UL 2556

STANDARD FOR SAFETY

Wire and Cable Test Methods

UL Standard for Safety for Wire and Cable Test Methods, UL 2556

Fifth Edition, Dated April 30, 2021

Summary of Topics

This revision of ANSI/UL 2556 dated June 3, 2021 is being issued to editorially correct the formula for wraps, in G.1(b).

As noted in the Commitment for Amendments statement located on the back side of the title page, UL, CSA, and ANCE are committed to updating this harmonized standard jointly. However, the revisions dated June 3, 2021 will not be jointly issued by UL, CSA, and ANCE as these revisions address a UL editorial correction only.

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The editorial correction in the revisions dated June 3, 2021 is in accordance with Proposal (s) on this subject dated February 21, 2020 and October 30, 2020.

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NMX-J-556-ANCE-2021
Fifth Edition

CSA Group
CSA C22.2 No. 2556:21
Fifth Edition

Underwriters Laboratories Inc.
UL 2556
Fifth Edition

Wire and Cable Test Methods

April 30, 2021

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ANSI/UL 2556-2021

Commitment for Amendments

This standard is issued jointly by the Association of Standardization and Certification (ANCE), the Canadian Standards Association (operating as "CSA Group"), and Underwriters Laboratories Inc. (UL). Comments or proposals for revisions on any part of the standard may be submitted to ANCE, CSA Group, or UL at anytime. Revisions to this standard will be made only after processing according to the standards development procedures of ANCE, CSA Group, and UL. CSA Group and UL will issue revisions to this standard by means of a new edition or revised or additional pages bearing their date of issue. ANCE will incorporate the same revisions into a new edition of the standard bearing the same date of issue as the CSA Group and UL pages.

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This Standard is subject to review within five years from the date of publication, and suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup. org and include "Proposal for change" in the subject line: Standard designation (number); relevant clause, table, and/or figure number; wording of the proposed change; and rationale for the change.

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This ANSI/UL Standard for Safety consists of the Fifth Edition including revisions through June 3, 2021. The most recent designation of ANSI/UL 2556 as an American National Standard (ANSI) occurred on April 30, 2021. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page (front and back), or the Preface.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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PREFACE

This is the harmonized ANCE, CSA Group, and UL standard for Wire and Cable Test Methods. It is the Fifth edition of NMX-J-556-ANCE, the Fifth edition of CSA C22.2 No. 2556, and the Fifth edition of UL 2556. This edition of NMX-J-556-ANCE supersedes the previous edition published on December 15, 2015. This edition of CSA C22.2 No. 2556 supersedes the previous edition published on December 15, 2015. This edition of UL 2556 supersedes the previous edition published on December 15, 2015.

This harmonized standard was prepared by the Association of Standardization and Certification (ANCE), CSA Group, and Underwriters Laboratories Inc. (UL). The efforts and support of the Technical Harmonization Committee for Wire and Cable Test Methods, of the Council on the Harmonization of Electrotechnical Standards of the Nations of the Americas (CANENA), are gratefully acknowledged.

This standard is considered suitable for use for conformity assessment within the stated scope of the standard.

The present Mexican standard was developed by the WG Metodos de Prueba para Conductores, from CT 20 Conductores belonging the Comite de Normalizacion de la Asociacion de Normalizacion y Certificacion, A. C., CONANCE, with the collaboration of the manufacturers and users of electric conductors.

This standard was reviewed by the CSA Subcommittee on Test Methods for Wires and Cables, under the jurisdiction of the CSA Technical Committee on Wiring Products and the CSA Strategic Steering Committee on Requirements for Electrical Safety, and has been formally approved by the CSA Technical Committee.

Application of Standard

Where reference is made to a specific number of samples to be tested, the specified number is to be considered a minimum quantity.

Note: Although the intended primary application of this standard is stated in its scope, it is important to note that it remains the responsibility of the users of the standard to judge its suitability for their particular purpose.

Level of harmonization

This standard uses the IEC format but is not based on, nor is it considered equivalent to, an IEC standard.

This standard is published as an equivalent standard for ANCE, CSA Group, and UL.

An equivalent standard is a standard that is substantially the same in technical content, except as follows: Technical national differences are allowed for codes and governmental regulations as well as those recognized as being in accordance with NAFTA Article 905, for example, because of fundamental climatic, geographical, technological, or infrastructural factors, scientific justification, or the level of protection that the country considers appropriate. Presentation is word for word except for editorial changes.

Reasons for differences from IEC

This standard provides requirements for insulated wires and cables for use in accordance with the electrical installation codes of Canada, Mexico, and the United States. At present there is no IEC standard for wires and cables for use in accordance with these codes. Therefore, this standard does not employ any IEC standard for base requirements.

Interpretations

The interpretation by the standards development organization of an identical or equivalent standard is based on the literal text to determine compliance with the standard in accordance with the procedural rules of the standards development organization. If more than one interpretation of the literal text has been identified, a revision is to be proposed as soon as possible to each of the standards development organizations to more accurately reflect the intent.

Wire and Cable Test Methods

1 Scope

1.1 This standard describes the apparatus, test methods, and formulas to be used in carrying out the tests and calculations required by wire and cable standards.

1.2 Specific acceptance requirements are found in individual product standards.

1.3 Where a test method indicates a "specified" test parameter or condition, the parameter or condition is found in the individual product standard.

2 General

2.1 Units of measure

The unit of measure shall be SI. If a value for measurement is followed by a value in other units in parentheses, the second value represents a direct conversion or an alternative value. Except for conductor size, the first stated value is the requirement.

2.2 Normative references

Where reference is made to any Standards, such reference shall be considered to refer to the latest editions and revisions thereto available at the time of printing, unless otherwise specified.

ANCE (Association of Standardization and Certification)

In Mexico, NMX-J-556-ANCE is organized with the same clause numbering as UL 2556/CSA C22.2 No. 2556. Separate ANCE standards are published for test methods not covered in NMX-J-556-ANCE. Annex J provides a list of the harmonized NMX test method standards that apply to each test method.

NMX-J-040-ANCE
Wires and Cables – Determination of the Moisture Absorption in Insulations of Electrical Conductors – Test Method

NMX-J-066-ANCE
Wires and Cables – Determination of Diameter and Crosssectional Area of Electrical Conductors – Test Methd

NMX-J-093-ANCE
Wires and cables – Determination of the resistance to fire propagation on electrical conductors – Test method

NMX-J-177-ANCE
Wires and Cables – Determination of Thicknesses of Semiconducting Shields, Insulations, Protective Jackets or Others Elements in an Electrical Conductor – Test Method

NMX-J-178-ANCE
Wires and Cables – Ultimate Strength and Elongation of Insulation, Semiconducting Shields and Jackets of Electrical Conductors – Test Method

NMX-J-186-ANCE
Wires and Cables – Accelerated Ageing in Forced Convection Oven of Semiconducting Shields, Insulations and Jackets of Electrical Conductors – Test Method

NMX-J-189-ANCE
Electrical Products – Wires and Cables – Room-Temperature Flexibility Test for PVC Insulated Electrical Conductors – Test Method

NMX-J-192-ANCE
Flame Test on Electrical Wires – Test Method

NMX-J-194-ANCE
Wires and Cables – Oil Immersion, Gasoline or Other Fluid Aging for Insulations and Jackets of Electrical Conductors – Test Method

NMX-J-212-ANCE
Wires and Cables – Electrical Resistance, Resistivity and Conducting – Test Method

NMX-J-312-ANCE
Wires and Cables – Tenile Strength and Elongation at Break of Electrical Conductors – Test Method

NMX-J-417-ANCE
Wires and Cables – Convection Laboratory Ovens for Evaluation of Electrical Insulation – Specifications and Test Methods

NMX-J-437-ANCE
Wires and Cables – Determination of Light Absorption Coefficient of Polyethylene Pigmented with Carbon Black – Test Methods

NMX-J-472-ANCE
Wires and Cables – Determination of the Amount of Halogen Acid Gas and the Acidity of Acid Gases Released during the Combustion of Materials – Test Methods

NMX-J-474-ANCE
Electrical Products – Wires and Cables – Determination of Specific Optical Density of Smoke Generated by Electrical Wires and Cables – Test Methods

NMX-J-498-ANCE
Vertical Tray – Flame Test – Test Method

NMX-J-553-ANCE
Wires and Cables – Weather Resistance of Insulation or Jacket of Electrical Conductors – Test Method

CSA Group

C22.1
Canadian Electrical Code, Part I

CAN/CSA-C22.2 No. 0
General Requirements – Canadian Electrical Code, Part II

CSA-C22.2 No. 126.1
Metal cable tray systems

ASTM International

ASTM A29/A29M
Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for

ASTM D412
Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers – Tension

ASTM D470
Standard Test Methods for Crosslinked Insulations and Jackets for Wire and Cable

ASTM D471
Standard Test Method for Rubber Property-Effect of Liquids

ASTM D1603
Standard Test Method for Carbon Content in Olefin Plastics

ASTM D1835
Standard Specification for Liquefied Petroleum (LP) Gases

ASTM D4218
Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique

ASTM D5025
Standard Specification for Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials

ASTM D5207
Standard Practice for Confirmation of 20-mm (50-W) and 125-mm (500-W) Test Flames for Small-Scale Burning Tests on Plastic Materials

ASTM D5374
Standard Test Methods for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

ASTM D5423
Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

ASTM D6370
Standard Test Method for Rubber-Compositional Analysis by Thermogravimetry

ASTM E8/E8M
Standard Test Methods for Tension Testing of Metallic Materials

ASTM E662
Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials

ASTM E1131
Standard Test Method for Compositional Analysis by Thermogravimetry

ASTM G151
Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

ASTM G155
Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

GPA (Gas Processors Association)

GPA 2140
Liquefied Petroleum Gas Specifications and Test Methods

IEC (International Electrotechnical Commission)

IEC 60695-11-3
Fire hazard testing – Part 11-3: Fire hazard testing – Part 11-3: Test flames – 500 W flames – Apparatus and confirmational test methods

ISO (International Organization for Standardization)

ISO 10093
Plastics – Fire tests – Standard ignition sources

NEMA (National Electrical Manufacturers Association)

NEMA VE 1
Metal Cable Tray Systems

2.3 Safety

2.3.1 General

It is not the intent of this standard to address all of the safety issues associated with its use. It is the responsibility of the user of this standard to train personnel, establish proper health and safety procedures and be aware of, and comply with, local, state/provincial, and national regulatory restrictions that apply.

2.3.2 Chemical hazards

Some tests use materials that local, state/provincial, and national regulatory agencies have determined to be hazardous. These tests shall be performed under controlled conditions that allow for proper safety and protection of personnel. Information and instructions contained in material safety data sheets (MSDS) for handling, working, and disposal of hazardous chemicals shall be followed. Furthermore, discharges of these chemicals to the environment, that is, the air, water, or ground, shall comply with the latest applicable regulations.

2.3.3 Electrical hazards

Certain test procedures require high voltage. It is important that the equipment be designed to comply with good engineering practices, with safety being an integral part of the design. To avoid electric shocks in such cases, necessary precautions shall be taken and test equipment manufacturers' recommendations shall be followed.

2.3.4 Mechanical hazards

Some tests utilizing mechanical equipment can expose the operator to mechanical hazards. Care shall be exercised to protect eyes, fingers, hands, and other body parts from injury.

2.3.5 Thermal hazards

In tests requiring elevated temperatures, precautions shall be taken to avoid skin burns when handling materials exposed to heat.

2.3.6 Fire and explosion hazards

Some tests use materials that local, state/provincial, and national regulatory agencies have determined to be hazardous. These tests shall be performed under controlled conditions that allow for proper safety and protection of personnel. Information and instructions contained in material safety data sheets (MSDS) for handling shall be followed. Some gases can settle and become an explosion hazard. Consult the gas supplier for special precautions to be taken.

2.4 Definitions

The following definitions apply in this standard. Terms used throughout this standard which have been defined in this clause are in capital-type reduced font:

DIRECTION OF LAY: The direction, designated as left-hand (counterclockwise) or right-hand (clockwise), in which any component recedes from an observer looking along the longitudinal axis of the conductor or assembly.

FLAME: To undergo combustion in the gaseous phase with emission of light.

GLOWING COMBUSTION: Combustion of a material in the solid phase without flame but with emission of light from the combustion zone.

LENGTH OF LAY: The length along the longitudinal axis of the conductor or assembly for any component to complete one revolution.

MICROMETER: As used in this document, "micrometer" means a device for measuring dimensions to small tolerances. This device may utilize mechanical, optical, video, or other technology.

NORMAL VISION: Vision without any aid other than the examiner's normal corrective lenses, if any.

ROOM TEMPERATURE: 25 ±10 °C (77 ±18 °F).

2.5 Test temperature

Tests shall be conducted at ROOM TEMPERATURE unless otherwise specified.

2.6 Reports

In addition to the specific reporting requirements for each test, the following shall be included as a minimum in all reports:

a) name of test facility;

b) date of report;

c) product description;

d) name of test conducted; and

e) test result.

3 Conductor Tests

3.1 Conductor diameter

3.1.1 Scope

This test establishes the method for determining conductor diameter.

3.1.2 Apparatus

The apparatus shall consist of the following:

a) a micrometer having flat surfaces on both the anvil and the end of the spindle, with a resolution and accuracy of 0.001 mm (0.0001 in);

b) a caliper with a resolution and accuracy of 0.001 mm (0.0001 in); or

c) a laser micrometer with a resolution and accuracy of 0.001 mm (0.0001 in).

3.1.3 Preparation of specimens

The specimen shall be taken from a sample of wire, cable, or cord, finished or during manufacture, and shall be removed from its surrounding insulation or coverings (when present) and straightened, with care being taken not to stretch it.

3.1.4 Procedure

Three measurements of the maximum and minimum diameters shall be made. All measurements of a stranded conductor shall be made over the strands and not at the interstices. The diameter measurements shall be taken near each end and in the center of the specimen.

3.1.5 Results and calculations

3.1.5.1 The diameter shall be the average of the six measurements.

3.1.5.2 When a member diameter cannot be directly measured in a Rope-lay conductor, the outside diameter of the Rope-lay conductor shall be measured and member outside diameter shall be calculated using the following formula:

$$D_1 = \sqrt{\frac{D^2}{n}}$$

where:

D1 = The calculated outside diameter of the member (mm)

D = The outside diameter of a Rope-lay conductor (mm)

N = The number of members

3.2 Cross-sectional area by mass (weight) method

3.2.1 Scope

This test establishes the method for determining the cross-sectional area of a conductor by the mass (weight) method.

3.2.2 Apparatus

The apparatus shall consist of the following:

a) a balance accurate to 0.1 percent of mass measured; and

b) a length-measuring device accurate to 0.1 percent of length measured.

3.2.3 Preparation of specimens

The specimen shall be taken from a sample of wire, cable or cord, finished or during manufacture, and shall be removed from its surrounding insulation or coverings (when present) and straightened, with care being taken not to stretch it.

3.2.4 Procedure

3.2.4.1 The test specimen shall consist of a straight length of a conductor cut from a sample of the wire, cable, or cord, finished or during manufacture. The length of specimen shall be a minimum of 1 m (3 ft) for up to 8.37 mm^2 (8 AWG) and 0.5 m for larger than 8.37 mm^2 (8 AWG).

3.2.4.2 The specimen shall be at ROOM TEMPERATURE and shall have both of its ends perpendicular to the longitudinal axis of the conductor. The specimen shall be weighed and the density of conductor material shall be used to calculate the cross-sectional area.

3.2.5 Results and calculations

3.2.5.1

$$Area = \frac{(1000/L)(100M)}{\rho(100+k)} mm^2 (cmil)$$

where:

M = mass, g (lb)

L = length, mm (ft)

ρ = density, g/cm^3 (lb/(cmil·1000 ft))

= for copper, bare or tin, lead, lead-alloy or nickel-coated, 8.89 g/cm^3 (0.003027 lb/(cmil·1000 ft))

= for copper, silver-coated, 8.95 g/cm^3 (0.003049 lb/(cmil·1000 ft))

= for copper-clad aluminum, annealed, 3.32 g/cm^3 (0.001130 lb/(cmil·1000 ft))

= for aluminum, Alloy 1350, 2.70 g/cm^3 (0.000919 lb/(cmil·1000 ft))

= for aluminum, ACM, 2.71 g/cm^3 (0.000924 lb/(cmil·1000 ft))

= for nickel, 8.80 g/cm^3 (0.002996 lb/(cmil·1000 ft))

= for iron, 7.87 g/cm^3 (0.002680 lb/(cmil·1000 ft))

k = increment (increase) of weight in percent due to stranding

= 0 for solid

= 2 for concentric and bunch-stranded

= 3 to 6 for rope-lay-stranded conductors having concentric stranded members (Classes G and H) as follows:

49 wires or less, k = 3

133 wires, k = 4

259 wires, k = 4.5

427 wires, k = 5

over 427 wires, k = 6

= 4 to 7 for rope-lay-stranded conductors having bunch-stranded members (Classes I, K, and M) as follows:

7 by bunch-stranded members, k = 4

19 by bunch-stranded members, k = 5

7 x 7 by bunch-stranded members, k = 6

19 x 7 by bunch-stranded members, k = 7

37 x 7 by bunch-stranded members, k = 7

61 x 7 by bunch-stranded members, k = 7

3.2.5.2 In case of a question regarding area compliance, the actual weight increment due to stranding shall be calculated using the following formula:

$$k = 100(m - 1)$$

The value of m shall be calculated as follows:

a) For concentric unit or conductor

$$m_c = \frac{1 + n_1 m_1 + n_2 m_2 + \ldots + n_x m_x}{1 + n_1 + n_2 + \ldots + n_x}$$

where:

m_c = ratio increase due to concentric stranding

n_x = number of wires in layer x

$$m_x = \sqrt{1 + \left(\frac{\pi(D - d)}{L}\right)^2}$$

where:

m_x = ratio increase due to stranding

D = diameter over the layer

d = diameter of individual wire or component

L = lay length of layer

NOTE: Dimensions may be in mm or inches, provided that they are consistent throughout the calculation.

b) For bunched unit or conductor

$$m_b = \sqrt{1 + \left(\frac{\pi(D - d)}{\sqrt{2}\,L}\right)^2}$$

where:

m_b = ratio increase due to bunching

D = diameter over bunched unit

d = diameter of individual wire

L = lay length of bunch

NOTE: Dimensions may be in mm or inches, provided that they are consistent throughout the calculation.

c) For rope-stranded conductors with one roping operation, calculate m_R, based on m_b and m_c above, treating the individual units as if they were solid conductors:

$$m_R = m_u\, m_c \text{ or } m = m_u\, m_b$$

where:

m_u = ratio increase due to unitizing (single roping), where m_u is calculated for the single roped assembly in the same way as m_c or m_b, treating each concentric or bunched component as solid

d) For multiple rope-stranded conductors with two roping operations, calculate m_m, based on m_b and m_c above, treating the individual ropes as if they were solid conductors:

$$m_m = m_r\, m_u\, m_c \text{ or } m = m_r\, m_u\, m_b$$

where:

m_r = ratio increase due to multiple roping (second roping operation), and is calculated for the multiple rope assembly in the same way as $m_u \times m_c$ or $m_u \times m_b$, treating each single rope component as solid

e) For a 19-wire combination round-wire unilay-stranded conductor (this variety of unilay conductor consists of a straight central wire of diameter D, an inner layer of six wires of diameter D with each wire having a LENGTH OF LAY designated as LOL, and an outer layer consisting of six wires of diameter D alternated with six smaller wires having a diameter of 0.732 × D and with all twelve wires of the outer layer having the same LENGTH OF LAY LOL and DIRECTION OF LAY as the six wires of the inner layer), application of the first formula in Item (a) gives

$$M_{\text{combo unilay}} = \frac{1 + 6m_2 + 6m_3 + (6 \times 0.732^2) \times m_4}{1 + 6 + 6 + (6 \times 0.732^2)}$$

where:

m_2 = the ratio increase (layer lay factor) for the inner layer

m_3 = the ratio increase for the wires of diameter D in the outer layer

m_4 = the ratio increase for the wires of 0.732 × D in the outer layer

As in item (a)

$$m = \sqrt{1 + \pi^2 / n^2}$$

where:

n = the lay ratio:

= for the central wire of diameter D, n_1 = infinity

= for the 6 wires of diameter D in the inner layer

$$n_2 = \frac{LOL}{2D}$$

= for the 6 wires of diameter D in the outer layer

$$n_3 = \frac{LOL}{3.464D}$$

= for the 6 wires of diameter 0.732 × D in the outer layer

$$n_4 = \frac{LOL}{3.732D}$$

When n_2 and n_3 and n_4 each equal or exceed 10, an estimate of

$$m = \sqrt{1 + \pi^2 / n^2}$$

is

$$m = 1 + \pi^2 / \left(2n^2\right) = 1 + \frac{4.9348}{n^2}$$

Then

$$m_2 = 1 + 19.7392 \times \frac{D^2}{(LOL)^2}$$

$$m_3 = 1 + 59.2141 \times \frac{D^2}{(LOL)^2}$$

$$m_4 = 1 + 68.7310 \times \frac{D^2}{(LOL)^2}$$

and

$$M_{\text{combo unilay}} = 1 + 42.8422 \times \frac{D^2}{(LOL)^2}$$

and

$$k = 4284 \times \frac{D^2}{(LOL)^2}$$

3.3 Cross-sectional area by diameter method

3.3.1 Scope

This test establishes the method for determining the cross-sectional area of any solid or stranded conductor consisting of round conductor or strand only, using diameter measurement(s).

3.3.2 Apparatus

The apparatus shall be as described in 3.1.2.

3.3.3 Preparation of specimens

The preparation of the specimen shall be as described in 3.1.3.

3.3.4 Procedure

The maximum and minimum diameters shall be determined at each end and in the center of the conductor or strand being measured. The diameter shall be the average of six measurements.

3.3.5 Results and calculations

The area of the solid wire shall be calculated as follows:

$$A = \pi d^2 / 4$$

where:

A = cross-sectional area, mm^2

d = diameter, mm

or

$$cma = d^2 \times 10^6$$

where:

cma = circular mil area

d = diameter, in

The cross-sectional area of the conductor shall be calculated as the sum of the area (s) of the solid conductor or strand.

3.3.6 Report

The report shall include, as a minimum, the cross-sectional area of the conductor.

3.4 DC resistance

3.4.1 Scope

This test establishes the method for determining the DC resistance of a conductor.

3.4.2 Apparatus

The apparatus shall consist of the following:

a) a 4-terminal measuring device for specimens of resistance of 1 Ω or less, with an accuracy of ±0.5 percent;

b) a 4- or 2-terminal measuring device for specimens of resistance greater than 1 Ω, with an accuracy of ±0.5 percent;

c) a temperature-measuring device with an accuracy of ±1 °C; and

d) a length-measuring device accurate to 0.1 percent of length measured.

3.4.3 Preparation of specimens

3.4.3.1 The specimen shall be a length taken from a wire, cable, or cord, finished or during manufacture, and shall have the following characteristics:

a) a resistance of at least 0.000 01 Ω (10 μΩ) in the test length between voltage contacts;

b) no surface cracks or defects visible with NORMAL VISION, and substantially free from surface oxide, dirt, and grease; and

c) no joints or splices.

d) a test length of at least 1 m (3.3 ft).

3.4.3.2 The test equipment and the test specimen shall be allowed to come to the same temperature as the surrounding medium.

3.4.4 Procedure

3.4.4.1 The electrical resistance of the conductor shall be determined using the measuring device described in 3.4.2. When a 4-terminal measuring device is used, the distance between each voltage contact and the corresponding current contact shall be at least 4.7 times the diameter of the specimen.

Care shall be taken to keep the magnitude of the current low and to minimize measurement time to avoid a change in resistance.

3.4.4.2 The test temperature, which shall be in the range of 10 – 35 °C, shall be recorded at the time the resistance measurement is taken.

3.4.4.3 The length of the specimen under test, between the voltage contact points, shall be recorded.

3.4.5 Results and calculations

3.4.5.1 The resistance of a specimen measured at a temperature other than 20 °C (or 25 °C), as determined by the product standard, shall be corrected to the resistance at 20 °C (or 25 °C) by means of the applicable multiplying factor from Table 1.

3.4.5.2 Resistance per unit length (R) of the conductor shall be calculated from the following formula:

$$R = \frac{r}{L}$$

where:

R = resistance per unit length of the conductor at 20 °C (or 25 °C), Ω/km

r = measured resistance of specimen corrected to 20 °C (or 25 °C), mΩ

L = length of specimen between voltage contact points, m

3.4.6 Report

The report shall include, as a minimum, DC resistance.

3.5 Physical properties of conductors (tensile strength, elongation at break, and ultimate strength)

3.5.1 Maximum tensile strength and elongation at break

3.5.1.1 Scope

This test establishes the method for determining the maximum tensile strength and the elongation at break, of a solid conductor, a single strand removed from a stranded conductor, or a stranded conductor as a unit.

NOTE: The test on a stranded conductor as a unit applies only to 8000 Series aluminum alloy conductors.

3.5.1.2 Apparatus

The apparatus shall consist of the following:

a) a power-driven machine provided with a device that indicates the actual maximum load at which a specimen breaks. The machine shall be capable of operating at power-actuated jaw speeds of 12 to 305 mm/min (0.5 to 12 in/min) and having a precision of 20 percent of the set speed. The applied tension as indicated shall be accurate to 2 percent or less of the value read; and

NOTE 1: A method for calibrating the machine is specified in ASTM D412.

NOTE 2: Jaws as described in ASTM E8 have been found to be acceptable.

b) a length-measuring device with an accuracy of 1 percent of the length measured.

3.5.1.3 Preparation of specimens

The test shall be made on a single wire that has been carefully removed from the cable or cord, finished or during manufacture, while not altering the properties of the test specimen. The specimen shall be carefully straightened and cut to a length sufficient to allow a space of approximately 0.3 m (12 in) between the jaws of the tensile testing machine when the specimen is in the initial test position. The straight specimen shall be gauge marked at two points 250 ±2 mm (10 ±0.08 in) apart.

3.5.1.4 Procedure

The specimen shall be gripped in the jaws of the machine with the gauge marks between the jaws, and the jaws shall be caused to separate at the rate indicated in Table 2 until the specimen breaks. In order to be accepted as valid, the break shall take place between the gauge marks and shall be no closer than 25 mm (1 in) to either gauge mark. The maximum load before break shall be recorded. The distance between the gauge marks at the time of break shall be recorded to the nearest 2 mm (0.08 in).

3.5.1.5 Results and calculations

The tensile strength shall be calculated from the following formula using the original specimen diameter d, measured as described in 3.1:

$$\frac{4W}{\pi d^2} MPa\ (lbf / in^2)$$

where:

W = maximum load before break, N (lb)

d = diameter, mm (in)

The percent elongation shall be calculated from the following formula:

$$\frac{L - 250}{250} \times 100$$

where:

L = distance between gauge marks at the time of break, mm

or

$$\frac{L - 10}{10} \times 100$$

where:

L = distance between gauge marks at the time of break, in

3.5.1.6 Report

The report shall include, as a minimum, the following:

a) maximum tensile strength; and

b) elongation at break.

3.5.2 Ultimate strength

3.5.2.1 Scope

This test determines the load at which any component of an aluminum conductor steel reinforced (ACSR) conductor breaks.

3.5.2.2 Apparatus

The apparatus shall consist of the following:

a) a power-driven machine provided with a device that indicates the actual maximum load at which a specimen breaks. The machine shall be capable of operating at power-actuated jaw speeds of 12 to 305 mm/min (0.5 to 12 in/min) and having a precision of 20 percent of the set speed. The applied tension as indicated shall be accurate to 2 percent or less of the value read; and

b) compression type or other suitable connectors.

3.5.2.3 Preparation of specimens

3.5.2.3.1 The test shall be made on a finished ACSR conductor, with the insulation, if any, removed.

3.5.2.3.2 The connectors shall be applied to a length of finished conductor so that there is a distance of 1.2 m (48 in) between the connectors. If a failure occurs, as indicated in the product standard, a referee test shall be conducted using a minimum distance of 15 m (50 ft) between the connectors.

3.5.2.4 Preparation of specimens

The connectors shall be gripped in the jaws of the machine and the specimen shall be pulled at a rate of 12 ±2 mm/min (0.5 ±0.1 in/min) until breakage of any wire occurs.

3.5.2.5 Results and calculations

The maximum load shall be recorded.

3.5.2.6 Report

The report shall include, as a minimum, maximum load.

3.5.3 Bending fatigue

3.5.3.1 Scope

This test determines the resistance to bending fatigue of a solid conductor.

3.5.3.2 Apparatus

The apparatus shall consist of the following:

a) a clamping device;

b) a metal plate for bending the specimen; and

c) two metal mandrels each having a diameter equal to that of the specimen +0, −10 percent, fixed to the clamping device, as shown in Figure 1.

3.5.3.3 Preparation of specimen

All coverings shall be removed from the specimen. The specimen shall be straightened and then secured firmly in the clamping device with a minimum of 150 mm (6 in) protruding above the mandrels.

3.5.3.4 Procedure

3.5.3.4.1 Using the metal plate, the specimen shall be bent over one mandrel to an angle of 90°, straightened and then bent in the reverse direction over the other mandrel to an angle of 90°, and again straightened. This shall be considered one cycle.

3.5.3.4.2 The procedure in 3.5.3.4.1 shall be repeated until the specimen breaks.

NOTE: The metal plate is used to ensure that the specimen conforms closely to the surface of the mandrel.

3.5.3.5 Results and calculations

The number of completed cycles, including partial cycles, shall be recorded.

3.5.3.6 Report

The report shall include, as a minimum, the number of completed cycles, including partial cycles.

3.6 High-current heat cycling for aluminum conductors

3.6.1 Scope

This test establishes the method for determining the connectivity of solid aluminum conductors.

3.6.2 Apparatus

The apparatus shall be in accordance with Figure 2 and Figure 3, and shall consist of 15 test jigs (duplex receptacle terminals) having the following characteristics:

a) One terminal baseplate, as shown in Figure 4, shall be made out of 0.76 ±0.03 mm (0.030 ±0.001 in) 70/30 ASTM sheet brass, Rockwell B 82-86 hardness.

b) Screws shall be made of AISI* 1010 carbon steel and located at 21.4 mm (0.84 in) centers. See Figure 5 for screw description.

*American Iron and Steel Institute.

NOTE: Carbon steel in compliance with ASTM 29 is recommended.

c) The other terminal baseplate (neutral side) shall be the same as described in Item (a) but, in addition, shall have immersion tin plating of less than 0.003 mm (0.0001 in) thickness.

d) The two binding head screws, size No. 8-32, used on the white terminal baseplate shall be zinc-plated a minimum of 0.003 mm (0.0001 in) thick and have a chromate conversion coating.

e) The other two binding head screws, size No. 8-32, in the yellow side (line) of the jig shall be zinc-plated a minimum of 0.003 mm (0.0001 in) thick and brass-finished.

f) Screws shall be free-running when finger torque is applied until the screwhead engages with the wire.

3.6.3 Preparation of specimens

Thirty-one specimens of insulated solid 3.31 mm^2 (12 AWG) aluminum wire of length 610 to 685 mm (24 to 27 in) shall be prepared for the test.

3.6.4 Procedure

3.6.4.1 The test conductor shall be connected to form a loop under the screwhead. The end of the test conductor to be connected to the device binding screws shall be formed in a plane to have a bend as shown in Figure 3, with the inside diameter of the bend equal to approximately 0.5 mm (0.02 in) more than the nominal diameter of the device terminal screw. The end of the conductor shall not project from under the head of the screw more than 1/2 the diameter of the test conductor.

3.6.4.2 Terminal screws shall be tightened to a torque of 0.68 N·m (6.0 lbf-in) and held for 30 seconds. Jigs shall be connected together at terminal screws A and B by means of a 610 to 685 mm (24 to 27 in) piece of aluminum conductor. Terminal screws C and D of each jig shall be connected by a 610 to 685 mm (24 to 27 in) piece of the conductor. One thermocouple (Type J, 30 AWG iron constantan) shall be cemented or soldered in accordance with Figure 4, attached at the midpoint (on the breakoff tab) of each terminal baseplate between the screws. These jigs shall then be connected to a 40 A, 60 Hz constant current supply and subjected to 50 cycles of operation, with each cycle consisting of 3.5 hours ON and 0.5 hours OFF. Care shall be taken not to disturb the connecting wires after applying the torque.

3.6.4.3 Temperature measurements shall be taken in accordance with the method described in 3.6.4.4 and 3.6.4.5.

3.6.4.4 Temperature measurements at each connection shall be made, starting with the 25th cycle, and at every 25 cycles thereafter for a total of 5 measurements. Measurements shall then be taken every 40 cycles for a total of 3 measurements, and then every 80 cycles for a total of 3 measurements. This will yield 11 measurements in total for each connection.

NOTE: The cycle of measurement may vary from that specified to the extent of allowing it to occur during regular working hours.

3.6.4.5 Connection stability shall be determined by the following criteria:

a) At any point in the test there shall be no temperature rise in excess of 100 °C over the ambient temperature.

b) The stability factor (ΔT) shall be determined for each of the 11 data points for each of the connections monitored (the stability factor is defined as the maximum temperature rise of any one data point above the average temperature rise of all 11 data points for a particular connection). The data points are those described in 3.6.4.4.

For each point monitored, the ΔT shall not be greater than 10 °C.

3.6.4.6 Where a temperature exceeds 175 °C (1 thermocouple measurement) within the first 50 cycles of test, the result shall not be counted in the overall performance rating. The device shall be removed and replaced by two new test jigs. These shall be inserted into the circuit in such a manner as not to disturb the wire connections or the other test jigs.

3.6.5 Results and calculations

The temperatures measured by all 30 thermocouples shall be recorded at the end of 500 cycles.

3.6.6 Report

The report shall include, as a minimum, temperature measurement on all thermocouples.

3.7 Length of lay

3.7.1 Scope

This test establishes a method for determining the LENGTH OF LAY of any component of a conductor or assembly.

3.7.2 Apparatus

The apparatus shall consist of a length-measuring device accurate to 1 mm (0.04 in).

3.7.3 Preparation of specimens

3.7.3.1 Uncovered components (conductors or assemblies)

A specimen of sufficient length, determined by multiplying the number of complete revolutions to be measured (minimum of 2) plus 2 by the maximum lay length permitted for the component to be measured shall be cut from the sample and straightened. The specimen shall be tightly secured at both ends to a work surface to ensure that the components cannot untwist.

3.7.3.2 Covered components (insulated conductors, jacketed and/or taped assemblies)

A specimen of sufficient length, determined by multiplying the number of complete revolutions to be measured (minimum of 2) plus 2 by the maximum lay length permitted for the component to be measured shall be cut from the sample cable or cord and straightened. The specimen shall be tightly secured at both ends to a work surface to ensure that the components cannot untwist. A longitudinal window shall be cut in the covering(s) in the center portion of the specimen to expose the component to be measured, leaving the remaining covering intact at both ends. The length of the window shall be approximately 25 mm (1 in) longer than twice the specified maximum lay length. The width of the window shall be 180° or less.

Alternatively, the width of the window may be the entire circumference of the specimen. In this case, the window shall be cut prior to securing the specimen to the work surface. The two ends of the specimen shall be secured to the work surface. The radial orientation of the ends of the specimen relative to each other, after securement, shall be the same as prior to specimen preparation.

Example: If the specified maximum lay length is 57 mm (2.25 in), the window shall have the following approximate length:

$$(2 \times 57) + 25 = 139 \ mm$$

or

$$(2 \times 2.25) + 1 = 5.5 \ in$$

3.7.4 Procedure

The distance (D) required for at least two complete revolutions of the component shall be measured along the longitudinal axis of the specimen.

3.7.5 Results and calculations

The lay length shall be calculated as follows:

$$L = \frac{D}{N}$$

where:

L = lay length, mm (in)

D = distance, mm (in)

N = number of complete revolutions measured

3.7.6 Report

The report shall include, as a minimum, the LENGTH OF LAY of the component(s).

4 Insulation, Overall Covering, and Jacket Materials Tests

4.1 Thickness

4.1.1 Scope

The tests in this clause establish methods for determining the minimum thickness at any point, and the average thickness of conductor insulation, extruded overall covering, and jacket materials.

4.1.2 Apparatus

The apparatus shall consist of the following, whichever are applicable:

a) a pin-gauge dial micrometer capable of exerting a force of 0.25 ±0.02 N (0.056 ±0.004 lbf), having a nominal pin diameter of 1 mm (0.04 in) and an anvil having nominal dimensions of 1 mm by 8 mm (0.043 in by 0.312 in), and with a resolution and accuracy of 0.01 mm (0.001 in);

b) a micrometer microscope with a resolution and accuracy of 0.01 mm (0.001 in), except that in the case of referee measurements taken following non-compliance in accordance with 4.1.4.1.3, 4.1.4.2.3 or 4.1.4.2.4, the resolution and accuracy shall be 0.001 mm (0.0001 in);

c) a dial micrometer having flat surfaces on both the anvil and the end of the spindle that exerts a force of 0.10 to 0.83 N (0.022 to 0.187 lbf), both the spindle and anvil having nominal dimensions of:

1) 2 mm by 9.5 mm (0.078 in by 0.375 in), with a resolution and accuracy of 0.01 mm (0.001 in); or

2) 6.4 mm (0.25 in) in diameter with a resolution and accuracy of 0.01 mm (0.001 in);

d) a laser micrometer with a resolution and accuracy of 0.01 mm (0.001 in);

e) for mineral insulated cable, a file for flattening and smoothing the face of specimens; and

f) for mineral insulated cable, a steel gauge wire of a specified diameter.

4.1.3 Preparation of specimens

4.1.3.1 Minimum thickness at any point

4.1.3.1.1 A specimen having a maximum length of 8 mm (0.31 in), but in no case longer than the width of the anvil, shall be cut perpendicular to the longitudinal axis of the cable and removed. Any separators or other components shall be removed from the insulation or jacket under examination. If the jacket or insulation cannot be removed without damage, measurements shall be made using the micrometer microscope method described in 4.1.4.1.2.

4.1.3.1.2 In the case of mineral insulated cable, the face of one end of a specimen 8 mm (0.31 in) in length shall be filed to provide a surface that is flat and smooth. The mineral insulation shall then be removed to a depth of 3 mm (0.12 in) below the end of the sheath without disturbing the original position of the conductor(s).

NOTE: The specimen may be cut into segments to fit into the gauge.

4.1.3.2 Average thickness

4.1.3.2.1 Pin gauge and micrometer microscope methods

A specimen shall be cut and prepared in accordance with 4.1.3.1.

4.1.3.2.2 Difference method

A specimen of any convenient length shall be cut.

4.1.4 Procedure

4.1.4.1 Minimum thickness at any point

4.1.4.1.1 Pin gauge method

The specimen shall be placed on the pin, the movable members of the gauge permitted to come gently to rest on the specimen, and the thickness shall be read. In rotating the specimen, the movable member shall not be in contact with it. The procedure shall be repeated until the minimum thickness is found and recorded.

4.1.4.1.2 Micrometer microscope method

The point of minimum thickness shall be located and the thickness measured.

4.1.4.1.3 Mineral insulated cable

A steel gauge wire of the specified diameter shall be inserted gently between the conductors and sheath, and between adjacent conductors.

4.1.4.1.4 Non-compliance procedures

4.1.4.1.4.1 In case of non-compliance with the specified minimum insulation thickness at any point, a micrometer microscope or other optical instrument according to 4.1.2(b) shall be used to view the clean-cut end of one of the two specimens and to locate the point of minimum thickness.

4.1.4.1.4.2 In case of non-compliance with the specified minimum jacket thickness at any point, a micrometer microscope or other optical instrument according to 4.1.2 (b) shall be used to locate and measure the maximum and minimum thicknesses on each of the slices.

4.1.4.2 Average thickness

4.1.4.2.1 Averaging method

The minimum and maximum thickness shall be determined using the procedures described in 4.1.4.1.1 or 4.1.4.1.2. For insulation, measurements shall be made within the irregularities resulting from conductor stranding. For extruded-to-fill jackets, all measurements shall be made within the irregularities resulting from the conductors or other components. If the pin described in 4.1.4.1.1 does not fit within the irregularities, this method is not applicable.

4.1.4.2.2 Difference method

4.1.4.2.2.1 For insulation only, the average thickness shall be determined by determining the diameter over the insulation and the diameter over the uninsulated conductor. The minimum and maximum diameter over the insulation shall be measured at three points spaced no less than 50 mm (2 in) apart along the axis of the specimen and recorded. The average conductor diameter shall be determined in accordance with 3.1. The average thickness of insulation shall be calculated in accordance with 4.1.5.2.2.

4.1.4.2.2.2 For flexible cords only, the average thickness of jacket may be determined by measuring the diameter over the jacket and the diameter over core, including separator, under the jacket. The minimum and maximum diameter over the jacket and the core shall be measured at three points spaced no less than 50 mm (2 in) apart along the axis of the specimen and recorded. The average thickness of jacket shall be calculated in accordance with 4.1.5.2.2.

4.1.4.2.3 Non-compliance procedures – average thickness of insulation of thermoplastic and thermoset-insulated wires and cable, flexible cord and fixture wire

4.1.4.2.3.1 In case of non-compliance with the specified average insulation thickness requirements, a micrometer microscope or other optical instrument according to 4.1.2(b) shall be used.

4.1.4.2.3.2 Five sections 100 mm (4 in) long shall be cut from the non-compliant sample with one of the five points at the center of each section. Without damaging or stressing the insulation, the conductor and any separator shall be removed and the five tubes of insulation cut in two at their centers. Each cut shall be clean and perpendicular to the longitudinal axis of the tube. This yields ten specimens for measurement, however measurements shall be made on only five specimens – one specimen from each tube.

4.1.4.2.3.3 The clean-cut end of each of the five specimens shall be viewed through the instrument and the maximum and minimum thicknesses determined. In the case of stranded conductors, it is appropriate for the average insulation thickness to be 0.08 mm (3 mils) less than the specified average insulation thickness.

4.1.4.2.4 Non-compliance procedures – average thickness of jacket on flexible cord, fixture wire and elevator cable

In case of non-compliance with the specified average jacket thickness requirements, referee measurements shall be made by means of an optical device according to 4.1.2(b).

4.1.5 Results and calculations

Results shall be recorded.

4.1.5.1 Minimum thickness at any point

4.1.5.1.1 The minimum thickness shall be as measured in accordance with 4.1.4.1 and recorded. When individual strands are less than 1.09 mm (0.043 in), and the measurement is made using the micrometer microscope method, 0.08 mm (0.003 in) shall be added to the measured value. The addition of the 0.08 mm (0.003 in) to the measured value does not apply to compact or compressed stranded conductors, or where a separator is used over the stranded conductor, or where measuring the thickness of a tape insulation.

4.1.5.1.2 For insulation thickness measurements following non-compliance, the recorded value shall be rounded to the nearest 0.01 mm (0.001 in) and compared with the specified minimum insulation thickness at any point. The results obtained with the optical instrument shall be considered conclusive.

4.1.5.1.3 For jacket thickness measurements following non-compliance, the maximum and minimum thicknesses of each slice shall be recorded to the nearest 0.001 mm (0.0001 in). The smallest of the four measurements shall be rounded to the nearest 0.001 inch (0.01 mm) and compared with the specified minimum jacket thickness. The results obtained with the optical instrument shall be considered conclusive.

4.1.5.2 Average thickness

4.1.5.2.1 Averaging method

The average of the measurements obtained in 4.1.4.2.1 shall constitute the average thickness of the insulation or jacket.

4.1.5.2.2 Difference method

The six overall diameter readings obtained in 4.1.4.2.2 shall be averaged. The average insulation thickness shall be calculated as the difference between the average overall diameter and the diameter over the uninsulated conductor, including the separator, if present, divided by two. The average jacket thickness shall be calculated as the difference between the average diameter over the jacket and the diameter over the core, including the separator, divided by two.

4.1.5.2.3 Measurements in case of non-compliance

4.1.5.2.3.1 For insulation thickness, the maximum and minimum thicknesses of each specimen obtained in accordance with 4.1.4.2.3 shall be recorded to the nearest 0.001 mm (0.0001 in). The average of the ten measurements shall be calculated and rounded to the nearest 0.001 mm (0.0001 in) and compared with the specified average thickness. The results obtained with the optical instrument shall be considered conclusive.

4.1.5.2.3.2 For jacket thickness, the maximum and minimum thicknesses of each slice shall be recorded to the nearest 0.001 mm (0.0001 in). The average of the four measurements shall be calculated and then rounded to the nearest 0.001 mm (0.0001 in) and compared with the specified average jacket thickness. The results obtained with the optical instrument shall be considered conclusive.

4.1.6 Report

The report shall include, as a minimum, the following:

a) minimum thickness at any point; and

b) average thickness.

4.2 Physical properties (ultimate elongation and tensile strength)

4.2.1 Scope

These tests establish methods for determining ultimate elongation and tensile strength of insulation and jacket materials under specified conditions as described in 4.2.8.

4.2.2 Materials and reactants

Fluids as specified in the product standard shall be used.

4.2.3 Apparatus

The apparatus shall consist of the following:

a) a power-driven machine provided with a device that indicates the maximum load reached. The machine shall be capable of separating the grips at speeds of 500 ±25 mm/min (20 ±1 in/min), and also at 50 ±5 mm/min (2 ±0.2 in/min). The applied load as indicated shall be accurate to 2 percent or less of the value read;

b) an extensometer or scale for determining the elongation with a resolution of 2 mm (0.1 in) or better;

c) dies B, C, D, E or F as described in ASTM D412 or NMX-J-178-ANCE. Dies C and D shall be used with 25 mm (1 in) gauge marks. Dies B, E, and F shall be used with 50 mm (2 in) gauge marks. Dies capable of cutting a 6.3 mm or 3.2 mm (0.250 or 0.125 in) wide specimen having parallel sides are permitted. The tolerance on the width between the cutting edges in the parallel portion of the die shall be -0.00, +0.05 mm (-0.000, +0.002 in);

NOTE: Tolerances on the remaining portions of the die are not critical.

d) a caliper with a resolution and accuracy of 0.01 mm (0.001 in);

e) a dial micrometer having a 6.3 to 6.4 mm (0.248 to 0.252 in) diameter flat presser foot exerting a total force of 0.83 ±0.03 N (3.0 ±0.1 ozf) on a rectangular anvil measuring approximately 9 x 2 mm (0.35 x 0.08 in). The face of the anvil on the minor dimension shall be slightly convex. Alternatively, these measurements shall be made with a dead-weight dial micrometer having a presser foot 6.4 ±0.2 mm (0.248 ±0.010 in) in diameter and exerting a total of 85 ±3 gf or 0.83 ±0.03 N (3.0 ±0.1 ozf) on the specimen – the load being applied by means of a weight. The presser foot shall be at least 2 mm (0.08 in) onto the edge of the specimen for each measurement. Micrometers shall have a resolution and accuracy of 0.01 mm (0.001 in);

f) a micrometer with a resolution and accuracy of 0.001 mm (0.0001 in);

g) a heated bath for oil capable of maintaining the specified temperature within ±1 °C;

h) weather (sunlight) resistance apparatus. Xenon-arc radiation and water-spray exposure equipment shall comply with ASTM G151 and Cycle 1 of the Common Exposure Conditions in ASTM G155 or NMX-J-553-ANCE. The specimen shall be mounted in the specimen holders of the equipment. The xenon-arc apparatus shall be provided with a daylight filter. The spectral power distribution (SPD) shall conform to the requirements of the Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc with Daylight Filters in Table 1 of ASTM G155 for a xenon lamp with a daylight filter. Operation of the lamp assembly shall maintain a level of spectral irradiance at the specimens of at least 0.35 W/(m^2·nm) monitored at a wavelength of 340 nm.

i) a forced air-circulating oven. The apparatus for the air-oven aging of specimens shall be as indicated in NMX-J-417-ANCE or ASTM D5423 (Type II ovens) and ASTM D5374 and shall circulate the air within the aging chamber at high velocity. Fresh air shall be admitted, continuously, to the chamber to maintain normal oxygen content in the air surrounding the specimens. The exhaust ports of the oven shall be adjusted to achieve 100 to 200 complete fresh-air changes per hour. For purposes of calculating the number of fresh air changes the volume of the oven shall be based on the interior dimensions of the oven. The blower, fan, or other means for circulating the air shall be located entirely outside the aging chamber. The oven shall be capable of maintaining the temperature specified in Table 3;

j) a power-driven splitting or skiving machine consisting of an adjustable upper pressure roller, a band knife or a rotary bell knife, and a power-driven feed roller that passes a sample across the knife blade thereby separating or slicing the sample into layers, with no resulting heating of the sample material from which die-cut specimens are to be prepared. The machine shall be used for the following:

1) to produce a strip of insulation from a 13.3 mm^2 (6 AWG) or larger conductor or a strip of jacketing material; and

2) to remove irregularities from samples of insulation, jacket, or the like;

k) a power-driven buffing machine (grinding wheel). The abrasive wheel shall be nominal No. 36 grit (particle size of 0.486 mm (0.019 in). The wheel shall run true and shall not vibrate. The diameter of the wheel is not specified; however, 0.12 – 0.16 m (4.75 – 6.25 in) has been found appropriate. The rotary velocity of the wheel shall be 2500 – 3500 r/min. The diameter and rotary velocity of the wheel shall be selected to give the wheel a peripheral speed (rpm x π x wheel diameter) of 15 to 25 m/s (3000 to 5000 ft/min). The machine shall have a slow feed that applies light pressure and removes very little material at one cut, thereby not overheating the specimen or the wheel;

CAUTION: The maximum wheel diameter and the maximum wheel rpm specified in this item are not to be used together, as this combination will result in a peripheral speed above 25 m/s (5000 ft/min). This applies even for wheels that are marked as being intended for a peripheral speed above 25 m/s (5000 ft/min).

l) a suitable block or draw plane;

m) a balance accurate to 0.1 percent of mass measured;

n) a length-measuring device accurate to 0.1 percent of length measured;

o) a hand- or power-driven machine with steel grips may be used for stretching a conductor for the purpose of removing the conductor from the insulation; and

p) a temperature-measuring device with an accuracy of ±1 °C.

In each type of apparatus, provision shall be made for suspending each specimen vertically within the chamber without touching the sides of the chamber or any other specimen.

4.2.4 Preparation of specimens

4.2.4.1 Sample selection and number of specimens

4.2.4.1.1 Samples shall be taken from a wire, cable or cord, finished or during manufacture, at any time following curing of the compound, where applicable.

4.2.4.1.2 A minimum of six specimens per sample shall be tested "as received" and after accelerated aging or liquid immersion. If the specimen breaks outside of the gauge marks or the grips of the mechanical extensometer at a value below that specified as the acceptable minimum, the test results shall be disregarded and the test shall be repeated with another specimen.

4.2.4.2 Forms of specimen

4.2.4.2.1 General

Each specimen shall be in one of the following forms:

a) If insulation, it shall be tubular or die-cut, prepared in accordance with 4.2.4.2.2 or 4.2.4.2.3, if the wire or cable is smaller than 13.3 mm^2 (6 AWG) and has an insulation thickness of 2.5 mm (0.10 in) or less. In all other cases, it shall be die-cut and prepared in accordance with 4.2.4.2.3.

NOTE: For tubular specimens, if stranded conductors cannot be removed without damage to the insulation, the insulation may be slit longitudinally and the conductors removed.

b) If a jacket, it shall be die-cut, prepared in accordance with 4.2.4.2.3. Alternatively, for jackets where the nominal thickness is less than 0.76 mm (0.03 in) or where the overall diameter is not greater than 5.1 mm (0.2 in), the jacket shall be tested in one of the following ways:

1) in its finished tubular form;

2) die-cut without performing the buffing operation when this would reduce the thickness to less than 0.38 mm (0.015 in); or

3) carefully slit longitudinally and tested in its finished form when the specimen cannot be removed in a tubular form without damage and cannot be die-cut due to its physical size.

Where die-cut specimens are required, they shall be prepared before further conditioning as described in 4.2.4.2.3 and 4.2.5.1.3.

4.2.4.2.2 Tubular specimens

A tubular specimen shall be prepared from a sufficient length of wire, cable, or cord, finished or during manufacture, less any coverings. The conductor shall be removed. Methods for removing the conductor are described in Annex A.

4.2.4.2.3 Die-cut specimens

A die-cut specimen shall be prepared from a sufficient length of sample, less any coverings, as follows:

a) The sample shall be slit longitudinally and removed from the underlying component. The separator or strand shield, if any, shall be removed.

b) The internal and external irregularities shall be removed using the apparatus described in 4.2.3 (j), (k), or (l), whichever is best suited for the material, to provide a smooth specimen of uniform thickness. The thickness shall not be reduced by more than 50 percent except for specimens with an as-received thickness of 5 mm (0.2 in) or more. Adhering insulation shall be removed from a jacket sample. Adhering jacket shall be removed from an insulation sample.

NOTE: For rigid or hard specimens, which cannot be flattened in preparation for skiving or buffing, the specimens may be immersed in warm water at a temperature set below 60 °C for several minutes to make the material pliable. After water immersion and removal from the water, all surface moisture should be blotted from the surface of the specimens by means of a clean, absorbent cloth that is free of lint.

c) After allowing the sample to rest for at least 30 minutes, the specimen shall be cut from the smoothed section using one of the dies specified in 4.2.3(c). The use of a press for operating the cutting die is recommended. The sample shall be placed on a smooth surface of wood or another material that will not damage the cutting edges of the die. The cross-sectional area of the center constricted portion of a die-cut specimen shall be no greater than 16 mm^2 (0.025 in^2).

4.2.5 Procedure

4.2.5.1 Determination of cross-sectional area

4.2.5.1.1 Tubular specimens

The cross-sectional area shall be calculated from the following formula:

$$A = \frac{\pi}{4}(D^2 - d^2)$$

where:

A = cross-sectional area, mm^2 (in^2)

D = the lowest average of maximum and minimum diameters over the sample measured at a position midway between the ends of the sample and at positions approximately 25 mm (1 in) on each side of the midposition, mm (in)

d = the highest average of maximum and minimum diameters over the underlying component (including any separator) measured at points approximately 10 mm (0.39 in) from each end of the specimen, mm. In the case of a conductor consisting of very fine strands, it can be difficult to take the measurement as described. In such a case, an annular section of insulation shall be carefully removed as shown in Figure 6; the average conductor diameter may be measured at that location, mm (in)

NOTE: For jackets tested in their finished tubular form in accordance with item (b) (1) of 4.2.4.2.1: d = the average of wall thickness measurements (measured using an optical micrometer) multiplied by 2, subtracted from D.

4.2.5.1.2 Parallel, flat or irregularly shaped specimens

The cross-sectional area shall be calculated from the following formula:

$$A = \frac{1000W}{LD} mm^2 \text{ or } \frac{W}{LD} in^2$$

where:

A = cross-sectional area, mm^2 (in^2)

W = mass of the specimen with the conductor(s) removed, g, minimum 5 g (0.011 lb)

L = length of the specimen, mm (in)

D = density of the compound, g/cm^3 (lb/in^3)

NOTE: An acceptable method of determining density is described in Annex B.

4.2.5.1.3 Die-cut specimens

The cross-sectional area shall be determined using the width of the cutting die and the minimum thickness of the smoothed section, to the nearest 0.01 mm (0.001 in), using the dial micrometer as described in 4.2.3 (e). The area shall be calculated from the following formula:

$$A = t \times w$$

where:

A = cross-sectional area, mm^2 (in^2)

t = minimum thickness of the smoothed section, mm (in)

w = width of the cutting die, mm (in)

4.2.5.2 Ultimate elongation and tensile strength

The elongation and tensile strength tests shall be conducted simultaneously at ROOM TEMPERATURE. The specimen shall be conditioned at ROOM TEMPERATURE for at least 30 minutes prior to testing. Video, laser, or mechanical extensometers or a scale method shall be used to determine elongation. Two gauge marks, 25 mm ±2.5 mm (1 in ±0.10 in) apart and essentially equidistant from the center of the specimen, shall be placed on the specimen. These gauge marks shall be at right angles to the direction of pull in the testing machine and as narrow as possible, to facilitate measurement. The specimen shall be completely at rest while being marked. The specimen shall be clamped in position, with the gauge marks between the grips so that the section between the gauge marks is straight but not under tension. The distance between a gauge mark and the adjacent grip shall not exceed 13 mm (0.5 in). The grips shall be separated at a uniform rate until the specimen ruptures. The rate of separation shall be 8.5 mm/s (20 in/min) unless specified otherwise in the product standard. During the separation of the jaws, the distance between the gauge marks shall be measured continuously so that the distance at the instant of rupture can be recorded to within 2 mm (0.1 in). The maximum load before break, W, shall be recorded to the nearest 0.5 N (0.1 lbf). If the specimen breaks outside of the gauge marks or the grips of the mechanical extensometer at a value below that specified as the acceptable minimum, the test results shall be disregarded and the test shall be repeated with another specimen.

4.2.6 Results and calculations

4.2.6.1 General

The average ultimate elongation and tensile strength shall be based on the first five acceptable tests as defined in 4.2.4.1.

4.2.6.2 Ultimate elongation

The percentage elongation shall be calculated from the following formula:

$$\frac{L_2 - L_1}{L_1} \times 100$$

where:

L_2 = spacing between gauge marks or grips of mechanical extensometer at rupture, mm (in)

L_1 = initial spacing between gauge marks or grips of mechanical extensometer, mm (in)

4.2.6.3 Tensile strength

The tensile strength shall be calculated from the following formula:

$$TS = \frac{W}{A}$$

where:

TS = tensile strength, MPa (lbf/in^2)

W = maximum load before break, N (lbf)

A = cross-sectional area, mm^2 (in^2)

4.2.7 Report

The report shall include, as a minimum, the following:

a) type of exposure;

b) average values for aged and unaged specimens; and

c) average retention values.

4.2.8 Conditioning of specimens

4.2.8.1 As-received (unaged) specimens

The apparatus and procedure outlined in 4.2.3 – 4.2.6 shall apply to determinations of tensile strength and elongation of insulation, jacket, and similar coverings when tested in the as-received condition.

4.2.8.2 Short-term air-oven aging

4.2.8.2.1 Prior to air-oven aging, measurements necessary for the calculation of cross-sectional area shall be made. The specimens shall be suspended within the appropriate test chamber described in 4.2.3, so that they will not come in contact with one another or with the sides of the chamber. Specimens having widely different properties or composition shall be aged in separate test chambers. The specimens shall be heated at the specified temperature for the specified period of time. Oven temperatures shall be recorded throughout the period of aging. Following air oven aging, the specimens shall be removed from the oven and allowed to rest for 16 to 96 hours at ROOM TEMPERATURE.

4.2.8.2.2 Ultimate elongation and tensile strength shall be determined using the apparatus and procedure outlined in 4.2.3 – 4.2.6. Gauge marks shall be applied after the conditioning.

4.2.8.3 Oil resistance

4.2.8.3.1 Prior to the oil resistance test, the gauge marks shall be applied and measurements necessary for the calculation of cross-sectional area shall be made. The immersion vessel shall have a minimum volume of 100 ml (6 in^3). The vessel shall be filled with a specified oil and then placed in a bath or oven as described in 4.2.3. Specimens shall be suspended in the vessel and maintained at the specified temperature and time. Care shall be taken to minimize contact with the walls of the vessel or other specimens. Oil shall not be allowed to get inside a tubular specimen of insulation. In the case of a jacket, both surfaces (inside and out) shall be exposed to the oil.

4.2.8.3.2 Following immersion, the specimens shall be blotted to remove excess oil, and allowed to rest for 16 to 96 hours at ROOM TEMPERATURE.

4.2.8.3.3 Ultimate elongation and tensile strength shall be determined using the apparatus and procedure outlined in 4.2.3 – 4.2.6. Gauge marks shall be applied before the conditioning.

4.2.8.4 Gasoline resistance

4.2.8.4.1 The immersion vessel shall have a minimum volume of 100 ml (6 in^3). The bottom 25 mm (1 in) of the vessel shall be filled with tap water, and the remainder of the vessel filled with equal volumes of iso-octane and toluene maintained at 23 ±1 °C.

NOTE: See ASTM D471 (Fuel C) for the iso-octane and toluene blend.

4.2.8.4.2 Specimens shall be suspended in the vessel and maintained at the specified temperature and time. Specimens shall be suspended in the vessel with care taken to minimize contact with the walls of the vessel or other specimens. Fluid shall not be allowed to get inside a tubular specimen of insulation. In the case of a jacket, both surfaces (inside and out) shall be exposed to the fluid.

4.2.8.4.3 Following immersion, the specimens shall be blotted to remove excess fluid, and allowed to rest for 16 to 96 hours at ROOM TEMPERATURE.

4.2.8.4.4 Ultimate elongation and tensile strength shall be determined using the apparatus and procedure outlined in 4.2.3 – 4.2.6. Gauge marks shall be applied after the conditioning.

4.2.8.5 Weather (sunlight) resistance

4.2.8.5.1 Scope

This test establishes the method for determining the resistance of wire and cable components to degradation when exposed to weathering effects (filtered light and moisture)

4.2.8.5.2 Xenon-arc exposure

Samples of finished cable or specimens prepared as described in 4.2.4 shall be tested in the xenon-arc apparatus as described in 4.2.3(h) for the specified number of hours, except that the pH of the water shall be 4.5 – 8.0, and the surfaces exposed to the light source shall not be buffed, skived, or planed away. Gauge marks shall be applied after the conditioning. For comparative purposes, specimens from unaged cables shall be prepared in an identical manner. Each cycle shall consist of 102 minutes of light and 18 minutes of light and water spray. Samples shall be mounted in accordance with the xenon-arc apparatus manufacturer's instructions. Following the exposure, the samples or specimens shall be removed from the test apparatus and retained in still air under conditions of ambient ROOM TEMPERATURE and atmospheric pressure for not less than 16 hours and not more than 96 hours.