalent the technology has become globally.

1.3 Development history

Thin plastic-coated metals were first developed for use as radial-moisture barriers for telephone cable in the early 1960's. They have been successfully utilized, up to the present time in this application. These coated metals have also been used for moisture barriers and shielding as well as armoring in many other types of cables, such as control, coaxial, instrumentation, fiber optic, undersea, etc. Such coated metals have also found application as moisture barriers for low, medium, and high-voltage power cable, where design parameters have been more restrictive. These design parameters may require special considerations. The considerations and their implementation will be covered in this guide.

Longitudinal water-blocking of power cables have a long history starting first with the use of non-polymeric absorbers and filling compounds. More recently, cable producers have used polymeric water absorbers in the form of yarns, tapes, fillers and powders for longitudinal water blocking within the conductors. This method is also employed around the concentric neutrals, under the metallic shield, screens, and within the interstitial areas between conductors of multi-core cables as well as around the layers of steel wire armoring and other places within a cable.

1.4 Utilization and trends

Many moisture-impervious power cable designs making use of radial and longitudinal-moisture barriers have been commercialized. There is an upward trend in their acceptance on a worldwide basis. Various country and international standards have been initiated or issued covering bonded sheaths and/or longitudinally water-blocked power cables. The bibliography 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. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies. ~~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~~

ASTM B 736-002006, Standard Specification for ~~AEIC CS 5-94, Specifications Cross-Linked Polyethylene Insulated Shielded Power Cables Rated 5 Through 46 kV, 10th ed.¹AEIC 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.

~~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.~~

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~~

ICEA T-31-610-2007, Guide for Conducting a Longitudinal Water Penetration Resistance Test on Blocked Conductor.

ICEA T-34-664-2007, Test Method for Conducting Longitudinal Water Penetration Resistance Tests on Longitudinal Water Blocked Cables.

IEEE Std 532™-2007, Guide for Selecting and Testing Jackets for Power, Instrumentation and Control Cable.^{1,2}

~~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.~~

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

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

⁵IEEE 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.

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

⁷IEEE 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.

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

3. Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary: Glossary of Terms & Definitions should be referenced for terms not defined in this clause.³

blocked conductor: A stranded conductor whose interstices are filled with water-swellaable yarns, powders, combinations of tapes over the conductor or a gel compound that prevents the migration of moisture longitudinally through such interstices. Water-blocking tapes and yarns are most commonly used in compact stranding and segmented conductors. Blocking can also be achieved by the use of a rubber-like extrudable or pumpable material within the strands. *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~~

bonded sheath: A sheath design in which a plastic-coated metallic tape, either pre or post-coated, is longitudinally or helically wrapped over the core of a cable with an overlap or seam and the coating on the tape is bonded to the cable jacket during the jacket extrusion process. This coated metallic component may be smooth or corrugated. Alternatively an adhesive coating or jacket may be used over a bare metallic substrate to form a bonded sheath.

~~**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~~

cable core: The portion of a cable inside the sheath and for medium and high-voltage cable includes the conductor, the conductor shield, the insulation, and the extruded insulation shield.

filling compound: A highly viscous material that is injected into conductors, typically under pressure and high temperature.

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

laminate sheath: a sheath consisting of various layers such as shield and jacket lying one over another. These layers may not, per the definition of “laminate,” have to be bonded together. If the layers are adhered to each other, then the sheath can be called a bonded or laminated sheath. ~~**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~~

longitudinal water blocking: Term used to describe a cable design that prevents the longitudinal flow of water, moisture or contaminants along the cable core. The term can refer to the materials that provide a method for blocking the longitudinal ingress of water, moisture or contaminants along the cable core, concentric neutral, metallic shield, screen, armoring or other cable interstices, during cable manufacturing as well as, during cable transport, storage, installation, splicing, termination or from a defect or sheath damage after installation.

~~**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.~~

¹ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

² The IEEE standards or products referred to in this clause are trademarks of the Institute of electrical and Electronics Engineers, Inc.

³ The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.

metal-laminate covering: Per the CIGRE WG B1-25 [B86] definition, a metal laminate covering consisting of several layers of plain or smooth (not corrugated) metal and plastic layers bonded together to get a special set of properties: bending ability, radial water tightness. For the purpose of this document, the terminology “bonded sheath” is used.

moisture-impervious cables: These are cable designs that prevent both the radial and longitudinal entrance of moisture into the cable core.

non-woven water-blocking tapes: Cable tapes consisting of one or more non-woven webs plus other materials needed to maintain mechanical integrity. Super absorbing powders are locked into the non-woven tapes to provide water blocking capabilities to the tape. Depending on the location of such tapes within a cable, they may also provide cushioning to absorb expansion of the cable core. They may provide a way of binding the cable elements. They may be non-conducting or semi-conducting. Also, the tape may be called a water-swellable tape.

plastic-coated metallic tape: A plastic-coated metal or coated metal in tape form for use on cable manufacturing lines that is made of aluminum, copper, lead, or other metal substrate coated on one or both sides with a tightly adhering polymeric coating. The coating used may consist of either an adhesive polyolefin copolymer that self-bonds to the metal substrate during the laminating or extrusion coating process or another polymeric compound that is adhered through the use of a supplemental adhesive. Solvent-based polymeric coatings may also be used.

radial-moisture barriers: Cable designs that incorporate a metal layer as a component of the sheath that effectively blocks the transmission of moisture from a radial direction.

strand-blocking: A means for filling the strand interstices with a material that will block the movement of moisture or contaminants through stranded conductors. Strand blocking can take the form of a filling compound that occupies the entire space between the stranded wires or be in the form of a swellable water-blocking material that occupies a fraction of the space between the stranded wires but which expands rapidly in volume upon contact with water to actively seek out and overfill cable free space to block the flow of water.

swellable water-blocking material: A water-blocking tape, water-blocking yarn or water-blocking filler that incorporates a super absorbent powder, fiber and/or UV cured coating that will swell upon contact with moisture. A jelly-like material is formed to block the longitudinal ingress and movement of moisture.

under-jacket type: A moisture barrier applied under the jacket and over the metallic shield or concentric neutral of a medium or high-voltage power cable or a combination moisture barrier and shield as used over the core in low-voltage instrument or control cable and in medium, high, or extra-high voltage power cable.

water-blocking yarns: A spun yarn formed with a combination of polymeric fibers, super absorbent fibers and longitudinal or helical filament reinforcement.

woven water-blocking tapes: A woven synthetic web with a coating of swellable powder on one side. Woven water-blocking tapes are commonly used as a peripheral wrap over the conductor and therefore must also function as a barrier against penetration of the extruded conductor screen into the free space between the stranded conductor wires.

4. Description of cable designs utilizing radial-moisture barriers and longitudinal water blocking

4.1 Description of cables with radial- ~~jacket~~ moisture barriers

There are two major types of metallic moisture barriers for providing radial-moisture protection to low, medium, high, and extra-high voltage cables. One major type uses a longitudinally applied, relatively thin “foil”, or sheet, type of metallic tape, bare or plastic-coated, folded over the cable core with a single overlap or seam. The longitudinally formed ~~metallie-~~ tape has the overlap sealed with a plastic adhesive in the overlap. Sealing the overlap with a ~~sealed-overlap plastic layer~~ is proven technology as a moisture barrier for all voltage classes of power cable as demonstrated by the many references ~~to this construction~~ listed in the bibliography (see Clause 8).

The second type of metallic moisture barrier uses a relatively thick tube of lead, aluminum, copper or bronze over the core of the cable to provide a radial-moisture barrier.

4.1.1 Longitudinally-applied metallic tape as a radial-moisture barrier

The longitudinally-applied metallic tape type of bonded-sheath design incorporates a metallic tape as a moisture barrier directly under the jacket of cable intended for various applications where protection from radial-moisture entry is needed. The metallic moisture barrier can be a thin foil or sheet type of metallic substrate that is coated on one or both sides with adhesive coatings (plastic-coated metal) or uncoated (bare). A plastic-coated tape may not be necessary if the cable jacket has adhesive characteristics and can bond directly to the bare metallic substrate or tape wrapped over the cable core. Both plastic-coated and bare metallic tapes are wrapped longitudinally over the cable core with a single overlap or seam. In the case of the plastic-coated metal tape the outer coating on the tape is bonded to the cable jacket by the heat transferred during the extrusion of the jacket. Because of the bond of the tape to the jacket, the plastic-coated metal can be applied smooth, that is, without corrugations. However if desired the metal-plastic tape can be corrugated in line to provide the cable with a bonded sheath with increased flexibility. In the case when the tape is the plastic-coated metal, the extrusion process can also provide heat to form a seal of the coating or coatings in the overlap. In the case of the uncoated (bare) tape, where bonding to the jacket is not desired, the tape cannot be longitudinally applied in a smooth configuration and is therefore corrugated in line by means of a corrugating machine. The corrugations provide the finished cable with flexibility. In the case where an adhesive jacket is used, the bare tape may be applied smooth. The overlap of the bare tape is sealed with a hot melt adhesive that, when applied into the overlap, completes the radial-moisture barrier. The overlap of a cable using the bonded sheath design with plastic-coated metal is also frequently sealed using a hot melt adhesive. Overlap sealing methods are covered in 5.3.

To obtain the principal advantage of the longitudinally-applied tape as a moisture barrier, a key design consideration should be given to the thickness of the metallic layer. The metallic tape, either plastic coated or bare should be thick enough so that there are no pinholes present. It should be mechanically strong to withstand cable manufacture, installation and use without rupture or tearing. Such damage could mean that the primary moisture barrier has been violated. With optimal combinations of jacket thickness, plastic-coated metals have typical metal thicknesses in the range of 0.1 mm (0.004 inches or 4 mils) to 0.38 mm (0.015 inches or 15 mils). For designs using corrugated bare metals, the metal thicknesses are in the range of 0.15 mm (0.006 inches or 6 mils) to 0.3 mm (0.012 inches or 12 mils). A thicker minimum tape thickness is generally used with the bare tape option because, versus the bonded sheath, the supplemental effect of the bond to the jacket is absent for providing mechanical strength to the sheath. So a thicker metallic tape is used to increase the strength of the sheath. In the bonded sheath design, the adhesion between the plastic-coated metal and the jacket combines the flexibility of the plastic jacket with the strength of the metallic component of the tape. The mechanical properties of the bonded sheath cable are improved versus those of a cable without adhesive bonding, that is, un-bonded. The bond in the bonded sheath design provides for increased bend radius and greater hoop strength which could facilitate the installation process for the cable. However, for the cable without a bond to the jacket, the termination and splicing process for the metallic tape can be approached in a conventional manner using clamps or soldering without the need for special grounding devices. The grounding process for cable with a bonded sheath is covered in 13.3.

Either bare or plastic-coated metal tape is generally corrugated perpendicular to the axis of the cable (i.e., laterally or axially), to provide the cable increased flexibility. The profile of the corrugations is sinusoidal and the number of corrugations per unit length can vary according to cable diameter. The depth of the corrugations is typically a minimum of 0.8 mm (0.032 inch or 32 mils).

In the case of the bonded sheath, the bond between the jacket and tape provided by the coating on the plastic-coated metal provides a longitudinal water block in the jacket-tape interface and the sealed coating(s) in the overlap and/or a hot melt adhesive provides a radial and longitudinal water block at the overlap. When the bare corrugated tape is used, there is no bond to the jacket so water can flow in the jacket moisture barrier interface. Likewise, with the bare tape, as with the plastic-coated metal tape, the sealed overlap provides a longitudinal and radial-moisture barrier. To deal with the potential presence of water along the overlap of the bare metal option, a water-swellaable tape can be placed over the overlapped seam. If (when) water gets under the jacket, it can encounter the water-swellaable tape which may impede the water from penetrating around or into the hot melt adhesive in the overlap of the bare tape. There could, however, be an increased propensity for corrosion of the bare metallic tape with the potential for voiding in the tape-jacket interfaces.

In rare instances, the plastic-coated metal may be wrapped helically around the cable core and bonded to the cable jacket. The subsequent bonded sheath can provide a radial-moisture barrier through the sealing of the helical overlap along the length of the cable. However, the mechanical properties of the cable may suffer due to a lack of flexibility when compared to cables with longitudinally applied plastic-coated tapes bonded to the cable jacket.

4.1.2 Metallic sheath as a radial-moisture barrier

Metallic moisture barriers use a relatively thick tube of lead, aluminum, copper or bronze. The lead or aluminum can be applied over the cable core by an extrusion process. Alternatively, a tape of aluminum, copper or bronze can be applied longitudinally over the cable core with the edges of the tape butting together. This “seam” is then welded together to form a tube enclosing the cable core. Corrugations can be applied to the tube after welding to give the metallic moisture barrier added flexibility. A jacket may be applied over the tube for additional protection from moisture and mechanical abuse.

~~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~~

~~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 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.~~

4.2 Description of power cables with longitudinal water blocking

Longitudinal water blocking of power cables can take one or more of the following forms:

- Longitudinal water blocking of the conductor
- Longitudinal water blocking of the metallic shield/concentric neutral/screen
- Longitudinal water blocking of the interstitial spaces between conductors in multi-core low-voltage and medium-voltage cables
- Longitudinal water blocking of steel tape or steel wire armoring
- Longitudinal water blocking of the interface between the metallic component of the bonded sheath and the cable core

4.2.1 Longitudinal water blocking of stranded conductors

The presence of water in a stranded conductor could lead to water treeing and subsequent insulation failures. Many cable users call for blocked strands to prevent water from flowing through the conductor. In some cases, water blocking materials in the form of swellable tapes, yarns or powders, or a combination of these materials, are used to provide longitudinal water blocking of the conductor. In some cases, semi-conducting filling compounds are injected into the free space or extruded between the layers of the conductor.

When swellable water-blocking material is used, a common practice is to evaluate the ratio between the free space in the cable and the amount of water blocking gel produced by the swellable-water blocking material upon contact with water. As the gel forms, it actively seeks out and fills the free space inside the cable. The free space should be properly overfilled to provide acceptable water blocking of the conductor strands. Careful consideration should be given to the aging performance of the water blocking material with the potential for decades of exposure at the rated operating temperature of the power conductor, typically 90° C. Uniform distribution of the swellable-water blocking materials inside the strands of the conductor is a requirement for consistent water blocking. The effect of ions in groundwater should also be considered in that these ions could reduce the swelling capabilities of water-swellable materials.

For conductors blocked with filling compounds, care should be taken to fill all cable spaces during cable manufacturing because any unfilled areas may result in a path for longitudinal water flow.

4.2.2 Longitudinal water blocking of metallic screen/concentric neutral wires

It is common practice with MV and HV underground cables to water block the copper wires, straps, metallic screens, and/or concentric neutrals to prevent longitudinal water paths within and along these shields or strands in the event of sheath damage or joint failure. One method is to use a semi-conducting water blocking tape below the copper wires and a non-conductive water blocking tape above the copper wires and under the jacket. Another method is to use two semi-conducting tapes, one over and one under the wires or straps.

4.2.3 Longitudinal water blocking of space between core elements in multi-core cables

In multi-core LV and MV power cables the free space between the insulated conductors or wires (such as a neutral wire) is a large volume channel for longitudinal water flow. Where needed, it is possible to water block the free space with swellable-water blocking materials, typically yarns, tapes or a combination of the two.

4.2.4 Longitudinal water blocking of wire or strap armoring

The free space around steel wire or steel-strap armoring can be longitudinally water blocked with yarns, tapes or a combination of the two. This armored cable design is common in coastal areas or in areas with high-water tables or in industrial plants in Europe.

4.2.5 Longitudinal water blocking of the bonded or un-bonded laminate sheath

Water-swellable tapes can be used to block the longitudinal flow of water in the interface between the metallic component of the bonded or un-bonded laminate sheath and the cable core for all voltage classes.

Such tapes may serve as a bedding tape in medium, high, and extra-high voltage cables to absorb lateral expansion and contraction with temperature fluctuations due to loading on the cable.

Medium and high-voltage power cables, in general, may require semi-conducting tapes that provide electrical continuity between the metallic moisture barrier, the metallic shield or screen and the semi-conducting insulation shield.

~~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.~~

~~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 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 1248-84⁹ 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 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.

⁹Information on references can be found in clause 2.

- e) ~~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 (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. Materials ~~Metal-plastic laminates used~~ for moisture barrier and water-blocking functions

5.1 Description

A laminate plastic-coated metallic foil or sheet consists of a relatively thin metallic “foil” or sheet layer, usually 0.10 mm to 0.38 mm (4 mils to 15 mils) in thickness, which is coated on one or both sides with a plastic layer with typical thickness between 0.05 mm to 0.10 mm (2 mils to 4 mils). The plastic layer can be insulating or conductive. A strong adhesive bond should be formed between the plastic layer and the metal layer. The bond should ~~be selected that will~~ not lose its properties after long-term exposure to heat and moisture ~~cycling~~. In all cases, the metal layer should be pinhole free as such holes ~~entirely~~ could defeat its purpose as a moisture barrier.

5.2 ~~Laminates~~ Plastic-coated metals for ~~under-jacket~~ radial designs for all voltage classes

5.2.1 General

The type of metal chosen for a plastic-coated metal depends on the cable design and the role the metallic component plays as a moisture barrier and/or shield. Present choices include lead foil, copper or aluminum sheet. All of these metals can be coated ~~or laminated~~ with suitable plastics to achieve the desired composite structure. ~~Laminates can be~~ Plastic-coated metal using lead foils are designed primarily for moisture barrier functions. A copper or aluminum composite could be used as a moisture barrier or for dual functions as both moisture barrier and metallic shield.

5.2.2 Coating classes

Two classes of plastic-coated metal currently exist for use in the bonded sheath designs. One class is adhesively compatible with polyethylene (PE), copolymers of PE, and chlorinated polyethylene (CPE) jackets. The other class is compatible with polyvinyl chloride (PVC) based jackets. Reference ASTM B 736-002006⁴ for shielding stock can be used as a baseline reference for both types of plastic-coated metals.

Plastic coatings or films exist for each class that will satisfactorily adhere to a specific metal substrate. The resulting plastic-coated 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—a radial—moisture barrier in various cable constructions. The film coating may be applied to one or both sides of the metallic layer as the cable design dictates. Plastic layers on both sides of the metal substrate increase the corrosion resistance of the~~

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plastic-coated metal and enhances the cable manufacturing process. Plastic-coated foils coated on one side or coated on both sides have found application in bonded-sheath cable designs.

Typically low-voltage cables use two-side coated plastic-metal composites while medium and high-voltage cables use one-side coated plastic-metal composites. One key factor in using two-side coated metals in low-voltage cables is to provide corrosion protection to the moisture barrier because it may also be acting as an electrical shield which requires electrical continuity to perform its electrical functions. Since low-voltage cables do not typically require longitudinal water blocking, the coating on the inside of the moisture barrier facing the core acts to protect the combination metallic moisture barrier-electrical shield from corrosion in case water gets inside the cable. Restricting corrosion, in turn, preserves the electrical shielding function of the cable. In the case of MV and HV cables, there is typically a means for protecting the cable sheath interfaces from the longitudinal flow of water thereby restricting the potential for corrosion. So a one side coated metal with the bare side facing the core may be used. Typically there are screen wires under the bonded sheath so the electrical shielding function of the cable may not be compromised by any incidental corrosion of the metallic moisture barrier. However, the key factor in using a one-side coated metallic moisture barrier on MV and HV cable is the fact that the bare side of the metallic moisture barrier provides electrical continuity with the cable core over the entire length of the cable. This facilitates transfer of shield currents to the metallic moisture barrier and can reduce the amount of standing voltage that may develop on the moisture barrier.

⁴Information on references can be found in Clause 2.

There are differences between one and two-side coated-metallic tapes when the overlap sealing process is considered. A two-side coated tape may be easier to seal because it only requires that the two coatings on each side of overlap be melted to form a seal. The bond to the metallic substrate for the coatings has been established in the manufacturing process for the plastic-coated metal and does not need to be reformed. With a one side coated tape, a new bond must be formed between the coating on the one side of the overlap and the bare metal on the other side of the overlap. This requires extra heat energy to form the bond and so preheat by various methods may generally be used. If sufficient heat is applied, the seal at the overlap of a one side coated metallic tape can equal that of a two-side coated metallic tape. However, from a practical point of view, equivalent bond levels may be difficult to achieve when using a one-side plastic-coated metallic tape versus a two-side plastic-coated metallic tape. So, in general, the sealing of the overlap using a single coating on a one-side coated metallic tape may only be feasible for low-voltage cables of relatively small diameters. To achieve an overlap seal with medium and high-voltage cables that may use one side coated metals, a hot melt adhesive may be inserted into the overlap. Additional details of using hot melts for sealing the overlap are covered later in the guide (see 5.3). It should be pointed out that once the sufficient amount of seal strength is obtained, the cable properties are essentially the same no matter how the overlap seal was obtained, whether with a one side coated metal, a two-side coated metal, or by insertion of a hot melt into the overlap. In the early days of development of bonded sheaths on medium-voltage cable with plastic-coated metallic tapes, the overlap seal was obtained using both one and two-side coated tapes. These cables were able to pass the thermal loading tests [B26]. There was the possibility that the sheath could expand during the heating cycle and not fully recover to its original dimensions during the cooling cycle because of the strength of the overlap seal using the coatings on the tape. With the use of hot melt adhesives in the overlap, the sheath could more easily expand and contract due to the elasticity of the hot melt in the overlap and the original sheath dimensions could be more closely retained [B41].

The coatings used in such plastic-coated metals may also be classed as either insulating or conductive. An insulating layer is generally used when a plastic-coated metal is coated on only one side so as to be bonded to an outer nonconductive jacket. Semi-conducting coatings are used on the side of the plastic-coated metal facing the cable core to provide electrical contact between the semi-conducting layer insulation screen on the core of a medium or high-voltage cable and the metallic shield of the moisture barrier or to a semiconducting cable jacket.

The plastic film or coating on a plastic-coated metallic shield typically meets the following requirements:

- a) The plastic layer is able to adhere to itself or to bare metal under the specified conditions of temperature, pressure, and time. ~~The metal film needed to form a bond at the overlap of the longitudinally formed tape during the cable manufacturing process. The metal-coating bond should not degrade show a decrease in bond strength upon exposure to water. The film must pass the test requirements of ASTM B 736-002006-2007. The coating should be able to withstand the~~ temperatures normally encountered in operating cables.

- b) The ~~film~~ coating should exhibit a strong bond to the jacket. This bond should not diminish, to any appreciable extent, with extended water exposure and temperature cycling.

5.2.3 Coated aluminum as a moisture barrier

Plastic-coated aluminum is most often chosen as a moisture barrier from an economic standpoint for all voltage classes. Aluminum can also be utilized as a surge shield in low-voltage cables for instrument and tray cable applications in areas with substantial lightning activity, but can also be selected for moisture barrier purposes only. A minimum thickness of 0.15 mm (6 mils) may be needed for proper handling, forming about the cable core, and to provide mechanical strength in the finished cable. Coated-aluminum tape is not typically chosen as a combination shield and moisture barrier for medium, high, and extra-high voltage cables, but is only used as a moisture barrier.

5.2.4 Coated copper as a moisture barrier

Plastic-coated copper tape can be chosen as a moisture barrier for all voltage classes in power cables. Frequently, low-voltage cables in substations use coated copper for shielding as well as moisture protection. Most often, coated copper is used as a bonded sheath over a copper wire neutral or wire screen for medium or high-voltage cable. Coated copper can serve to protect from galvanic corrosion in that it is of the same composition as the wire neutral or screen versus the type of galvanic cell that could occur when an aluminum barrier is used in conjunction with a copper wire neutral or screen. See Bow, K.E. et al. [B37].

Another factor favoring copper is that it is easier to terminate. In splicing and terminating, copper can have an advantage because it can be soldered or mechanically clamped more readily than other materials. See Bow, K.E. et al. [B39].

A coated-copper tape can be chosen as a combination shield and moisture barrier for low and certain types of medium-voltage cables. Copper is chosen when maximum conductivity is required. The coated copper metallic moisture barrier can be used as an electrical shield to supplement the wire neutrals of a medium-voltage cable or the wire screen of a high-voltage cable. A minimum thickness of 0.15 mm (6 mils) may be required with copper tape to provide short circuit capabilities or to supplement the short circuit capability of the wire screen. A minimum thickness of 0.05 mm (0.002 inches) may be sufficient to prevent pinholes, but is not sufficient from a mechanical point of view unless reinforced with relatively thicker plastic layers. From a fatigue and mechanical point of view, the minimum thickness may be sufficient for a moisture barrier, but possibly not from an electrical point of view.

5.2.5 Coated lead foil as a moisture barrier

In general, when a plastic-coated lead foil is used as moisture barrier in bonded sheath designs, there is a need to reinforce the lead foil with adherent polymer layers to provide strength. A minimum lead thickness of 0.05 mm (2 mils) is usually necessary to reduce the possibility of pinholes and provide fatigue resistance. The use of lead foil coated with polymer layers is significantly more environmentally acceptable than the use of lead sheaths in terms of the volume of lead involved. The thin foil of lead is isolated from the environment by the presence of the plastic layers; in addition, the adhesive bond of the plastic layers to the lead minimizes contact between the lead and moisture in the environment.

It has been found that the composite construction of lead foil and plastic films can allow the lead to behave like a plastic material during thermal loading see Uematsu, T. et al [B30]. The bonding is therefore capable of expanding and contracting with the cable jacket. It has been found that foil-plastic film composites with metals other than lead, such as copper or aluminum foils, may not exhibit the same type of plastic behavior as exhibited by the plastic-coated lead. Load cycling at higher temperature limits, or use on large diameter power cables, has the potential to split or fracture aluminum or copper foils thereby reducing the ability of these types of moisture barrier composites to radially block moisture. However, they may be suitable for low-voltage and certain medium-voltage cables.

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.

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 nonelectroconductive jacket. Conductive layers of film are used when electrical contact between the metal substrate and other conducting components of the cable is required.

5.3 Adhesives for sealing the overlap ~~Laminates for on-core designs~~

There are designs where an additional adhesive is necessary to enhance the bond strength and moisture barrier integrity of the overlap formed with longitudinally applied plastic-coated metals. Most often a hot melt adhesive is used to seal the overlap with one side coated metallic tapes. The ability to seal a single layer of coating in the overlap may be difficult because of the limited amount of temperature and heat retention available for sealing the overlap during the jacketing process. The ~~adhesion~~ occasions where a hot melt adhesive may be needed can also result from a need to fill the space within a corrugated overlap, as an example, or by soft or uneven under-lying cable surfaces. Such circumstances can prevent the proper heat-sealing of the plastic coatings of the coated metal. Hot-melt adhesives, extruded with suitable application equipment into the overlapped seam before it is fully closed, are commonly used under these circumstances. Their fast set-up time and their ability to adhere to the plastic film of the plastic-coated metal, as well as to most bare metals and jacketing materials, contribute to their ability to form a water-tight seal. Hot melts based on copolymers such as ethylene vinyl acetate (EVA) have been found adequate for sealing low-voltage and some medium-voltage cables. However, hot melt adhesives based on thermoplastic elastomers (TPE) have found favor for medium and high-voltage cables because of their ability to allow the overlap to move and therefore accommodate thermal loading see Butterbach, R. et al. [B41]. The use of TPE based hot melts as sealants for the overlap has been shown to allow sufficient thermal expansion and contraction of the cable core to take place such that additional cushioning layers under the bonding sheath may not be needed or could be reduced in thickness.

Specific types of adhesive coatings are required for adhesive compatibility with the various types of PE or PE copolymer jackets. Other types are required for compatibility with PVC jackets.

~~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 Properties and testing of coated metals ~~Optional seam adhesives~~

5.4.1 Coating adhesion to metal substrates

The adhesion between the plastic coating and the metal substrate of a plastic-coated metal can be measured according to test procedures shown in ASTM B 736-002006. The value of adhesion should not show any substantial decrease when aged in the presence of moisture, at elevated temperatures or after temperature and heat cycling. Many factors affect the values obtained from the coating adhesion test including the following:

- a) Metal thickness
- b) Coating thickness
- c) Test speed
- d) Temperature

Such factors should be considered when evaluating different laminates coated metals. All peel tests are relative and can be affected by parameters of the test, sample configuration and the tensile or physical properties of the layers being separated.

5.4.2 Flexibility

The flexibility of the metal-a foil type of plastic-laminate plays -coated metal needed to accommodate thermal cycles can play a key role in the long-term life of the a medium or high-voltage 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. Since this bonding is expanding and contracting with the cable jacket during thermal cycling in medium or high-voltage cable it should possess the ability to flex without generating cracks which could compromise the ability of the foil to act as a moisture barrier.

5.4.3 Fatigue

~~It is essential that metal plastic laminates~~ The metallic foil bonds such as those based on lead foil, as described in 5.2.5 for on-core-bonded sheath constructions, should have the ability to resist fatigue from repetitive cycles of expansion and contraction. Laminates See Furusawa, H. et al. [B48]. Bonding materials chosen for these types of designs can be tested for fatigue according to a procedure set forth in ASTM E 796-94 [B80].

5.4.4 Bond strength to jacket

~~For under jacket metal plastic laminates~~ plastic-coated metal used as radial-moisture barriers in all voltage classes of cable, a key performance criterion is jacket adhesion. This value can be measured with procedures patterned after those set forth in ASTM D1876-93 [B83] and ASTM 4565-99 [B84]. The metal-to-coating bond as well as the coating-to-jacket bond should be stable and show no significant loss after resistant to water and temperature aging. 4565-90a and ASTM D