

UL 2556

Wire and Cable Test Methods

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Underwriters Laboratories Inc. (UL)
333 Pfingsten Road
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UL Standard for Safety for Wire and Cable Test Methods, UL 2556

Second Edition, Dated July 19, 2007

Summary of Topics

This New Second Edition of ANSI/UL 2556 Includes the Following:

- 1. Addition of Flame Tests***
- 2. Revision of Determination of Cross-Sectional Area by Weight to Apply to Any Conductor***
- 3. Addition of Cross-Sectional Area by Diameter Method***
- 4. Addition of Definition of Left-Hand and Right-Hand Lay and New Method for Determining Length of Lay***
- 5. Editorial Revision to Xenon Arc Exposure for the Weather Resistance Test***
- 6. Addition of Method to Determine Carbon Black Content***
- 7. Addition of Figure Illustrating the Spark Test Bead Chain Configuration***
- 8. Clarification of the Cold Bend Test Procedure Regarding Returning the Specimen to Room Temperature***
- 9. Correction of Several Temperature Correction Factors in Table E.1***
- 10. Addition of Informative Annex J Detailing Which ANCE Test Method Documents are Included in the Trinational Test Methods Standard***

The new requirements are substantially in accordance with UL's Proposal(s) on this subject dated October 6, 2006 and April 6, 2007.

As indicated on the title page (page 1), this UL Standard for Safety is an American National Standard. Attention is directed to the note on the title page of this Standard outlining the procedures to be followed to retain the approved text of this ANSI/UL Standard.

The UL Foreword is no longer located within the UL Standard. For information concerning the use and application of the requirements contained in this Standard, the current version of the UL Foreword is located on ULStandardsInfoNet at: <http://ulstandardsinfo.net/ul.com/ulforeword.html>

The master for this Standard at UL's Northbrook Office is the official document insofar as it relates to a UL service and the compliance of a product with respect to the requirements for that product and service, or if there are questions regarding the accuracy of this Standard.

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New product submittals made prior to a specified future effective date will be judged under all of the requirements in this Standard including those requirements with a specified future effective date, unless the applicant specifically requests that the product be judged under the current requirements. However, if the applicant elects this option, it should be noted that compliance with all the requirements in this Standard will be required as a condition of continued Listing and Follow-Up Services after the effective date, and understanding of this should be signified in writing.

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Association of Standardization and Certification
NMX-J-556-ANCE-2007
Second Edition



Canadian Standards Association
CSA C22.2 No. 2556-07
Second Edition



Underwriters Laboratories Inc.
UL 2556
Second Edition

Wire and Cable Test Methods

July 19, 2007



ANSI/UL 2556-2007

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ISBN 1-55436-011-0

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The most recent designation of ANSI/UL 2556 as an American National Standard (ANSI) occurred on July 12, 2007.

This ANSI/UL Standard for Safety, which consists of the Second Edition, is under continuous maintenance, whereby each revision is ANSI approved upon publication.

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Preface

This is the common ANCE, CSA, and UL standard for Wire and Cable Test Methods. It is the second edition of NMX-J-556-ANCE, the second edition of CSA C22.2 No. 2556, and the second edition of UL 2556.

This common standard was prepared by the Association of Standardization and Certification (ANCE), the Canadian Standards Association (CSA), 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.

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.

This standard will be submitted to the Standards Council of Canada (SCC) for approval as a National Standard of Canada.

This standard has been approved by the American National Standards Institute (ANSI) as an American National 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 shall it be considered equivalent to, an IEC standard. This standard is published as an equivalent standard for ANCE, CSA, 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.

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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.

ANCE effective date

The effective date for ANCE will be announced through the Diario Oficial de la Federación (Official Gazette) and is indicated on the cover page.

CSA effective date

The effective date for CSA International will be announced through CSA Informs or a CSA certification notice.

UL effective date

UL 2556 is effective immediately for reference by other standards.

A UL effective date is one established by Underwriters Laboratories Inc. and is not part of the ANSI approved standard.

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Wire and Cable Test Methods

1 Scope

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.

Note: *Specific acceptance requirements are found in individual product standards.*

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

For undated reference to standards, such reference shall be considered to refer to the latest edition and all revisions to that edition up to the time when this standard was approved. For dated references to standards, such reference shall be considered to refer to the dated edition and all revisions published to that edition up to the time the standard was approved.

ANCE (Association of Standardization and Certification)

NMX-E-034-SCFI

Plastic Industry – Carbon Black Contents on Polyethylene Materials – Test Methods

NMX-J-178-ANCE

Electrical Products – Wires and Cables – Determination of Cross Sectional Area of Stranded Electrical Conductors Related to the Mass – Test Method

NMX-J-192-ANCE

Flame Test on Electrical Wires – 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-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 (Canadian Standards Association)

CAN/CSA-C22.2 No. 126.1-02

Metal cable tray systems

ASTM (American Society for Testing and Materials)

A 29/A 29M-03

Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for

D 412-98a(2002)e1

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

D 471-98e1

Standard Test Method for Rubber Property-Effect of Liquids

D 1603-01

Standard Test Method for Carbon Black in Olefin Plastics

D 1835-05

Standard Specification for Liquefied Petroleum (LP) Gases

D 4218-96(2001)

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

D 5025-05

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

D 5207-03

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

D 5374-93(1999)

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

D 5423-93(1999)

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

D 6370-99(2003)

Standard Test Method for Rubber-Compositional Analysis by Thermogravimetry

E 8-01e2

Standard Test Methods for Tension Testing of Metallic Materials

E 662-03e1

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

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E 1131-03

Standard Test Method for Compositional Analysis by Thermogravimetry

G 151-00

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

G 153-00ae1

Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

G 155-00ae1

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

GPA (Gas Processors Association)

GPA 2140-97

Liquefied Petroleum Gas Specifications and Test Methods

IEC (International Electrotechnical Commission)

IEC 60695-11-20 (2003-08)

Fire hazard testing – Part 11-20: Test flames – 500 W flame test methods

ISO (International Organization for Standardization)

ISO 10093:1998

Plastics – Fire tests – Standard ignition sources

NEMA (National Electrical Manufacturers Association)

VE1-2002

Metal Cable Tray Systems

2.3 Safety

2.3.1 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, which 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.

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

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

- 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).

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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

The diameter shall be the average of the six measurements.

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

- a) a balance accurate to 0.1% of mass measured; and
- b) a length-measuring device accurate to 0.1% 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.

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3.2.4 Procedure

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 mm² (8 AWG) and 0.5 m for larger than 8.37 mm² (8 AWG).

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

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

where

M = mass, g (lb)

L = length, mm (ft)

p = density, g/cm³ (lb/(cmil•1000 ft))

= for copper, bare or tin, lead, lead-alloy or nickel-coated, 8.89 g/cm³ (0.003027 lb/(cmil•1000 ft))

= for copper, silver-coated, 8.95 g/cm³ (0.003049 lb/(cmil•1000 ft))

= for copper-clad aluminum, annealed, 3.32 g/cm³ (0.001130 lb/(cmil•1000 ft))

= for aluminum, Alloy 1350, 2.70 g/cm³ (0.000919 lb/(cmil•1000 ft))

= for aluminum, ACM, 2.71 g/cm³ (0.000924 lb/(cmil•1000 ft))

= for nickel, 8.80 g/cm³ (0.002996 lb/(cmil•1000 ft))

= for iron, 7.87 g/cm³ (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:

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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

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

where

m_c = ratio increase due to concentric stranding

n_x = number of wires in layer x

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

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 can 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 can 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

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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 $0.732 \times D$ 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

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

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 $0.732 \times D$ in the outer layer

As in item (a)

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

where

n = the lay ratio:

= for the central wire of diameter D, $n_1 = \text{infinity}$

= 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 x 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

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

is

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

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

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

and

$$k = 8422 \times \frac{D^2}{(\text{LOL})^2}$$

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 Clause 3.1.2.

3.3.3 Preparation of specimens

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

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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, mm²

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.

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3.4.2 Apparatus

The apparatus shall consist of

- a) a 4-terminal measuring device for specimens of resistance of 1Ω or less, with an accuracy of $\pm 0.5\%$;
- b) a 4- or 2-terminal measuring device for specimens of resistance greater than 1Ω , with an accuracy of $\pm 0.5\%$;
- c) a temperature-measuring device with an accuracy of $\pm 1^\circ\text{C}$; and
- d) a length-measuring device accurate to 0.1% of length measured.

For (a) and (b) where applicable, the yoke resistance (between reference standard and test specimen) shall not be less than 0.1% of either the reference standard or the test specimen, unless a suitable lead compensation method is used or it is known that the coil and lead ratios are sufficiently balanced so that variation in yoke resistance will not decrease the bridge accuracy below rated requirements.

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 $0.000\ 01\ \Omega$ ($10\mu\Omega$) 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.

3.4.3.2 The reference standard 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 Clause 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 circumference 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 $10 - 35^\circ\text{C}$, 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:

$$R = r/L$$

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), $\text{m}\Omega$

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.

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3.5.1.2 Apparatus

The apparatus shall consist of

- 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% 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 D 412.

Note 2: Jaws as described in ASTM E 8 have been found to be acceptable.

- b) a length-measuring device with an accuracy of 1% 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 Clause 3.1:

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

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

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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

- 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% 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

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

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.

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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

- 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% , 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, 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, 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.

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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 Figures 2 and 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 Standard A 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.

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3.6.3 Preparation of specimens

Thirty-one specimens of insulated solid 3.31 mm² (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 s. 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 500 cycles of operation, with each cycle consisting of 3.5 h ON and 0.5 h OFF. Care shall be taken not to disturb the connecting wires after applying the torque.

3.6.4.3 Temperature measurement shall be taken in accordance with the method described in Clauses 3.6.4.3.1 and 3.6.4.3.2.

3.6.4.3.1 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.

3.6.4.3.2 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 3.6.4.3.1.

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

3.6.4.4 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.

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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 a length at least 4 times 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 a length at least 4 times 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:

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

or

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

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3.7.4 Procedure

The distance (D) required for 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:

$$L = D/2$$

where

L = lay length, mm (in)

D = distance, mm (in)

3.7.6 Report

The report shall include, as a minimum, the length of lay of the component(s).

4 Insulation 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 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 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);
- 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), with a resolution and accuracy of 0.01 mm (0.001 in); and
- d) a laser micrometer with a resolution and accuracy of 0.01 mm (0.001 in).

4.1.3 Preparation of specimens

4.1.3.1 Minimum thickness at any point

A specimen having a maximum length of 8 mm, 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 Clause 4.1.4.1.2.

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 Clause 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.

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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 Clause 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. If the pin described in Clause 4.1.4.1.1 does not fit within the irregularities, this method is not applicable.

4.1.4.2.2 Difference method

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 Clause 3.1.

4.1.5 Results and calculations

Results shall be recorded.

4.1.5.1 Minimum thickness at any point

The minimum thickness shall be as measured in Clause 4.1.4.1. 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.

4.1.5.2 Average thickness

4.1.5.2.1 Averaging method

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

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4.1.5.2.2 Difference method

The six overall diameter readings obtained in Clause 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.

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 Clause 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:

- 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 D 412 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;
- 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 9×2 mm (0.35×0.08 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 as follows:
 - i) Xenon-arc: Xenon-arc radiation and water-spray exposure equipment shall comply with ASTM G 151 and ASTM G 155 or NMX-J-553-ANCE. The specimens 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 ASTM G 155, Table 1, 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 monitored at a wavelength of 340 nm.
 - ii) Carbon-arc: The apparatus shall comply with ASTM G 151 and ASTM G 153 or NMX-J-553-ANCE. The apparatus is to include twin arcs struck between two sets of vertical carbon electrodes that are 13 mm or 1/2 inch in diameter and are individually enclosed in clear globes of heat-resistant optical glass (9200-PX Pyrex glass or its equivalent) that is opaque at wavelengths shorter than 275 nm (1 % transmission at 275 nm as the nominal cutoff point) and whose transmission improves to 91 % at 370 nm. The spectral power distribution of the emission from the globes shall comply with Table 1 of ASTM G 153 or NMX-J-553-ANCE;
- 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 D 5423 (Type II ovens) and ASTM D 5374 and shall circulate the air within the aging chamber at high velocity. Fresh air is to 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:
 - i) to produce a strip of insulation from a 13.3 mm^2 (6 AWG) or larger conductor or a strip of jacketing material; and
 - ii) to remove irregularities from samples of insulation, jacket, or the like that are not thinner than 0.76 mm (0.03 in);
- 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 ($\text{rpm} \times \pi \times \text{wheel diameter}$) 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;

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

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

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 Clause 4.2.4.2.2 or 4.2.4.2.3, if the wire or cable is smaller than 13.3 mm² (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 Clause 4.2.4.2.3.
- b) If a jacket, it shall be die-cut, prepared in accordance with Clause 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:
 - i) in its finished tubular form;
 - ii) die-cut without performing the buffing operation when this would reduce the thickness to less than 0.38 mm (0.015 in); or

- iii) 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 Clauses 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. See 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 Clause 4.2.3, Items j), k), or l), whichever is best suited for the material, to provide a smooth specimen of uniform thickness. Adhering insulation shall be removed from a jacket sample. Adhering jacket shall be removed from an insulation sample.
- c) After allowing the sample to rest for at least 30 min, the specimen shall be cut from the smoothed section using one of the dies specified in Clause 4.2.3. The use of a press for operating the cutting die is recommended (see Clause 4.2.3). 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 a die-cut specimen shall be no greater than 16 mm² (0.025 in²). The thickness shall be not less than 0.38 mm (0.015 in).

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:

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

where

A = cross-sectional area, mm² (in²)

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 may 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)

4.2.5.1.2 Parallel, flat or irregularly shaped specimens

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

$$A = \frac{W}{0.15D} \text{ mm}^2 \quad \text{or} \quad \frac{W}{6D} \text{ in}^2$$

where

A = cross-sectional area, mm² (in²)

W = mass of a specimen 150 mm (6 in) long, with the conductor(s) removed, g (oz)

D = density of the compound, g/cm³ (oz/in³)

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

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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 Clause 4.2.3, Item (e). The area shall be calculated from the following formula:

$$A = t \times w$$

where

A = cross-sectional area, mm² (in²)

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 min prior to testing. Video, laser, or mechanical extensometers or a scale method shall be used to determine elongation. When other than a mechanical extensometer is used, two gauge marks, 25 mm (1 in) apart and 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 25 mm (1 in) 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.

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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 Clause 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:

$$TS = W/A$$

where

TS = tensile strength, MPa (lbf/in²)

W = maximum load before break, N (lbf)

A = cross-sectional area, mm² (in²)

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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 Clauses 4.2.3 to 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

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 Clause 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 required period of time specified in the product standard. 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 h at ROOM TEMPERATURE.

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

4.2.8.3 Oil resistance

The immersion vessel shall have a minimum volume of 100 ml (6 in³). The vessel shall be filled with a specified oil and then placed in a bath or oven as described in Clause 4.2.3. Specimens shall be suspended in the vessel and maintained at the temperature and time specified in the end product standard. 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.

Following immersion, the specimens shall be blotted to remove excess oil, and allowed to rest for 16 to 96 h.

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

4.2.8.4 Gasoline resistance

The immersion vessel shall have a minimum volume of 100 ml (6 in³). 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 D 471 (Fuel C) for the iso-octane and toluene blend.

Specimens shall be suspended in the vessel and maintained at the temperature and time specified in the end product standard. 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.

Following immersion, the specimens shall be blotted to remove excess fluid, and allowed to rest for 16 to 96 h.

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

4.2.8.5 Weather (sunlight) resistance

4.2.8.5.1 Xenon-arc exposure

Samples of finished cable shall be exposed in the xenon-arc apparatus for the number of hours specified by the product standard, in accordance with the procedure described in NMX-J-553-ANCE or Cycle 1 exposure in ASTM G 155, except that the pH of the water shall be 4.5 – 8.0. Each cycle shall consist of 102 min of light and 18 min of light and water spray. Samples shall be mounted in accordance with the xenon-arc apparatus manufacturer's instructions.

4.2.8.5.2 Carbon-arc exposure

Samples of finished cable shall be exposed in the weathering apparatus for the number of hours specified in the product standard, in accordance with the procedure described in ASTM G 153 or NMX-J-553-ANCE, except that the pH of the water shall be 4.5 – 8.0. Each cycle shall consist of 17 minutes of light and 3 minutes of light and water spray. The carbon arcs shall operate continuously and carry a current of 15 to 17 A each at a drop in rms potential of 120 to 145 V. Samples shall be hung vertically in the drum of the apparatus.

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4.2.8.5.3 Specimen preparation and testing

Following either exposure, the samples 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 and not more than 96 h. Ultimate elongation and tensile strength shall be determined using the apparatus and procedure described in Clauses 4.2.3 to 4.2.6. 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 cable shall be prepared in an identical manner and tested simultaneously.

4.3 Dry temperature rating of new materials (long-term aging test)

4.3.1 Scope

This test verifies the dry temperature rating of new materials, and establishes short-term air oven aging parameters and requirements.

Note 1: The long-term aging test evaluates a material for its dry temperature rating only. Other properties are evaluated based on requirements in the applicable wire and cable standard.

Note 2: For the product standard, after sufficient experience with a new material has been compiled, the material will be submitted for inclusion in the standard in a timely manner.

4.3.2 Apparatus

The apparatus shall be as specified in Clause 4.2.3.

4.3.3 Preparation of specimens

4.3.3.1 Specimens shall be prepared as described in Clause 4.2.4.

4.3.3.2 The total number of specimens in the oven shall enable removal of specimens in sets of six at a time, in intervals of 90, 120, and 150 d and, at the manufacturer's request, in additional intervals of 180 and 210 d.

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4.3.4 Procedure

4.3.4.1 The specimens shall be aged as described in Clause 4.2.8.2 at the temperature determined in Clause 4.3.4.2.

4.3.4.2 The oven temperature, T_{test} , shall be 102% of the desired temperature rating expressed on the Kelvin scale. This temperature shall be calculated, in °C, using the following formula (T_{test} shall be rounded to the nearest whole number):

$$T_{\text{test}} (^{\circ}\text{C}) = 1.02 \times (273.15 + T_{\text{rating}} (^{\circ}\text{C})) - 273.15$$

Note: The test temperatures applied for the most common temperature ratings are given in Table 4.

4.3.4.3 Sets of six specimens shall be removed at the intervals specified in Clause 4.3.3.2.

4.3.4.4 Test specimens in each set shall be tested individually for ultimate elongation and tensile strength as described in Clause 4.2.3 to 4.2.6. The ultimate elongation and tensile values for each set of specimens shall be averaged for each aging time interval. If the results of one or more of the six specimens differ significantly, the results from only one specimen may be discarded.

4.3.5 Results and calculations

4.3.5.1 The ultimate elongation and tensile strength shall be calculated in accordance with Clause 4.2.6.

4.3.5.2 The ultimate elongation or tensile strength at 300 d shall be determined by the following formula:

$$U_{(t)} = U_{90} \times e^{-R(t - 90)}$$

where

$U_{(t)}$ = ultimate elongation, % or tensile strength, MPa (lbf/in²)

U_{90} = regression constant (ultimate elongation or tensile strength computed at 90 d)

R = decay constant as determined in Clause 4.3.5.4

t = time, d

See Annex C for a sample calculation.

4.3.5.3 The variables in the formula, transformed as $Y = \ln[U_{(t)}]$, $B = \ln[U_{90}]$, and $T = (t - 90)$, convert the formula into linear form $Y = B + RT$.

4.3.5.4 Using the 90 d and longer-term data, the constants B and R shall be determined by least squares linear regression. The projected ultimate elongation or tensile strength at 300 d shall then be calculated using the formula in Clause 4.3.5.2.

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