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IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables

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

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Foreword

(This Foreword is not a part of IEEE Std 635-1989, IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables.)

Guidance on protective coverings is not included in this guide. This topic is covered in a separate guide, IEEE Std 532-1982, IEEE Guide for Selecting and Testing Jackets for Cables. It is not the intent of this guide to make direct comparison with other metallic sheathing materials.

This guide will be revised from time to time to incorporate the latest information available. Indebtedness is hereby acknowledged to other engineers, whose names are not listed herein, for offering valuable comments and suggestions.

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CLAUSE PAGE

IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables

1. Purpose and Scope

1.1 Purpose

The purpose of this guide is as follows:

1) Outline requirements and establish design guidelines for the selection of aluminum sheaths for extra-high, high-, medium-, and low-voltage cables.
2) Establish basic installation parameters for aluminum-sheathed cables.
3) Provide references to industry standards and codes incorporating design and installation requirements of aluminum-sheathed cables.
4) Provide a comprehensive bibliography of literature related to the subject.

1.2 Scope

This guide covers power cables incorporating aluminum sheaths, except those of the SF_6 rigid-bus type.

2. Definitions

aluminum sheath: An impervious aluminum or aluminum alloy tube, either smooth or corrugated, which is applied over a cable core to provide mechanical protection.

low-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage of 1000 V or less, the cable having an aluminum sheath as a major component in its construction.

medium-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 1000 V to 72 500 V, the cable having an aluminum sheath as a major component in its construction.

high-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 72 500 V to 242 000 V, the cable having an aluminum sheath as a major component in its construction.

extra-high voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 242 000 V, the cable having an aluminum sheath as a major component in its construction.

3. References

The cable may be in accordance with one or more of the references listed below. The installation must be in accordance with the applicable electrical code or wiring regulations.

[1] ANSI/NFPA 70-1990, National Electrical Code.[1]

[2] CSA Std C22.1-1990, Canadian Electrical Code, pt. I, Safety Standards for Electrical Installations.[2]

[3] CSA Std C22.2, no. 123-M1985, Aluminum Sheathed Cables.[3]

[4] CSA Std C68.1-1965, Paper-Insulated Power Cable “Solid” Type.

[5] *Aluminum Standards and Data*, Jan. 1976 (5th ed.), The Aluminum Association, Inc.

[6] ICEA P-45-482-1979 (2nd ed.), Short-Circuit Performance of Metallic Shielding and Sheaths of Insulated Cable.[4]

[7] NEMA WC4-1988 (ICEA S-65-375, 2nd ed.), Varnished-cloth-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy. (See references [21] through [24] in this section.)[5]

[8] AEIC 1-68-1968, Impregnated-paper-insulated lead-covered cable (10th ed.), Supplement 2.[6]

[9] EEI 55-16, *Underground Systems Reference Book*. New York: The Edison Electric Institute Transmission and Distribution Committee, 1957.[7]

[10] SCHIFREEN, C. S. Cyclic Movement of Cable—Its Causes and Effects on Cable Sheath Life. *AIEE Transactions*, vol. 63, 1944, pp. 1121–1129.

[11] SCHIFREEN, C. S. Thermal Expansion Effects in Power Cables. *AIEE Transactions*, vol. 70, pt. I, 1951, pp. 160–170.

[12] HALFMANN, E. S. Critical Inside Dimensions for Power Cable Manholes. *AIEE Transactions*, vol. 69, pt. II, 1950, pp. 1576–1581.

[13] IEC (International Electromechanical Commission) 141-1 (1976), pt. I, Oil-Filled, Paper-Insulated, Metal-Sheathed Cables and Accessories for Alternating Voltages up to and including 400 kV.[8]

[14] YANAGIUCHI, H. Analysis of Strain in Corrugated Aluminum Sheath of Cables. *Journal of the Institute of Electrical Engineering of Japan*, vol. 85-12, no. 927, Dec. 1965, pp. 103–107.

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[1]The National Electrical Code is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Copies are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.
[2]In the US, CSA Standards are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018. In Canada they are available at the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3.
[3]In the US, this document is available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.
[4]ICEA publications are available from Insulated Cable Engineers Association, Inc., P.O. Box P, South Yarmouth, MA 02664.
[5]NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.
[6]AEIC documents are available from the Publication Department, the Association of Edison Illuminating Companies, 600 N. 18th Street, Birmingham, AL 35291-0992.
[7]EEI publications are available from the Edison Electric Institute, 1111 19th Street, NW, Washington, DC 20036.
[8]IEC publications are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[15] BIANCHI, G., DURSO, M. A., and OCCHINI, E. Design and Test of a Flexible EHV Cable Connection for a Floating Plant. *IEEE Transactions on Power Apparatus and Systems*, PAS-96, no. 2, Mar./Apr. 1977.

[16] LANFRANCONI, G. M., GUALTIERE, G., and CAVALLI, M. 330 kV Oil-Filled Cables Laid in 1600 ft. Vertical Shaft at Kafue Gorge Hydraulic Plant. *IEEE Paper* T73-126-0.

[17] Weld-joints for 115 kV Cable Sheath. *Electrical World*, Dec. 15, 1972.

[18] AEIC CS4-1979, Impregnated-Paper-Insulated Low-Pressure Oil-Filled Cable.

[19] BS 6480-1988, British Standard Impregnated Paper-Insulated Cables for Electricity Supply: pt. I, Lead or Lead Alloy Sheathed Cables for Working Voltages up to and including 33 kV.[9]

[20] JIS C3613-1987, O. F. Type Paper-Insulated Aluminum-Sheathed Power Cables.[10]

[21] NEMA WC3-1980 (R 1986) (ICEA S-19-81, 5th ed.), Rubber-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[22] NEMA WC5-1973 (R 1979, 1985) (ICEA S-61-402, 3rd ed.). Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[23] NEMA WC8-1976 (R 1982, 1988) (ICEA S-68-516), Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

[24] NEMA WC7-1982 (R 1988) (ICEA S-66-524), Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electric Energy.

[25] AEIC CS5-1987, Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 through 35 kV, 9th ed.

[26] AEIC CS7-1987, Specifications for Crosslinked Polyethylene Insulated Shielded Power Cables Rated 46 through 138 kV, 2nd ed.

[27] AEIC CS6-1989, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV, 5th ed.

[28] Test Program for Corrugated Type ALS Aluminum-Sheathed Cables, Underwriters' Laboratories, Inc.

[29] VDE 0255/11.72, Specifications for Mass-Impregnated Paper-Insulated Metal-Sheathed Cables for Electricity Supply (except external gas-pressure and oil-filled cables).[11]

[30] IEC 55, Paper-Insulated Metal-Sheathed Cables for Rated Voltages up to 18/30 kV, 55-1 (1978) pt. I: Tests, 55-2 (1965), Tests on Impregnated-Paper-Insulated Metal-Sheathed Cables.

[31] McILVEEN, E. E. Aluminum-Sheathed Control Cable. *AIEE Transactions on Power Apparatus and Systems*, no. 22, 1956, pp. 1376–1384.

[9]BS Standards are published by the British Standards Institution, 2 Park Street, London W1A 2BS UK. Copies are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.
[10]JIS Standards are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.
[11]VDE Standards are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

4. Advantages and Limitations of Aluminum Sheaths

A cable designer or user should be aware of the merits and limitations of aluminum-sheathed cable and assign an order of importance to each property to satisfy the requirements of the specific application where power cables are involved.

4.1 Advantages

4.1.1

The use of an aluminum sheath reduces the weight of the cable compared with those having other metallic sheaths, thereby simplifying installation and lowering shipping costs. Furthermore, longer pulling lengths are possible with reduced cable weight.

4.1.2

As a sheath, aluminum is characterized by high electrical conductance and consequently by high short-circuit capability. In addition, high conductance offers excellent protection against lightning.

4.1.3

Aluminum has very good mechanical properties, for example, hardness and fatigue resistance. Therefore, the possibility of sheath fatigue failure due to vibrations and movement induced by thermal cycling is minimal.

4.1.4

Aluminum has a higher yield point, higher tensile strength, and less creep by comparison with other more ductile sheathing materials. These attributes permit fewer clamps for installations in tunnels or above ground. The high hoop strength of aluminum sheath is particularly important in pressurized cables, since it may permit a reduction in the number of stop joints and pressure tanks.

4.2 Limitations

4.2.1

Aluminum is a relatively active metal chemically, and care must be taken to provide adequate protection against corrosion.

4.2.2

Because of its rigidity, smooth aluminum-sheathed cable is more difficult to bend than corrugated aluminum-sheathed cable.

4.2.3

For jointing and terminating, aluminum sheath requires techniques different from those applicable to other commonly used metals, and retraining of splicing and terminating crews may be necessary.

4.2.4

Because of its high electrical conductance, losses resulting from induced sheath currents and eddy currents are substantial. These losses can be reduced by selecting thinner sheaths and by using special sheath bonding methods for single-conductor cables.

5. Applications

5.1 Background

In the mid-1940's, attention was focused on aluminum as a sheathing material because of the scarcity of lead. As the technical and economic advantages of aluminum were recognized, its use escalated rapidly.

Initially, aluminum was used in applications previously dominated by lead, namely, solid-type paper-insulated medium-voltage cables. The aluminum sheath was of the smooth type; corrugated sheath was not used initially because of compound drainage. Subsequently, however, the corrugated sheath found widespread acceptance, mainly in low-voltage extruded-dielectric cables, and large-size oil-filled high-voltage cables, where impregnating compound drainage into the corrugations is not a factor for consideration.

5.2 Products and Installation Conditions

5.2.1

Considerable experience has been gained in the use of aluminum-sheathed cables in the following products and installation conditions:

1) Low-voltage cables, type MC in accordance with SCHIFREEN [11][12]and types RA60, RA75 and RA90 in accordance withCSA Std C22.1-1986 [2] and CSA Std C22.2 no. 123-M1985 [3].
2) General purpose, pressurized, serf-contained paper-insulated oil-filled medium and high-voltage cables
3) Shaft cables, mainly self-contained oil-filled and extruded-dielectric types
4) Tunnel cables
5) Nonpressurized impregnated-paper-insulated medium-voltage cables with a smooth sheath used in vertical risers

5.2.2

Medium-voltage solid-type impregnated-paper-insulated cables, incorporating annular-corrugated aluminum sheaths, may be used provided that the impregnate is of the nondraining type, and that the corrugations are filled with a suitable compound.

5.2.3

Severe expansion and contraction of the cable in aerial installations may take place during load or ambient cycles. Extreme care must be exercised to provide for this behavior.

6. Aluminum Metals and Alloys

6.1 General

Aluminum sheathing metals and alloys are characterized by good general corrosion resistance, high thermal and electrical conductivity, good mechanical properties, and excellent workability. Such metals are typified by those in *Aluminum Standards and Data* [5]. Furthermore, no instance of failure due to stress corrosion cracking in service or in a laboratory is known. A moderate increase in strength may be obtained by work hardening. Iron and silicon are the major impurities.

[12]Numbers in brackets correspond to those of the references listed in Section 3.

Alloys in the categories considered are not normally expected to stress-corrode in any environment. Aluminum corrodes in strong alkalis, mercurial compounds, most strong acids, and aqueous solutions containing copper and other heavy metals. These environments should be avoided. Chloride pitting can be a problem in some environments. These pits can initiate fatigue damage or even penetrate the specimen.

6.2 Selection and Application

In general, the selection of the proper sheathing alloy is determined by the manufacturing method, and for the purpose of this guide the two principal alloys used for sheathing with their respective methods of application are described below:

6.2.1 Universal Aluminum Metals

The metals in this group contain 99.45-99.6% aluminum; the balance includes mainly silicon and iron. The composition of a typical metal is shown in Table 1.

Universal aluminum metals are used for general purpose sheaths of cables installed in vertical shafts, for seam-welded strip, and for aluminum tube used for the “sinking” (draw-down) manufacturing process. For example, Aluminum 1350, 1145, 1050 and 1060 belong to this group.

Table 1—Composition of a Typical Universal Aluminum Metal

Aluminum minimum (%)	Iron maximum (%)	Silicon maximum (%)	Other Elements maximum (%)
99.45	0.3	0.3	0.17

6.2.2 Pure Aluminum Metals

The metals in this group contain at least 99.7% aluminum. They are normally supplied in the form of billets and used for the direct sheath extrusion process. Typical composition and properties are shown in Table 2.

Table 2—Composition of Some Typical Pure Aluminum Metals

Aluminum minimum (%)	Iron maximum (%)	Silicon maximum (%)	Other Elements maximum (%)	
			each	total
99.80	0.10	0.06	0.03	0.10
99.75	0.12	0.08	0.03	0.10
99.70	0.20	0.10	0.03	0.10

Other aluminum metals and alloys may be used for applications requiring special properties; none of them are heat-treatable. Alloy 3003 has been used; the conductivity of this ahoy is significantly lower than that of Aluminum 1350.

For further information on aluminum and aluminum alloys, refer to the appropriate national and international standards or handbooks listed in Section 3., for example, *Aluminum Standards and Data* [5].

7. Smooth and Corrugated Sheaths

Selection of smooth or corrugated sheath is dictated by the requirements of the specific application. The order of importance of the various properties has been ranked to enable a proper selection. In general, smooth aluminum sheaths may offer advantages for core diameters up to about 1 in (25 mm). Beyond that size, corrugated sheaths are preferred, because large diameter cables with smooth aluminum sheaths become difficult to handle in manufacture and during installation. It should be recognized that even below 1 in (25 mm) core diameter, cables with corrugated aluminum sheaths are much easier to install than smooth-sheathed cables.

7.1 Smooth Aluminum Sheath

7.1.1 Advantages

A smooth sheath offers the following advantages:

1) A smooth sheath is easier to manufacture because of the absence of corrugations, although the latter are normally applied in tandem with the sheathing process.
2) It is easier to wipe than a corrugated sheath. On the other hand, on large cables a smooth sheath could introduce higher stress on wipes.
3) It is less susceptible to elongation during pulling and to elongation that may occur in long vertical installations.

7.1.2 Limitations

A smooth sheath has the following limitations:

1) It is stiffer than a corrugated sheath; therefore, a larger bending force is needed.
2) A smooth sheath requires a larger bending radius because it is susceptible to buckling in sharp bends, which means larger shipping reels and larger manholes are needed. This increases shipping and installation costs. For larger cables, special bending tools are required for installation. Recommended bending diameters are given in Section 11. It should be noted that for larger cables, European practice employs bending diameters from 25 to 35 times cable diameter. Once bent into place, it is difficult to reinstall the cable in another configuration.
3) A smooth sheath is more likely to be linked during installation, especially in small sizes, because installers tend to bend it to smaller radii than recommended.

7.2 Corrugated Aluminum Sheath

7.2.1 Advantages

A corrugated aluminum sheath offers the following advantages:

1) It features high crush resistance, and therefore, less susceptibility to mechanical damage.
2) A corrugated sheath offers a higher degree of flexibility, requiring a smaller bending force, smaller shipping reels, and smaller manholes. The corrugated sheath may be at least 25% thinner than a smooth sheath, resulting in substantial material savings. This is somewhat offset by the metal that goes into the corrugations and the additional jacket material required due to the larger cable diameter. The use of thinner sheaths applies only in cases where the thickness is not dictated by electrical conductance requirements (for example, raceway and equipment grounding conductor) or hoop stress in high-pressure oil-filled cables.

7.2.2 Limitation

The cable diameter of a corrugated sheath is larger than its smooth counterpart, despite the thinner corrugated sheath.

8. Selection of Sheath Thickness

8.1 Mechanical Factors

Handling, installation and service considerations are major factors in determining the thickness of coverings for power cable insulation's. These factors are mechanical in nature, and an indication of performance can be obtained by testing such parameters as:

1) Crush resistance
2) Fatigue resistance
3) Bendability

In addition, those cable constructions involving internal fluid pressures, such as serf-contained gas or oil-filled paper-insulated types, or paper-insulated riser cables, require adequate hoop strength to resist bursting or rupture of the aluminum sheath.

8.2 Grounding and Relaying Considerations

Metallic sheaths may be used for ground equipment and ensuring relay operation under fault conditions, but electrical codes do not permit their use as a current-carrying conductor. While conductance may dictate a minimum thickness for single-conductor cables, in multiple-conductor constructions the cross-sectional area of the sheath required to satisfy the mechanical factors is more than sufficient to ensure adequate grounding. Wherever electrical codes govern, they must be followed.

8.3 Process Constraints

There are three distinct methods of applying aluminum sheaths; namely, direct extrusion, seam welding, and tube sinking or die swaging (Section 10.). A review of the various standards suggests that the thickness were the result of constraints imposed by processing as well as the considerations covered in 8.1 and 8.2.

8.3.1 Smooth Sheaths

When looking for a guide to thickness for nonpressurized cables, it was natural to turn to lead sheath practice. Accordingly, Table 3 was originally established on the basis of 66% of the recognized lead-sheath walls for rubber-insulated conductors, and was then modified from information gained on experimental cables.

If the wall thickness is plotted against maximum core size, the result is a straight line except at the lower end. Experience has shown that with normal installation practices, no buckling or deformation of the sheath occurs with this wall thickness. See McILVEEN [32].

For direct extrusion or the extrusion of tube stock, the aluminum has to be of high purity to permit processing.

With the tube-sinking process, optimum mechanical properties develop after about 25% reduction of the tube and the finished sheath exhibits properties of the $^1/_4$-hard temper. The resulting physical or electrical properties, or both, are fortuitous occurrences with respect to design.

Table 3—Average Thickness of Smooth Finish Aluminum Sheaths

Calculated Diameter of Core		Sheath Thickness	
in	**mm**	**mil**	**mm**
0–0.400	0–10.16	35	0.89
0.401–0.740	10.19–18.80	45	1.14
0.741–1.050	18.82–26.67	55	1.40
1.051–1.300	26.70–33.02	65	1.65
1.301–1.550	33.05–39.37	75	1.90
1.551–1.800	39.40–45.72	85	2.16
1.801–2.050	45.72–52.07	95	2.41
2.051–2.300	52.10–58.42	105	2.67
2.301–2.550	58.45–64.77	115	2.92
2.551–2.800	64.80–71.12	125	3.18
2.801–3.050	71.15–77.47	135	3.43
3.051–3.300	77.50–83.82	145	3.68
3.301–3.550	83.85–90.17	155	3.94
3.551–3.800	90.20–96.52	165	4.19
3.801–4.050	96.55 – 102.9	175	4.45

8.3.2 Corrugated Sheaths

The improved bendability resulting from the corrugations enables the thick sheaths associated with large power cables to be handled with less risk of buckling and rupturing. For this reason, directly extruded sheaths may be corrugated.

Corrugations provide improved mechanical characteristics and, therefore, corrugated sheaths are designed with thickness that are less than those in Table 3. These reduced thickness also permit a faster welding process and, of course, decrease the amount of sheath metal, thereby improving the economics.

8.4 Functional Design Considerations

8.4.1 Solid-Type Impregnated-Paper-Insulated Cables

Where cables are installed on poles, vertically in buildings, or in conduit runs with a considerable change in elevation, cables could be subject to compound migration, causing oil pressure in excess of the strength of the sheath and, particularly, the joint sleeve. This critical sheath thickness may be calculated as follows:

$$t = \frac{D_i H}{5P}$$

where

t = sheath thickness (in)

D_i = internal diameter of sheath (in)
H = height (ft)
P = permissible hoop stress (3500 lbf/in^2 for corrugated and smooth sheaths)

or

$$t = \frac{D_i H}{220P}$$

where

t = sheath thickness (mm)
D_i = internal diameter of sheath (mm)
H = height (m)
P = permissible hoop stress (24 MPa for pre corrugated and smooth sheaths)

NOTE — For general purposes, the thickness shown in Table 3 will satisfy the foregoing equations, while in cases of high internal pressure, the critical thickness calculated by these formulas may govern.

8.4.2 Self-Contained

The following should be considered in designing an aluminum sheath for low-pressure oil-filled cable.

To determine the internal hydraulic pressure, the sheath thickness t can be calculated according to the following formula:

$$t = \frac{D_i H_m}{2P}$$

where

D_i = internal diameter of sheath (in or mm)
H_m = maximum internal pressure (lbf/fin^2 or MPa)
P = permissible hoop stress (3500 lbf/in^2 or 24 MPa for Universal Aluminum Metals)

NOTE — An approximate formula developed overseas for corrugated sheaths is as follows:

$t = (D_i/50) + 0.6$ (mm), or

$t = (D_i/50) + 0.024$ (in)

where D_i is the inside diameter of the sheath, in millimeters or inches, respectively.

8.4.3 Medium- and High-Voltage Polymeric-Insulated Cables

Because of the absence of hydraulic pressure in these types of cables, the main determinant may be short-circuit requirements, which can be calculated in the following manner:

$$A = I \sqrt{\frac{t_i}{0.0125 \log\left(\frac{\mathrm{T} + 228.1}{313.1}\right)}} \text{(cmil)}$$

or

$$A = I\sqrt{\frac{t_i}{48600\ \log\left(\frac{T + 228.1}{313.1}\right)}}(\mathrm{mm}^2)$$

where

A	= metallic cross-sectional area of sheath
t_i	= duration of short circuit(s)
I	= short-circuit current (A)
T	= maximum allowable short-circuit temperature of the sheath (°C)

For suitable values of T refer to ICEA P-45-4821979 [6].

The sheath must withstand the short-circuit energy (current magnitude and duration) without damage to the underlying components or the outer jacket.

8.4.4

In some cases, thickness greater than those indicated by the above formulas will be required for manufacturing reasons.

8.5 Thicknesses

The following tables represent current practices in North America. Because of the different core diameter ranges, it is not practical at this time to put the thickness into a single table.

8.5.1

Table 3, as explained in 8.3.1, is basic and may be found in NEMA WC3-1980 [21], NEMA WC5-1973 [22], and NEMA WC8-1976 [23]. Short circuit requirements must also be considered (ICEA P-45-482-1979 [6]).

Table 4 displays thickness specified by CSA Std C22.2 no. 123-M1985 [3] for smooth seamless aluminum sheaths. Except for core diameters below 0.59 in (15 mm), they are somewhat more conservative than in Table 3.

Table 5 provides the thickness specified by CSA Std C22.2 no. 123-M1985 [3] for corrugated sheaths. These vary in relation to those in Table 4, but generally run from 90% of the thickness in Table 4 for the smaller core diameters to 33% of the thickness in Table 4 for the larger core diameters.

Table 6 presents the thickness for longitudinally applied, formed, welded, and corrugated aluminum strip sheaths, which are commercially available with underwriters' laboratories labels in the US.

Table 4—Minimum Thickness of Smooth Seamless Sheath per CSA Std C22.2 No. 123-M1985 [3]

Calculated Diameter of Core		Minimum Sheath Thickness	
mm	in	mm	mil
Up to 10.0	Up to 0.394	0.7	27.6
10.01–15.0	0.394–0.590	1.0	39.4
15.01–20.0	0.591–0.787	1.2	47.2
20.01–25.0	0.788–0.984	1.5	59.0
25.01–30.0	0.985–1.181	1.7	66.9
30.01–35.0	1.182–1.377	2.0	78.7
35.01–40.0	1.378–1.574	2.2	86.6
40.01–50.0	1.575–1.968	2.7	106.3
50.01–60.0	1.969–2.362	3.2	126.0
60.01–70.0	2.363–2.756	3.7	145.7
70.01–80.0	2.757–3.149	4.2	165.3
80.01–90.0	3.150–3.543	4.7	185.0
90.01–100.0	3.544–3.937	5.2	204.7

Table 5—Minimum Thickness of Corrugated Aluminum Sheath per CSA Std C22.2 No. 123-M1985 [3]

Calculated Diameter of Core		Minimum Sheath Thickness	
mm	in	mm	mil
Up to 8.0	Up to 0.315	0.6	23.6
8.01–14.7	0.315–0.578	0.7	27.6
14.71–20.2	0.579–0.795	0.8	31.5
20.21–23.1	0.796–0.909	0.9	35.4
23.11–27.4	0.910–1.078	1.0	39.4
27.41–35.0	1.079–1.377	1.1	43.3
35.01–50.0	1.378–1.968	1.2	47.2
50.01–60.0	1.969–2.362	1.3	51.2
60.01–70.0	2.363–2.756	1.4	55.1
70.01–80.0	2.757–3.149	1.5	59.0
80.01–90.0	3.150–3.543	1.6	63.0
90.01– 100.0	3.544–3.937	1.7	66.9

Table 6—Minimum Thickness of Corrugated, Longitudinally Welded Aluminum Sheaths

Calculated Diameter of Cable Under Armor		Aluminum	
in	mm	mil	mm
0–2.180	0– 55.37	22	0.56
2.181–3.190	55.40– 81.03	29	0.74
3.191–4.200	81.05–106.7	34	0.86

9. Types of Corrugation

9.1 General

Sheath corrugations can either be helical or annular. In the helical type, the corrugation is performed by a rotating die or disk as the cable moves longitudinally. There are many possible variations of the helical corrugation type. The mechanical characteristics of the corrugated sheath can be largely influenced by choice of wall thickness and corrugation contour. In the annular type, the corrugation contour is perpendicular to the cable axis. The helical type is the most popular.

9.2 Helical Corrugations

9.2.1 Nonsymmetrical Type

This type of corrugation (see Fig 1) features a helical rib extending radically outward with a relatively long pitch so that there is a cylindrical portion of the sheath in contact with the cable core between the ribs. The hardening due to cold working covers a relatively large area of the sheath. Although the hinging tends to occur about the top of the profile, which is not work-hardened during the corrugation process, there is a chance of fracture due to the stress concentration at the root of the helical rib. Long-term experience with this type of corrugation has shown satisfactory performance in both extruded dielectric and oil-filled cables.

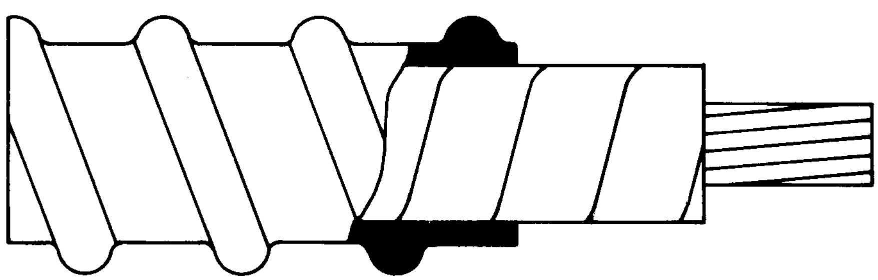

Figure 1—Nonsymmetrical Type (Helical) Corrugation

9.2.2 Symmetrical and Near-Symmetrical Corrugations

This type of corrugation (see Fig 2), which features a nearly sinusoidal configuration, was developed in the early 1950's and has found wide acceptance.

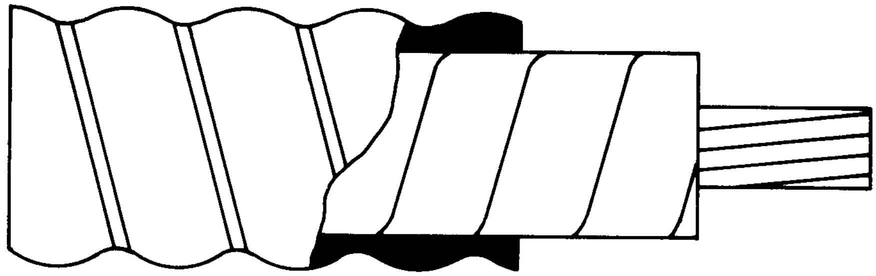

Figure 2—Symmetrical Type (Helical) Corrugation

A very large number of variations in the sinusoidal corrugation configuration is possible. Some designs feature a valley or trough radius that is smaller than that of the peak, thus approaching an arch design. In other designs, the proportions of the peak and valley radii are more nearly equal. Since the mechanical characteristics of the corrugated sheath depend on the interaction of several factors, that is, type of metal, temper, thickness, shape of helical corrugation and pitch, it is very difficult to isolate the effect of subtle changes in the shape of the sinusoidal corrugations. In determining the shape of the sinusoidal or near-sinusoidal corrugations, the design engineer strives for an optimum compromise of desirable mechanical characteristics, cable diameter, and cost.

One important characteristic of the symmetrical corrugation shape is that the corrugated sheath has a uniform cross-section in any plane perpendicular to its axis, resulting in a uniform bending characteristic. This corrugation contour features good metal fatigue resistance.

9.3 Annular Corrugations

Annular corrugations (see Fig 3) of the near-symmetrical type have been introduced recently for some special applications. The cross-section of the corrugated sheath along its longitudinal axis is nonuniform. In an annually corrugated sheath, the trough of the corrugations can be impressed into the cable core, thus constituting an impediment to the migration of impregnating oil between the core and the cable sheath. This is an advantage in mass-impregnated primary distribution cables where oil flow due to temperature changes is thereby restricted.

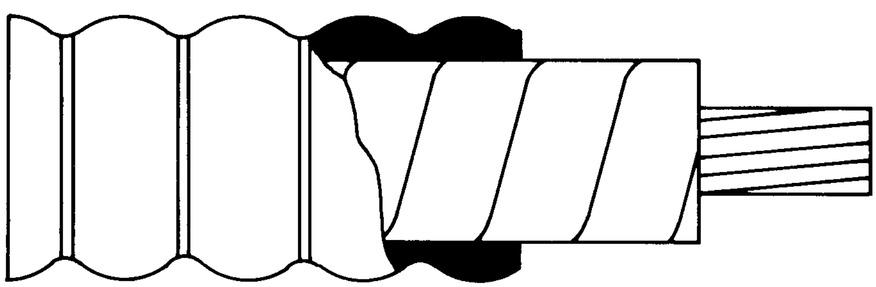

Figure 3—Symmetrical Type (Annular) Corrugation

10. Methods of Manufacture

10.1 Direct Extrusion Process

Using a ram press, the aluminum billet is loaded into the container and, by hydraulic pressure on the ram, the metal is forced around a hollow mandrel and through a die, forming a tube. The insulated core travels through the hollow mandrel and is thereby inserted into the tube or sheath.

There are two types of aluminum sheathing presses:

1) *Double Horizontal Ram Type:* Comprises a double-billet horizontal system.
2) *Continuous Single-Billet Type:* Comprises a single-billet (with reservoir) vertical system.

To minimize overheating of the cable insulation, extrusion of the aluminum sheath over the core is carried out through the use of lower temperatures (430 °C) and higher pressures than those used in extrusion of tube alone. Normally, some tube sinking is involved in the extrusion process.

Direct extrusion offers the following advantages:

1) The economy of scale achieved in long production runs.
2) The aluminum sheath is softer than that obtained by other processes because of the annealing effect of the hot-working of direct extrusion. Therefore, the sheath has better bending and handling characteristics.

The drawbacks of the direct extrusion process are as follows:

1) High capital cost of equipment and a high bay building are needed to accommodate the press.
2) The successive charges of billets, particularly those needed for extrusion of large-size sheaths in discontinuous type of presses, could introduce an element of risk of air or oxide inclusions at the billet joints.
3) Small-size branch circuit cables are difficult, and in some cases uneconomical, to process in short lengths with direct extrusion due to relatively long setup time.

10.2 Seam Welding

Using argon (argon/helium) for the aluminum arc-welding process, an over-sized tube is formed around the cable core from a longitudinally folded and welded strip; a simultaneous reducing operation brings the tube to sheath dimensions.

The seam-welding process is finding an increasing use. It features lower capital cost and allows the manufacture of small-size cables without the attendant difficulty normally experienced with the direct extrusion method. The same equipment may also be used for copper or steel sheath welding. Furthermore, there are no practical limitations to the diameter of cable for which this process can be used.

10.3 DIDD or the "Sinking" Process

The DIDD (draw-in-draw-down) process entails drawing the cable core into an aluminum tube, which has an inside diameter larger than the core, and swaging down or corrugating the sheath until the desired fit is obtained. This sinking operation of aluminum sheath is practicable due to the ability of the metal to sustain a moderate amount of cold-working without significant change in structure and properties.

The tube is extruded separately and delivered to the sheathing line on reels. The tube is laid out horizontally in a straight line, using rounding dies at the pay-off end, or special rollers. A steel line is threaded through the tube directly by magnetic means or by first blowing in a light line to pull in the steel line. The tube containing the insulated core is then passed through a draw-down or corrugation die located near the take-up end. This process has been largely abandoned in recent years in favor of seam welding and extrusion.

11. Parameters Dictating Bending Radii

11.1 Bending During Installation

Bending radii during installation are governed by allowable pulling tensions and sidewall pressures. Calculation of these forces can be accomplished using the method given in EEl 55-16 [9]. Experience has shown that the allowable sidewall pressure known to be safe in extruded-dielectric cables and in paper-insulated oil-filled cables results from tension of 350 to 400 lbf/ft (5 to 6 kN/m) of radius at the bend.

When pulling tension is applied to the cable while it is moving through a bend during installation, it is generally considered safe to use twice the radius specified for the cable fixed in its final position.

Sharp concentrated bends can, to some extent, be avoided by the use of suitable guides or mandrels.

For corrugated aluminum sheaths, it is desirable to establish the allowable sidewall pressure experimentally as the corrugations may cause imprints on the outer layers of the insulation. Resistance to sidewall pressure may be improved by a suitable choice of insulation shielding materials and cushioning binders between sheath and insulation or shield. Corrugations described in 9.2.1 are the most favorable in terms of sidewall pressures.

11.2 Curves with Cable Firmly Anchored or Embedded in Position

Bending radii that equal the cable drum diameter are generally considered acceptable. For sharper bends, mandrels or guides must be used and the cable may be trained to radii approaching those of the drum of the cable reel.

11.3 Expansion Loops, Offsets in Manholes

Such bends are necessary to accommodate the thermal expansion and contraction of the cable; their length and radius are therefore governed by the fatigue performance of the cable.

After establishing the appropriate minimum bending radius for the type of cable to be installed either experimentally or according to 11.4, cable support systems and manholes may be designed in accordance with practices well established for lead-sheathed cable (EEI 55-16 [9], SCHIFREEN [10] and [11], and HALFMANN [12]). The practice has been confirmed by favorable experience in Canada and Japan.

When using the fatigue-resistance calculating methods in EEl 55-16 [9], SCHIFREEN [10] and [11], and HALFMANN [12], special consideration should be given to particularly rigid cable structures such as those having conductors larger than 2000 kcmil (1000 mm^2) and to smooth-sheathed high-voltage power cables. For these cables, movement at the duct mouth will be greater than that of cables having other conventional metallic sheaths.

In some duct installations cables are spliced without offset in the manholes, the joints are aligned with the center of the duct, and both cable and joint are firmly clamped at frequent intervals. This installation method permits considerable reduction in the length of manholes. Special attention, however, ought to be given to the resistance of the joint connectors to pulling forces. The design of the cable-support system should prevent buckling and axial movement of the cable and also remove axial stress from the wipes or cast plumbs.

11.4 Bending Performance of Aluminum Sheaths

11.4.1 Smooth Sheath

The following are factors influencing the bending performance of a smooth sheath:

1) Hardness of the sheath metal, which is governed by the method of manufacture, composition, degree of cold working of nonheat-treatable metals, etc. Direct extrusion and higher purity aluminum can improve the bending performance because, in general, the harder the sheath, the more it tends to be susceptible to fatigue and fracture.
2) Bending diameter (in relation to cable diameter).
3) Looseness of the sheath. For example, a tight-fitting sheath improves the bending performance by preventing sheath deformation. (Tight-fitting sheaths are not desirable for oil-filled cable.)
4) Method of bending. For example, bending performance can, in certain cases, improve if the cable is under tension while bending takes place.
5) Radius of the groove of the bending mandrel in relation to the radius of the cable.
6) The ratio of the sheath diameter to sheath thickness, which should be in the order of 20:1 for satisfactory results at practical bending diameters.

Good cable design combined with good installation practice helps to ensure that the sheath does not buckle or deform significantly when the cable is bent to its minimum bending radius.

Because of the complex mechanical structure of an insulated conductor enclosed in a metal sheath, the bending radius at which buckling will occur is difficult to predict; but it is established that increasing the sheath thickness decreases the buckling radius and the minimum permitted bending radius. However, increasing the sheath thickness increases both the force required to bend the cable and the cost of the cable. Furthermore, smooth aluminum-sheathed cable is already much more difficult to bend than lead-sheathed cables of equal sheath thickness. Because of these factors, the practice has been to select thinner walls for aluminum sheaths and to accept values of bending radii larger than those for lead sheaths.

AEIC 1-68-1968 [8] provides guidance on shipping reel diameters and mandrel diameters for bending tests to prevent creasing or wrinkling of tapes. IEC 141-1 (1976), pt. I [13] provides guidance on bending of cable samples for impulse tests. Neither one offers any guidance on installation bending radius.

The bending radius at the inner edge of any bend of type MC cable with smooth aluminum sheath is specified to be no less than in ANSI/NFPA 70-1990 [1]:

1) Ten times the external diameter of the sheath for cable not more than $^3/_4$ in (19 mm) in external diameter; if conductors are shielded, the bending radius shall not be less than twelve times the overall diameter of the cable.
2) Twelve times the external diameter of the sheath for cable more than $^3/_4$ in (19 mm), but not more than $1^1/_2$ in (38 mm) in external diameter.
3) Fifteen times the external diameter of the sheath for cable more than $1^1/_2$ in (38 mm) in external diameter.

For solid-type impregnated-paper-insulated cable with a smooth aluminum sheath, the bending radii recommended in Canada are as follows:

Cable Overall Diameter	Minimum Bending Radius
≤ 50 mm (2.0 in)	$15 \times D_0$
> 50 mm (2.0 in)	$18 \times D_0$

In Japan, the allowable bending diameters are as follows:

Cable Type	**Diameter over Aluminum Sheath D_0** ≤ 30 mm (1.181 in)	**30-50 mm (1.969 in)**	**≥ 50 mm (1.969 in)**
Single core	40 D_0	50 D_0	60 D_0
Three core	23 D_0	23 D_0	23 D_0

For oil-filled cables, there are no established industry recommendations. Investigations are underway to determine the optimum bending radii.

11.4.2 Corrugated Sheath

A corrugated sheath is more flexible than a smooth sheath. The corrugated aluminum sheath accommodates bending by distributing bending forces uniformly on the corrugations, and bending diameters approach those determined by insulation and core diameter constraints.

The bending radius at the inner edge of any bend of type MC cable with a corrugated aluminum sheath is specified to be no less than seven times the external diameter of the sheath (ANSI/ NFPA 70-1990 [1]).

For solid-type impregnated-paper-insulated cable with a corrugated aluminum sheath, the bending radii recommended in Canada are as follows:

Cable Overall Diameter D_0	**Total Conductor Area**	**Minimum Bending Radius** ≤ 20 kV	**> 20 kV**
≤ 25 mm (≤ 1.0 in)		$8 \times D_0$	
> 25 mm (> 1.0)	≤ 760 mm^2 (≤ 1500 kcmil)	$8 \times D_0$	$10 \times D_0$
	> 760 mm^2 (> 1500 kcmil)	$10 \times D_0$	$12 \times D_0$

For oil-filled cables, there are no established industry recommendations. Investigation of fatigue resistance of corrugated sheath is underway, in the hope of arriving at optimum bending radii (see Section 12).

Based on favorable experience, current practice is to treat corrugated aluminum sheaths with sinusoidal corrugations and lead sheath as equal as far as the design of bending radii is concerned. Larger bending radii, however, are called for when greater than standard thicknesses or special alloys are used to resist high hoop stresses.

12. Fatigue Characteristics of Large-Size Corrugated-Aluminum-Sheathed Cables Installed in Restricted Manholes

The fatigue resistance of corrugated aluminum-sheathed cables is influenced mainly by the type of aluminum (Section 6), the type of corrugation profile (Section 9) and by the electrical and mechanical loading. (See YANAGIUCHI [14].)

Work done on the fatigue resistance of smooth and relatively small corrugated aluminum sheaths has led to the establishment of standards on the allowable bending radii (Section 11). The experience with the existing field installations provides sufficient assurance of the fatigue strength of corrugated sheaths.

Large-size aluminum-sheathed cables are finding an increasing use in duct and manhole installations. The increase in power transmission has led to increased voltages, and therefore large-diameter cables (incorporating large conductors and large insulation thicknesses) are being used. Physical limitations in urban areas and economic considerations restrict the maximum manhole size, forcing the cables to be bent to a radius smaller than generally recommended (see 11.4). Thus the strain on the sheath at the bends in the manhole becomes severe and increases the probability of sheath fatigue failure. Hence, it is essential to study the fatigue resistance of large-size cables under these conditions. Supporting empirical data are included in BIANCHI, DURSO, and OCCHINI [15].

Fatigue failure in an aluminum sheath can arise from two sources. Mechanical strains, due to expansion or contraction of the cable as a unit, can accumulate at bends in cable runs or in manholes. The second source of fatigue failure can be cyclic thermal stresses introduced by differential expansion of various cable components. The magnitude of this damage depends on the material properties of the aluminum, the geometry of the sheath, the type of electrical loading, and the thermal conductivity of the backfill.

These two components of loading can be either additive or subtractive. However, because of the corrugated shape of the sheath and because the bending strains are in opposite directions on the two sides of the cable, the worst effects of these two components could be present.

Studies are being carried out that will lead to better design methods for large-size corrugated sheaths. A summary of an unpublished preliminary report of such a study is included in Appendix B.

13. Installation Practices in Shafts

13.1 Self-Contained Oil-Filled Cables

In general, installation practices for aluminum-sheathed cables in vertical and inclined shafts are quite similar to those for other types of cable. Because of the susceptibility of aluminum to corrosion, additional care must be taken at the clamping points.

Several vertical and inclined installations involving aluminum-sheathed cables have been in service in various parts of the world and are operating satisfactorily. The following guidelines are recommended for the selection and installation of aluminum-sheathed cables:

1) The universal metal (99.5% aluminum) is preferred to the pure metal because of its higher hoop strength.
2) Intermittent cable supports are needed. The interval L between rigidly fixed cleats must not exceed the value (LANFRANCONI, GUALTIERE, and CAVALLI [16]):

$$L = 2\pi\sqrt{\frac{E_c I_c}{K\alpha\Delta T\ \mathrm{EA}}}$$

where
L = length between supports (in or mm)

$E_c I_c$ = total flexural rigidity of the complete cable (lbf×in^2 or MN×mm^2)
E_c = composite compression modulus of the whole cable (lbf/in^2 or MPa)
I_c = moment of inertia of the cable cross-section about a diameter (in^4 or mm^4)
K = safety factor, normally assumed in the order of 4
α = linear coefficient of expansion of conductor metal (/°C)
ΔT = temperature difference in the conductor between full load and no load (°C)
E = actual compression modulus of the conductor (lbf/in^2 or MPa)
A = cross-section of the conductor (in^2 or mm^2)

This equation is based on avoiding any buckling of the cable under the longitudinal thrust resulting from the thermal expansion of the conductor, and the thrust due to the thermal expansion of aluminum sheath is neglected.

In any splicing area or bay (if existing) in the middle of the shaft, or at bends, the ambient temperature could be substantially higher than the shaft, and therefore the intervals between cable supports would be reduced (LANFRANCONI, GUALTIERE, and CAVALLI [16]).

3) Although rigid clamping is the most recently used technique, in certain cases the clamps are designed to permit rotation of the clamp with the cable as it expands and contracts. The clamping interval for this type of system has not been established because of the limited number of installations of this type; a conservative approach is to use the relationship given in 13.1(2).
4) Supports can be secured either directly to the wall of the shaft or to an auxiliary steel structure anchored to the wall of the shaft.
5) Fixing the cable to the clamps can be started from the top or bottom of the shaft, depending upon the installation conditions. It is generally preferable to commence securing at the top of the shaft to prevent the full weight of the cable being applied to the lower supports during the clamping operation.
6) Cable fixing can either be rigid or pivotal. In the latter, offsets may be installed if sufficient space is available in the shaft. Installation of offsets generally reduces the number of supports required, thus reducing the cost of cleaning, although the actual installation of the cable is more onerous.
7) Several types of cable clamps are available and the choice of a particular design is predicated upon installation conditions. Wedge-type clamps are commonly used, and for sine-wave installation might be secured to the supporting steel work using a single-bolt fixing to permit some movement of the clamps and to allow the cable expansion bend to assume its normal profile without strain at the clamps.
8) The typical procedure for cable installation is as follows:
   a) The cable reel and control winch are situated above ground.
   b) The cable is fed into the shaft over rollers and is attached to a winch rope. The weight of the cable is supported by the winch rope.
   c) The speed of lowering of the cable is controlled by the winch. Nonrotating multistrand steel rope is recommended.

A schematic diagram for this cable installation is shown in Fig 4.

13.2 Cables with Extruded Insulations

Either smooth or corrugated aluminum sheath may be used. Normally, this type of vertical shaft cable is installed in high-rise buildings, and supported to the shaft wall at intermittent floors. The cable diameter and weight per unit length are normally, by far, smaller than oil-filled cables, and therefore the installation is less demanding.

According to ANSI/NFPA 70-1990 [1], the sheath must be close-fitting over the cable core. However, some clearance must be allowed between the core and the sheath in order to facilitate sheath stripping during the splicing and terminating operations. In riser cable installations comprising large conductors (particularly copper) with corrugated aluminum sheath, there could be incidents of core slippage caused by the weight of the core. It is recommended that offsets be incorporated between supports.

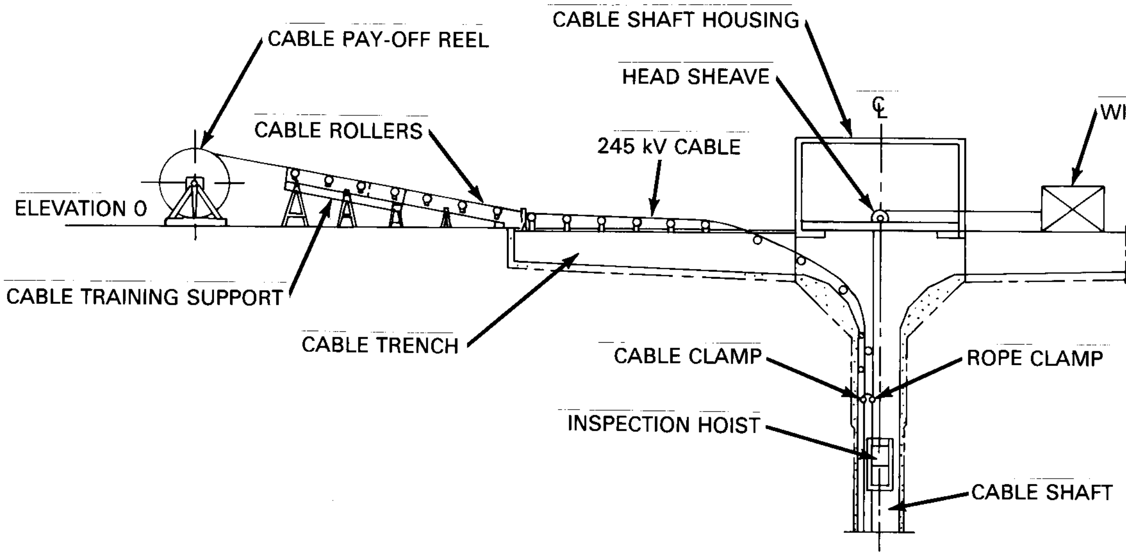

Figure 4—A Typical Schematic Diagram

14. Guidelines for Splicing and Terminating (Including Pulling Eyes)

14.1 Impregnated-Paper-Insulated and Self-Contained Oil-Filled Cables

14.1.1 General

There are three proven methods used to ensure a sound electrical and mechanical connection between the aluminum cable sheath and joint sleeves or terminal bases.

The most popular method, wiping, is similar to that used for lead-sheathed cable.

The second method of using a mold to cast the plumbing metal for increased mechanical strength requires similar expertise to that of a plumbing wipe.

The third method, welding, has been used successfully for special applications and requires special skills and equipment.

Additionally, mechanical joints using O-ring seals have been used successfully on a limited number of installations. There have been unsuccessful aerial installations using mechanical joints. However, mechanical joints using heat shrinkable tubing lined with special adhesives have been used. When using these insulating materials for mechanical joints, special care has to be taken to ensure electrical continuity between the aluminum cable sheath and joint sleeves or terminal boxes. Also, the heat shrinkable material and the adhesive must be compatible with the insulating liquid.

The first two methods require removal of the aluminum oxide from the cable sheath to establish a metal-to-metal bond. With the wiping and cast plumb methods this has to be done with extreme care and skill on the part of the installation crew.

It shall be recognized that joints and terminations represent a mechanical discontinuity in the cable core protection, and consideration must be given to the following rigorous conditions that they must be capable of withstanding:

1) The internal hydraulic pressures under both normal and emergency operation
2) The short-circuit and circulating sheath currents
3) The cable movement caused by thermal cycling due to temperature changes
4) Stresses in rigidly clamped or straight cables, that is, when cables are installed in manholes without offsets to accommodate cable expansion

An outline of each of the three sheath-jointing methods is given below.

14.1.2 Wiping

In wiping, to obtain a firm metal-to-metal bond (that is, without the intervention of aluminum oxide) the cable sheath is coated with a nonoxidizing tin alloy while simultaneously removing the aluminum oxide. A number of tinning alloys and fluxes are available for this purpose with temperature and duration of heat application suitable for the cable insulation and application.

The most frequently used method utilizes a tinning metal of 90/10 tin/zinc, which is wire brushed in a molten state into the aluminum surface.

After tinning, a conventional plumbers' stick wipe can be made between the cable sheath and the joint sleeve or terminal base using a 40/60 wiping solder in stick form. Pot wipes are not recommended due to the possibility of residuals or contamination, or both.

For further details see Appendix A.

14.1.3 Cast Plumb Mold

As an alternative to a plumbing wipe over the tinned sheath or to supplement the plumbing wipe to give increased mechanical strength, a cast plumb may be used. Basically, this method differs from wiping in that after tinning, instead of molding solder by hand, the 63/37 tin/lead solder is cast in a metal mold around the sheath to form an exceptional mechanical reinforcement and seal.

Details of the application of a cast plumb mold are given in Appendix A.

14.1.4 Welding

Because of the high temperature involved and the proximity of the cable insulation, sheath welding techniques developed to date are designed to keep the welds as small and as far from the insulation as possible. This involves forming the end of the cable sheath into a flange using a specially designed metal upsetting tool and making a small weld between the rim of this flange and a transition piece, which, in turn, is welded or bolted to the joint sleeve or pothead base.

The weld uses the conventional TIG or MIG methods with either argon or helium as the inert gas. Argon is preferred because of better control of the weld pool and arc and because there is less clouding and the metal stays brighter, enabling the welder to see the weld more clearly.

It should be noted that experience with welded joints for aluminum sheaths, although limited to a few special projects, has been commendable. It should also be noted that all welding on aluminum causes softening and loss of strength in the heat affected zone. This should be considered when designing any welded connection. The strength cannot normally be recovered since the alloys being used are not heat treatable.

14.2 Polymeric-Insulated Cables

Specially designed mechanical connectors are used to connect aluminum-sheathed polymeric-insulated cables to terminations and connection boxes. Many designs are commercially available, some with a proven service record of more than 25 years.

Solder wiping as described above may be employed on cables insulated with thermosetting materials but is not recommended for thermoplastic-insulated aluminum-sheathed cables due to extreme caution needed to avoid damage to the insulation during the tinning and wiping operations.

14.3 Pulling Eyes

Conventional pulling eyes are normally installed in the factory at the leading end of the cable on the reel. For self-contained oil-filled cable, a fitting is provided for oil feed through the pulling eye.

A typical pulling eye for self-contained oil-filled cable features a strong connection to the conductor as well as to the cable sheath. The hollow core conductor is clamped against the cylindrical portion of the pulling eye by wedge-shaped steel pieces that force the conductor segments against the inner wall of the pulling eye; the wedge incorporates a hollow channel for continuation of the oil feed. The aluminum sheath is hammered against the outside surface of the cylindrical portion of the pulling eye and wiped in the normal manner. Several other mechanical designs have been used for special applications and exceptional installation requirements.

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Annex A

Recommended Installation Practices for Hand Wipe and Cast Plumb Mold Technique for Sealing Aluminum-Sheathed Cables

(Informative)

(These Appendixes are not a part of IEEE Std 635-1989, IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables, but are included for information only.)

A.1 General

Installation requiring plumbers' wipes on joints or terminations of aluminum-sheathed cables should be viewed by the splicer with the same confidence as would the conventional lead sheath type. Full understanding of the minor but essential differences and practice in their execution will reward the splicer with consistent success in wiping aluminum-sheathed cables.

A.2 Required Tools and Materials

In addition to standard splicer's tools and splicing materials, the following tools and materials are required:

1) Aluminum file: double cut, rough “bastard” file for removing longitudinal die marks, scores and oxide film from aluminum sheath wipe area
2) Brass brush: stiff brass-bristle brush for brushing in the tinning metal to wet under the oxide film (steel wire brushes may leave steel particles, which could hamper the tinning process)
3) Tinning stick: for friction tinning aluminum sheath $^1/_2$ lb (200-250 g) stick of 90% tin 10% zinc alloy
4) Wiping sticks: 40% tin 60% lead alloy wiping sticks for making stick wipe after sheath is tinned
5) Stearine or flux: free wiping pad of mole-skin, wiper's cloth, or paper pad

A.3 Preparations for Jointing or Potheading

A.3.1

The aluminum-sheathed cables should be trained for proper manhole offsets, or pot-head locations. In the case of aluminum-sheathed cables, the stiffer sheath calls for special care and attention and a greater effort to achieve the desired bends. For this reason, the bending and training should be done gradually with the bending region distributed to avoid a sharp injurious bend. Where possible, bending mandrels or bending tools are worthy assets.

A.3.2

As much preparatory work as possible should be undertaken prior to cutting open the cables in order to keep exposure of the insulation to a minimum.

A.3.3

These prior preparations include the following:

1) Location of center line of joint or measurement of cable ends to be terminated
2) Location of the ends of the sheaths in a joint and partial scoring with a tube or pipe cutter, knife or hacksaw
3) Tinning and tinning protection of the aluminum sheath in the wipe region

A.4 Steps in Tinning Aluminum-Sheathed Cables

A.4.1 Cleaning and Cleanliness

One of the mandatory requirements for wiping aluminum-sheathed cables is cleanliness in performing the operations and cleanliness of the aluminum sheath and tools directly in contact with the aluminum and the tinned region.

A.4.1.1 Cleaning the Sheath

A slight film of oil may remain on the sheath from the manufacturing process. This oil film, grease, dirt, tar or asphalt from protective coverings should be thoroughly removed by solvents such as 1,1,1-trichloroethane or perchloroethylene. (OSHA regulations should be adhered to in choosing the solvent.) It is a good practice to keep from handling the sheath in the area to be tinned after the cleaning operation.

A.4.1.2 Clean Tools

In both the filing and brushing steps of the tinning technique, it is essential that any dirt on the file and brush used does not spoil the area tinned during the removal of the oxide. Such contamination as foreign metal particles of lead or copper, dirt, grease, asphalt, etc., prevent the thorough and complete wetting of the parent metal and can lead to a poor wipe or subsequent failure. It is good practice to reserve a clean file and brush for use on aluminum sheath only, keeping both cleansed with file card and solvent as often as necessary.

A.4.2 Tinning the Sheath

The tinning of the aluminum sheath is done in five definite steps for a length of 4–5 in (100–125 mm) at the wipe region as follows:

A.4.2.1 Step 1: Filing

The area to be tinned should be uniformly but not deeply filed to remove the heavy oxide film formed on the surface of the aluminum and to remove any longitudinal scores, die marks, or crevices. The filing should be done circumferentially around the sheath, not lengthwise along the sheath. A clean file for aluminum should be used.

A.4.2.2 Step 2: Friction Tinning

Immediately after filing, the prepared area should be heated moderately with a blow torch to a heat sufficient to melt the end of the tinning stick. Excessive heat should be avoided by testing with the end of the tinning stick.

After the prepared surface is sufficiently heated, the tinning solder of 90% tin, 10% zinc should be applied by *rubbing the stick firmly and evenly over the complete area to be tinned*. Light applications of the blow torch will be required to maintain the required tinning temperature. *No flux of any kind is required and is not to be used* as it will spoil the tinning metal underneath the ever-forming thin layer of aluminum oxide and prevent the tinning metal wetting the virgin metal thus exposed. The rubbing should leave the tinning solder deposited fairly evenly over the surface of the aluminum. Only moderate heat is necessary.

A.4.2.3 Step 3: Brushing

The friction tinning is to be followed immediately by vigorous and methodical brushing of the tinning solder through to the aluminum with a stiff brass-bristle brush, using only as much heat from the blow torch as is necessary to keep the solder molten and the brush bristles from packing with solder. This brushing assures that any remaining oxide is lifted, and promotes the thorough amalgamation of the solder with the aluminum.

A.4.2.4 Step 4: Re-tinning

Since most of the excess tinning solder has been scrubbed off, it is essential to re-apply a thin application of tinning solder to the area by rubbing the tinned surface firmly with the tinning stick, aided by moderate heat from the blow torch. Any difficult to reach places should be closely examined and rubbed at this time to assure complete coverage. The achievement of proper tinning can be checked by touch, brushing the molten solder with a clean cloth or paper pad. If the tinning is complete, the surface will be bright and smooth behind the cloth.

A.4.2.5 Step 5: Protective Cover

Immediately after Step 4, the tinned surface should be protected during the course of subsequent splicing or potheading procedures by a light coating of wiping solder. A solder of 40% tin, 60% lead in stick form is recommended. The end of the stick should be softened with a blow torch and, with minimum heating of the tinned surface, the tinned area should be lightly but completely covered with 40/60 solder with little or no rubbing. Stearine or other flux must *not* be used in any of the above 5 steps.

A.5 Wiping Aluminum-Sheathed Cables

Subsequent to the tinning procedure, all further operations are as in standard lead sheath wipes except that a stick wipe of 40/60 solder is preferred. A pot wipe or ladle wipe where molten solder is poured over the wipe area *is not to be used* due to the danger of excess heat and running solder stripping off the tinning and contamination of the pot solder by the zinc from the tinning solder. When a large wipe is to be made, a puddle wipe is satisfactory for extra reinforcement, provided the wiping solder is prepared in a clean ladle or clean pan and applied with a stearine-free wiping cloth. For puddle wipes, it is still necessary to make the initial seal with a stick wipe before adding the bulk of the metal using the puddle wipe.

In stick wiping, the wipe area should be heated with a blow torch just sufficiently to permit softening the wiping solder stick and keep the applied metal plastic. Excess heat can be avoided by testing with the end of the solder stick. It is good practice to apply the solder to the lead sleeve or wiping bell adjacent to rather than on the tinned aluminum sheath, and the metal built up on top of that first applied. The main purpose of this procedure is to prevent removal of the tinning solder from the aluminum. The plastic metal should be packed and patted into a nonporous mass rather than dragged using stearine-free wiping cloths or paper pads. The wipe should be shaped and dressed cleanly with a minimum of wiping or brushing and with precautions against excess application of heat.

No stearine or flux is necessary to achieve a satisfactory wipe. The sleeve or wiping bell should be tinned prior to the wiping operation away from the tinned surface to prevent any stearine or flux from contaminating the tinned surface.

A.6 Application of Cast Plumbs

The alternative method to wiping is the use of cast plumb mold. The latter consists essentially of a contoured container applied over the cable sheath and overlapping the joint casing for a distance of 4-6 in (100-150 mm). The container is filled with eutectic metal (63/37), displacing a hot liquid flux of palm oil to provide a hermetic seal between the cable sheath and the joint. This technique replaces the wipe and has been found to have higher resistance to internal pressures than a wipe. The details of the technique are as follows:

1) When the joint casing or pothead bell is in the correct position for application of the cast plumb molds, seal the end or ends with the heat-resistant gasket or packing provided. This seal must be made with great care to prevent the ingress of palm oil and eutectic metal into the joint sleeves or pothead bell later on.
2) Inspect the tinning of the sheath and wiping ends of the casing for imperfections.
   NOTE — It is essential that the tinning be done in the approved manner and done extremely well. Any suspicious portions of the tinning must be redone.
3) Place the cast mold in position and seal the ends with tight wrappings of cotton tape soaked with palm oil.
4) Proceed with making the cast plumb as follows:

a) Open top and bottom casing outlets or otherwise vent the accessory to be sealed.
b) Fill the mold with new palm oil preheated to 428 °F ± 6 °F (220 °C ± 3 °C). Heating the palm oil higher than this temperature darkens the oil and causes excess fumes.
c) Heat the palm oil in the mold to 350 °F-375 °F (175 °C-190 °C) by placing a torch on the mold, with an accurate dial type thermometer inserted in the mold.
Hold the palm oil at this temperature for five to eight minutes.
d) Fill the mold with the eutectic metal preheated to 482 °F–490 °F (250 °C–254 °C). The palm oil is thereby displaced. The surface of the molten eutectic in the solder pot should be protected from the formation of oxide by a film of palm oil during and after heating. Ladles used should be clean and preheated in the heated eutectic metal.

When pouring the eutectic into the mold, avoid as much as possible directing the stream of molten metal onto the tinned sheath. The metal should be poured in such a manner as to flow down the side of the mold, filing the mold gradually from the base and displacing the palm oil.

Allow the mold to cool slowly from the base upwards by periodically placing a torch on the upper section to maintain a molten surface while the lower part cools, as the eutectic alloy shrinks due to cooling. Top up the mold with more molten alloy until the complete mold of metal sets.

A.7 Protection Against Moisture

Since prolonged exposure to moisture (as may be found in direct burial or humid outdoor installations) may be detrimental to the wipe or cast mold, it is recommended that all wipes and the adjacent aluminum sheath be protected from moisture by careful application of a good waterproof protective coating. Suggested coating materials are waterproof paint, asphalt, heavy waterproof grease, or other impervious protective material.

Annex B

Fatigue Study of Large-Size Helically-Corrugated Aluminum-Sheathed Cables

(Informative)

An investigation of the fatigue resistance of large-size corrugated aluminum cable sheaths is briefly outlined here.

An experimental program on the fatigue strength of 3.0 in (76 mm) and 3.8 in (97 mm) diameter sinusoidal-type corrugated aluminum (99.7% — see Table 2) cable sheath specimens led to the fatigue life relationship shown in Fig B.1.

The corrugated sheath specimens were subjected to fully reversed axial push-pull loading without bending. During each text axial strains at various locations on the sheath surface were measured using long-life fatigue strain gauges.

The specimens were under low internal air pressure, and any sudden drop in this pressure indicating the formation of a crack was considered to indicate failure. This failure criterion determines the usefulness of the cable sheath based on the electrical requirements of the cable.

It is seen from Fig B.1 that a single curve is sufficient to represent the fatigue-life data for both the corrugated sheaths tested, even though the corrugation profiles are different in each case. However, because strain is a dimensionless parameter, the sheath-strain fatigue-life curve for the usual high-voltage cable sizes would be expected to fall about a single curve with an acceptable narrow band of scatter. More tests on sheath specimens with wide variations of geometrical dimensions are necessary to verify this relationship.

This relationship can be applied to calculate the fatigue resistance of corrugated-sheath cables, if the maximum strain in the cable can be analytically computed or estimated from field measurements.

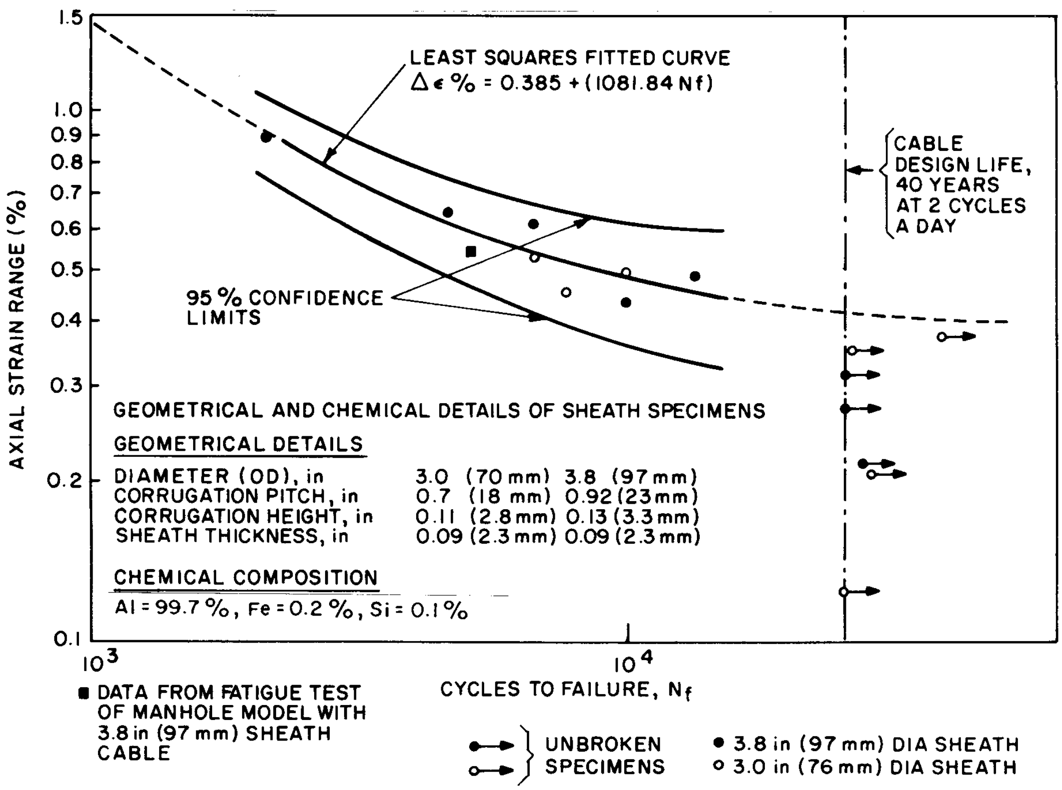

Figure B.1—Example of a Fatigue Life Relationship