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TECHNICAL SPECIFICATION

colour inside

Conductors for overhead lines – Fiber reinforced composite core used as supporting member material –
Part 2: Metallic matrix composite cores

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CONDUCTORS FOR OVERHEAD LINES – FIBER REINFORCED COMPOSITE CORE USED AS SUPPORTING MEMBER MATERIAL –

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IEC TS 62818-2 has been prepared by IEC technical committee 7: Overhead Electrical Conductors. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
7/753/DTS	7/755/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

A list of all parts in the IEC 62818 series, published under the general title *Conductors for overhead lines – Fiber reinforced composite core used as supporting member material*, can be found on the IEC website.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

The first conductors using a composite core were installed in the early 2000s. Since then, they have been increasingly used by utilities worldwide. As a result, there is a need for an IEC publication to agree on tests methods to qualify these cores.

Because of the potential variety of products possible for this purpose, this document does not set minima or maxima (usually provided by the manufacturer, but rather standardizes testing methods to ascertain the numerical values of the basic properties needed by the purchaser to choose the right supporting member material according to the properties of the overhead line conductors. Future discussion items for review may include: performance level and acceptance criteria, other ageing tests and criteria or other relevant tests.

In a future document, tests on the complete conductor which include the composite core will be covered in detail (for example salt fog, corrosion test, mechanical tests, etc.).

CONDUCTORS FOR OVERHEAD LINES – FIBER REINFORCED COMPOSITE CORE USED AS SUPPORTING MEMBER MATERIAL –

Part 2: Metallic matrix composite cores

1 Scope

This part of IEC 62818, which is a Technical Specification, establishes a system of fiber reinforced composite cores used as supporting member material in conductors for overhead lines which may be used as the basis for specifications. This document is applicable to fiber reinforced composite core, with a metallic matrix, used as supporting member material in conductors for overhead lines.

This document gives guidance on:

– defining the common terms used for fiber reinforced composite cores with a metallic matrix,
– prescribing common methods and recommendations to characterize the properties of fiber reinforced composite cores based on single or multi-wires, with MMC (Metallic Matrix Composite) used as a supporting member material in conductors,
– prescribing or recommending acceptance or failure criteria when applicable.

These tests, criteria and recommendations are intended to ensure a satisfactory use and quality under normal operating and environmental conditions.

This document does not prescribe performance or compliance criteria which may be required but indicative values could be given in Annexes for guidance.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-11:2021, *Environmental testing – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60216-1:2013, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results*

IEC 60468:1974, *Method of measurement of resistivity of metallic materials*

IEC 63248:2022, *Conductors for overhead lines – Coated or cladded metallic wire for concentric lay stranded conductors*

ISO 527-5:2021, *Plastics: Determination of tensile properties – Part 5: Test conditions for unidirectional fiber-reinforced plastic composites*

ISO 11359-1:2023, *Plastics – Thermomechanical analysis (TMA) – Part 1: General principles*

ISO 11359-2:2021, *Plastics – Thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

ISO 14125:1998, *Fiber-reinforced plastic composites – Determination of flexural properties*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
metallic matrix composite wire
MMC
assembly of continuous fibers (such as aluminum oxide, silicon carbide, or other ceramic fibers) embedded longitudinally in a metal matrix (such as aluminium)

3.2
composite core
MMC single or multi-wires including additional protection (metallic or non-metallic) if existing in the final application

3.3
external protective layer
outer layer made of a metal or alloy applied onto the MMC for the purpose of protecting it against external aggressions (such as corrosion, oxidation, etc)

Note 1 to entry: In case of a core based on an assembly of composite wires, this protective layer could be applied to:

- each individual wire,
- the assembly of wires.

Note 2 to entry: Individual wires could be protected with different materials. In this case, testing protocols shall be adapted in relation to the specific material.

3.4
fiber reinforced
continuous fibers incorporated within a metallic matrix in order to increase its performance

Note 1 to entry: It is achieved through specific processes such as infiltration, casting, etc.

3.5
fiber
organic or inorganic bundle of filaments that is essentially continuous

3.6
metal
matrix component of the MMC

Note 1 to entry: Many metals and alloys are possible, but aluminium is commonly used

3.7
porosity
measurement of the void fraction in the material over the total volume

Note 1 to entry: It results from a lack of matrix infiltration or from solidification shrinkage. It distinguishes itself from composite crack or fracture by that it is a lack of matrix but not a matrix mechanical fracture.

3.8
lot
group of production units of one type and size of wire, which was manufactured by the same manufacturer during the same time period under similar conditions of production

Note 1 to entry: A lot may consist of part or all of a purchased quantity.

Note 2 to entry: If agreed between the purchaser and the manufacturer, for example for the Type tests, a Lot could be composed of only one Production unit.

3.9
production unit
coil, reel, spool, or other package of individual composite core that represents a single usable length

3.10
sample
specimen(s) removed from a production unit(s) which is considered to have properties representative of a lot

3.11
specimen
length of composite core removed for test purposes

3.12
equivalent diameter
diameter of a circle which would have the same cross-sectional area as a given formed wire

4 Symbols and abbreviation terms

CTE	coefficient of thermal expansion (°C^{-1})
DC	direct current (A)
F_f	flexural load at break (N)
F_t	tensile load at break (N)
RTS	rated tensile strength (kN)
SEM	scanning electron microscope
TMA	thermo-mechanical analysis
$T_{C,CORE}$	maximum continuous temperature (°C) of the composite core
$T_{P,CORE}$	maximum peak-load temperature (°C) of the composite core
σ_f	flexural stress at break (MPa)

5 Requirements

5.1 Composite core manufacturing

Composite cores shall be produced according to the dimensional, mechanical and thermal properties agreed between purchaser and manufacturer, respecting the acceptance values and tolerances. These properties shall be uniform along the lot and every production unit shall be free of internal and external imperfections (e.g. high porosity, unwanted inclusions, scratches, notches, cracks). Each composite wire shall be produced with a single assembly of continuous fibers; no fiber end-to-end joint is allowed, unless clearly agreed between both parties.

5.2 Composite core sampling and tests

5.2.1 General

Tests on composite core are described in Clause 7 and shall be classified as:

a) Type test (T),
b) Sample test (S),
c) Routine test (R).

In order to ensure satisfactory quality of the core and to properly characterize its properties, a list of type tests, sample tests and routine tests is provided in Table A.1, with a suggested sampling.

For a more detailed characterization of the core, additional/optional tests are also proposed in the same table and described in Clause 8.

Laboratories and scheduling of tests shall be previously agreed between the purchaser and the manufacturer. Since ageing tests can be very long, the manufacturer's laboratory may be used under the supervision of an independent third party.

5.2.2 Type tests

Type tests are intended to establish design characteristics. They are normally made once on a prototype and repeated only in case of a change of materials or design (for example fiber types, matrix types, fiber volume ratio, or shape). The type tests performed for a given diameter may qualify a range of diameters to be agreed between the purchaser and manufacturer. The results of type tests are recorded as evidence of compliance with design requirements.

5.2.3 Sample tests

Sample tests are intended to verify the quality of materials and workmanship. They are performed on samples taken from the produced drums of finished core in order to verify the compliance with design specifications and type tests results.

The sampling of the sample tests is suggested in Table A.1.

5.2.4 Routine tests

Routine tests are intended to verify compliance and stability of core characteristics during the production of a lot. Sampling for Routine tests depends on the characteristics and monitoring systems for each production process.

5.3 Composite core traceability and packaging

In order to ensure composite core traceability, orders shall include at least the following information:

a) lot identification number,
b) number of production units per lot,
c) core size (diameter in mm, if applicable number of wires, sizes of wires, lay length and direction),
d) length of each type of core,
e) type and size of package and method of packing,
f) special package marking,
g) test report with quantitative results (if required).

The core shall be suitably protected against damage and deterioration which could occur in ordinary handling, shipping and storage.

Package marking shall not be easily removable during ordinary handling.

The manufacturer shall have raw material traceability for production units and lots.

6 Composite core thermal performance

6.1 General

Composite materials can experience a change in their composition and a deterioration of their mechanical performance after a long-term exposure to high temperatures. Thus, it is necessary to experimentally assess their inner resistance to thermal degradation in order to define the maximum temperature to be respected for a safe use of the complete conductor during the lifetime of the overhead line.

The metal matrix composite core thermal performance is defined by the two temperatures below:

a) Maximum continuous temperature of the composite core: $T_{\text{C,CORE}}$

b) Temperature limit for use in peak load of the composite core: $T_{\text{P,CORE}}$

These temperatures are intended to be measured at the external surface of the composite core.

$T_{\text{C,CORE}}$ and $T_{\text{P,CORE}}$ shall be determined from the experimental result of the test described in 7.2.7 and if needed 7.2.9.

A lower $T_{\text{C,CORE}}$ and $T_{\text{P,CORE}}$ value may be utilized if agreed upon between purchaser and manufacturer.

6.2 Maximum continuous temperature of the composite core: $T_{\text{C,CORE}}$

This temperature is the maximum continuous temperature at which the composite core can be exposed, without deterioration according to Appendix B, for a duration equal to its lifetime. The intended life expectancy of the core is typically 40 or 50 years.

Once the reference lifetime is defined, $T_{\text{C, CORE}}$ shall be determined by an extrapolation of the experimental results of the thermal aging test, as described in 7.2.9.

6.3 Temperature limit for use in peak load of the composite core: $T_{\text{P,CORE}}$

This temperature is the maximum peak load temperature at which the composite core can be exposed, without deterioration according to Annex B, for a maximum cumulative time during its lifespan.

The duration of this maximum time of exposure at high temperature is typically 400 to 1 000 hours cumulative during the life expectancy of the core.

As this temperature is related to the final use of the conductor for which the core will be used, a longer time can be specified by the purchaser, if needed.

7 Tests for the composite core characterization

7.1 General

Subclauses 7.1 to 7.3 describe the test methods for the assessment of the composite core properties at their initial state. The tests are separated into two groups. One group applies to individual (single) wires, and a second group to multiple wires that are stranded into a multi-wire core (typically a 7-, 19-, or 37-wire core). The tests are:

a) Single Wire
   1) Appearance (7.2.1)
   2) Diameter (7.2.2)
   3) Mass per unit length (7.2.3)
   4) Coefficient of thermal expansion (CTE) (7.2.4)
   5) Mechanical – Tensile Breaking Load (7.2.5)
   6) Mechanical – Flexural test (7.2.6)
   7) Isothermal aging (7.2.7)
   8) DC electrical resistivity (conductivity) (7.2.8)
   9) Thermal aging degradation test (Arrhenius method) (7.2.9)
b) Stranded Core (multi-wire)
   1) Appearance (7.3.1)
   2) Diameter (7.3.2)
   3) Lay ratio (lay length) (7.3.3)
   4) Lay direction (7.3.4)
   5) Mass per unit length (7.3.5)
   6) Mechanical – Tensile breaking load (7.3.6)
   7) Holding ability of external tape (if present) (7.3.7)
   8) Coefficient of thermal expansion (CTE) (7.3.8)

7.2 Tests for single wire

7.2.1 Appearance (wire)

The wire (including any protective layer) shall be free from any defects (scratch, scrape, notch, hole, or crack) not consistent with good commercial practice. This only covers defects significantly visible to the unaided eye (normal corrective lenses accepted). A representative photograph may be attached to the official test report at the request of the purchaser.

7.2.2 Diameter (wire)

The diameter of the single wire (including any protective layer) shall be measured with a device with an accuracy of at least 0,01 mm. Diameter(s) shall be expressed in millimeters to two decimals places.

Diameter(s) shall be measured by one of the following methods:

a) a continuous/in-line process measurement (in-line measurement), performed using a 2-axis or 3-axis caliper (laser or mechanical) with equal phase shifts in the same straight section. In addition, a rotating head device may be used where the diameter is continuously scanned during the rotation. The average value of the diameter should be reported.

b) a direct/manual measurement, performed using micrometers or callipers. The diameter shall be measured at a single point, but with two readings taken 90° from each other. The average value of the two readings shall represent the average diameter of the wire. If measurements are taken during a continuous production run, at least 2 diameter measurements shall be taken, one at the start and one at the end of the production unit. If samples are cut for the purpose of a direct/manual diameter measurement, one sample should cut be cut from either the start or end of the production unit, and the sample shall be at least 1 m long, and shall be measured in the middle. Minimum, maximum and average values of diameter shall be reported for each sample.

c) derive the cross-sectional area by Formula (1):

$$A = m / (l \times \rho) \quad (1)$$

where

A is the cross-sectional area, expressed in square millimeters (mm^2);

m is the mass, expressed in grams (g);

l is the total length, expressed in meters (mm);

ρ is the density of a wire, expressed in grams per cubic millimetre (g/mm^3)

Then the equivalent diameter is computed by Formula (2):

$$d = \sqrt{(4A / \pi)} \quad (2)$$

where

d is the equivalent diameter, expressed in millimetres (mm)

A is the cross-sectional area, expressed in square millimetres (mm^2)

This method is referenced in IEC 63248:2022, 7.4.2.3.

Cut a 1 m length of wire (accuracy of ± 0,1 % in length). Weigh the sample to determine the mass. The weighing apparatus should have an accuracy of ±0,1 %. Use the known wire density (provided by the manufacturer).

This method can be used for shaped or non-circular wires and the result reported as an equivalent diameter.

d) use a metallographic method, in which the wire shall be cut, mounted for metallographic preparation, and polished to verify the compliance of the shape of the cross section with the designed shape. The measurements shall be performed with an optical or mechanical device with an accuracy of 0,01 mm. The computation or template used for deriving the diameter should be provided.

The manufacturer shall provide a specification for the required wire diameter (d) and the permitted tolerance (t).

7.2.3 Mass per unit length (wire)

Mass per unit length shall be tested using an apparatus capable of measuring the mass (m) with an accuracy of ±0,1 %.

The value of mass per unit length shall be taken on a minimum number of one (1). The length (l) of each tested sample shall be at least 1 meter.

The report shall include the mean value of mass per unit length (in g/m).

The manufacturer shall provide a specification for the required mass per unit length (m/l) and the permitted tolerance.

7.2.4 Coefficient of thermal expansion (wire)

The coefficient of thermal expansion (CTE) of the core (including any external protective layer) can be measured using the following procedure. The CTE of the stranded core may also be measured (7.3.8), but it is suggested that only one of the measurements, the wire or the stranded core needs to be measured. This may be decided by agreement between the purchaser and manufacturer.

For an individual wire, the (CTE) can be measured using Thermo-Mechanical Analysis (TMA) in accordance with ISO 11359-1:2023 and ISO 11359-2:2021. At least 2 samples (repeatability) shall be randomly chosen and tested. The expansion shall be measured in the fiber direction (axial) between ambient temperature and $T_{\mathrm{P,CORE}}$ with a slope of 3 °C/min. The report shall present the TMA curves with the measured values of CTE in $°C^{-1}$ and list the average value represented by each curve. The maximum CTE of the obtained averages values, shall be the final result.

Consideration should be given to the accuracy and precision of the TMA method. It is critically important that care is taken to ensure that the recorded temperature is that of the test sample and not of the enclosure, which can be a major source of error.

The manufacturer shall provide a specification for the required CTE (α) and the permitted tolerance (t).

7.2.5 Mechanical properties – tensile breaking load (wire)

A tensile breaking load test shall be performed, in accordance with ISO 527-5:2021, to define the mechanical characteristic of a composite core wire. Only the breaking load value need be measured and reported. For type testing only, the tensile elastic modulus shall also be measured, in accordance with ISO 527-5:2021, and the tensile modulus shall be calculated from the slope of the load-elongation curve.

Clamping jaws and associated fixtures for the end of the sample used in the tensile test shall be correctly designed to transfer load without creating local stress concentrations, especially within and at the end of the clamping region. This may include such combinations as:

a) pneumatic grips with a very long gripping length (for example 30 cm),
b) wire adhesively bonded into long steel tubes with a short length of the tube having no wire, where the shorter gripping jaws can apply high pressure,
c) bolted grips with a long gripping region (for example 20 to 30 cm) with the end of the bolted section having no wire and a hole to receive a pin for attachment into the tensile test equipment.

A well-performing clamping jaw / end fixture assembly should produce a high proportion of fractures within the wire gauge length and not at the end fixture.

The gripping jaws of the tensile test frame should be well aligned relative to each other (for both translation and tilt), especially if shorter sample gauge lengths (less than 15 cm) are used. Poor alignment can lead to frequent fracture at the exit of the gripping jaw due to stress concentration, causing the measurement of artificially low loads.

It is suggested to use a minimum gauge length of 60 cm for standard size laboratory test frames; thus, the cut sample needs to be longer to account for the gripping region. Longer gauge lengths are permitted as some production test equipment is built to sample long lengths (for example 8 m).

In sample tests, only one test per production wire is required, although other sampling rates are permitted by agreement between the purchaser and manufacturer. In type testing, at least 5 samples of composite core wire shall be tested to have a reliable mean value.

If type-testing a finished stranded core or full-conductor, the individual core wires may be removed from the sample and tested. Thus a 7-strand core would yield 7 tensile tests, or a 19-strand core would yield 19 tensile tests, etc.

A load shall be introduced into the sample by control of the test frame crosshead speed. A strain rate of 0,02/min is recommended. This will typically load to failure in 30 to 60 s.

The breaking load of the sample, "F_t", shall be reported.

If a failure occurs at the end fixture or within the gripping region, or slip occurs, then if desired, the test may be repeated with a new sample. If the breaking load is above the minimum specification, then it may be acceptable to just use this value, knowing that the actual breaking load in the absence of a stress concentration from the fixture could be higher.

All wires shall have a tensile breaking load greater than the minimum specification provided by the manufacturer.

7.2.6 Mechanical properties – flexural breaking load (wire)

The flexural properties of composite wires shall be measured in accordance with the general set-up of ISO 14125:1998. The shape of test specimen shall be defined by the laboratory, in agreement with purchaser and manufacturer, using a 4-point bending device. If round wires are produced, it is recommended to use the round wires in the test.

For type testing, five specimens shall be tested.

Typically for a metal matrix composite it is suitable to just use the round as-manufactured wire, but this will require the adjustment of the peak-stress formula to account for the round wire.

Another consideration is to ensure the failure occurs in either tension or compression, but not in shear. The span-width to sample-thickness ratio controls this behaviour. Using a span-to-thickness ratio of 16 is recommended, although values 12 to 32 are permitted and may be needed to avoid shear failures. Note this requires a 4-point bend fixture (or additional fixtures) where the span width can be changed to accommodate different wire diameters.

The report shall describe the test design and include the flexural test curves with the mean values of:

– flexural load F_f at break (in N),
– flexural stress at break σ_f (in MPa).

The stress shall be calculated using the diameter values obtained in 7.2.2.

Photographs of the composite wire fracture behaviour shall be attached to the report, showing the type of fracture (tensile or compression).

The manufacturer shall provide a specification for the minimum flexural stress.

All wires shall have a breaking stress greater than the minimum specification provided by the manufacturer.

A 4-point bending formula is provided, using a fixture that has an inner span 1/3 of the outer span. This is a common choice, but sometimes there can be other configurations.

For this geometry, the governing equation for bending stress (σ) work is Formula (3):

$$\sigma = \frac{M \times c}{I_{xx}} \tag{3}$$

where

M is the bending moment, expressed in Newton metres (N × m);

c is the distance from the neutral axis, expressed in metres (m);

I_{xx} is the moment of inertia, expressed in kilogram metre squared (kg × m^2).

Formula (4) describes the governing equation for bending moment (M)

$$M = \frac{P}{2}\frac{L_{\text{out}}}{3} = \frac{P\,L_{\text{out}}}{6} \tag{4}$$

where

P is the force, expressed in Newtons (N);

L_{out} is the outer span length, expressed in metres (m).

The term L/3 results from the geometry (inner span is 1/3 of outer span) and is the span length between the inner and outer contact points. Note if the inner span was ¼ of the outer span length, then the L/3 term would change to 3L/8).

Formula (5) expresses the distance from the neutral axis.

$$c = \frac{d_{\text{wire}}}{2} \tag{5}$$

where

d_{wire} is the diameter of the wire, expressed in metres (m).

Formula (6) describes the governing equation for moment of Inertia (I_{xx}).

$$I_{xx} = \frac{\pi r^4}{4} = \frac{\pi d_{\text{wire}}^4}{64} \tag{6}$$

where

r is the radius of a round wire, expressed in metres (m);

Thus, the final formula for bending stress becomes Formula (7):

$$\sigma = \left(\frac{P\,L_{\text{out}}}{6}\right)\left(\frac{d_{\text{wire}}}{2}\right) / \left(\frac{\pi d_{\text{wire}}^4}{64}\right) = \frac{16\,P\,L_{\text{out}}}{3\pi d_{\text{wire}}^3} \tag{7}$$

All wires shall have a breaking bending stress greater than the minimum specification provided by the manufacturer.

7.2.7 Isothermal aging (wire)

An isothermal aging test shall be performed at the maximum (peak) intended use temperature. In this case, that would be at $T_{P,CORE}$. The duration of the test shall be chosen to reflect the intended maximum time of exposure to this temperature.

Twenty (20) test samples shall be taken from the same length of wire, and each sample shall have a length suitable for performing the subsequent tensile test in 7.2.5 and flexure test in 7.2.6. Five (5) of the test samples will be tested according to 7.2.5 without any heat exposure. Five (5) more of the test samples will be tested according to 7.2.6 without any heat exposure. Ten (10) test samples shall be placed in an oven, set at a temperature of $T_{P,CORE}$, and held for 400 hours. A different aging time may be used on agreement between purchaser and manufacturer (for example, 1 000 hours is another common time duration used for the highest temperature rating).

Test procedures and equipment shall be compliant to IEC 60216-4, where temperature tolerances and ventilation rates of air exchange of the natural air flow testing ovens are defined.

Specimens shall be placed parallel to the bottom of the oven and as close as possible to the thermocouple, avoiding the contact with the internal oven walls. As natural stratification of the air inside the oven can introduce a significant vertical gradient in temperature, it is recommended not to arrange the specimens of the same set of samples on different shelves.

After completion of the 400-hour heating, the samples may be removed from the oven and allowed to cool to room temperature. Once cool, five (5) samples are tested according to 7.2.5, and five (5) samples are tested according to 7.2.6.

The average breaking load for each condition is calculated (no aging, high temperature aging, tensile, flexure).

The type of fracture (tensile or compression), that occurs in flexure should be noted with the use of photographs.

7.2.8 DC electrical resistance (wire)

DC electrical resistance shall be measured on individual MMC wires, according to the method of IEC 60468:1974 (applying a 4-point method). The value of resistance shall be calculated as the average value of the measurements taken on at least one (1) sample. The length of each tested sample shall be at least 1 m. Optionally, the resistivity or conductivity may also be calculated and reported based on the diameter measured in 7.2.2.

The report shall include the mean value of resistance at 20 °C (Ω/m), or the resistivity (in Ω mm^2/m) or the conductivity (% IACS).

All wires shall meet or exceed the minimum conductivity specification or be less than the maximum resistance or maximum resistivity specification, provided by the manufacturer.

7.2.9 Thermal Aging degradation test (Arrhenius method) (wire)

As the composite core wire is designed to be the mechanical support or reinforcement of an overhead line conductor, it is required to maintain its strength during the whole lifetime of the overhead line itself, normally 40 or 50 years. A test with such a duration is not possible, thus only accelerated aging procedures are practical to demonstrate the durability of the core wire for the requested lifetime at a certain temperature. This maximum temperature under 40-50 years of exposure is defined as $T_{C,CORE}$.

The procedure for the accelerated ageing test is based on the Arrhenius curves method (IEC 60216-1:2013) and is summarized in Annex B. This involves aging core wires for various lengths of time at a few different temperatures. At the end of the thermal aging, the samples are tested for tensile breaking load as outlined in 7.2.5. At each combination of time and temperature, a minimum of five (5) wire samples should be tested and the average breaking load of each condition is computed and compared.

The result of this test is T_{40y}, the extrapolated theoretical limit temperature for 40 years lifetime (or T_{50y} for 50 years lifetime).

Note that for some metal matrix composite systems, there is very little to no reduction in strength of the material at temperatures far above $T_{C,CORE}$, even close to the melting temperature. In these cases, where there is so little strength change, and an Arrhenius analysis is not possible, it is sufficient to provide results of an isothermal aging test (as outlined in 7.2.7) which shows the core is stable at these much higher temperatures.

7.3 Tests for stranded core (multi-wire core)

7.3.1 Appearance (stranded core)

The stranded core shall be free from any defects (scratch, scrape, notch, hole, or crack) not consistent with good commercial practice. This only covers defects significantly visible to the unaided eye (normal corrective lenses accepted). A representative photograph may be attached to the official test report at the request of the purchaser.

7.3.2 Diameter (stranded core)

Diameter(s) shall be measured by one of the following methods and shall be measured midway between the capstan and the closing block on the stranding machine (maintains tension on the core):

a) a continuous/in-line process measurement (in-line measurement), performed using a 2-axis or 3-axis caliper (laser or mechanical) with equal phase shifts in the same straight section. Also, a rotating head device may be used where the diameter is continuously scanned during the rotation. The average value of the diameter should be reported.

b) a direct/manual measurement, performed using calipers. This caliper shall be graduated to be read in 0,01 mm. The diameter shall be measured at a single point, but with a minimum of two readings taken 90° from each other. The average value of the two readings shall represent the average diameter of the wire, rounded to two decimals of a millimetre. Note this measurement will have a low repeatability (high variability) given the high and low spots around a multi-wire core. It is preferred, if possible, when using the direct/manual measurement, to measure the diameter of a circumscribed circle (Figure 1), and measure at least three directions within the same cross section.

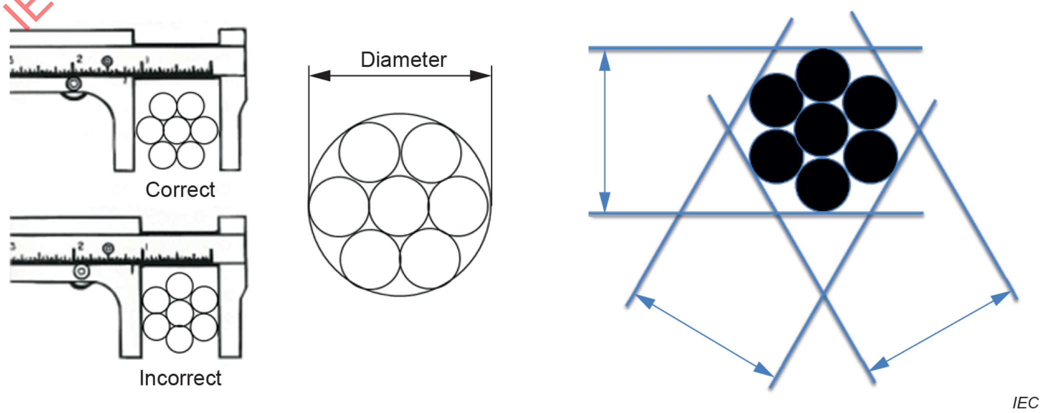

Figure 1 – Measurement of multi-wire core diameter

The use of a micrometer/caliper with long platens/faces (e.g. a minimum of 7,5 cm long), can easily capture the largest diameter and so is ideal for measuring the true circumscribed circle. In this case, two readings taken 90° from each other would be sufficient.

c) a direct/manual measurement using a diameter tape (pi-tape). The tape shall be capable of reading to 0,01 mm.

   If diameter is measured on a sample cut from a reel, then a direct/manual diameter measurement shall be used, and the sample shall be at least 1 m long. Prior to cutting, the ends shall be secured (for example by using tape or clamps), to prevent unwinding of the core. The measurement using calipers should then be taken at the center of the cut sample.

The manufacturer shall provide a specification for the required stranded core diameter (D) and the permitted tolerance (T).

7.3.3 Lay ratio (Lay Length) (stranded core)

The lay ratio of each layer of the core shall be obtained through the ratio of the measured lay length to the external diameter of the applicable layer.

Use a tape measure or ruler to obtain the lay length of the wires in each layer, and calipers or tape to obtain the external layer diameter.

The manufacturer shall provide a specification for the permitted ranges of lay ratio for each layer.

7.3.4 Lay direction

The direction of lay for each layer of the core shall be noted.

The manufacturer shall provide a specification for the permitted lay directions for each layer.

7.3.5 Mass per unit length (stranded core)

Mass per unit length shall be measured using an apparatus with an accuracy of ±0,1 %.

The value of mass per unit length shall be taken on a minimum number of one (1) sample. The length of each tested sample shall be at least 1 meter.

The report shall include the mean value of mass per unit length in g/m.

The manufacturer shall provide a specification for the required mass per unit length (M/L) and the permitted tolerance (T).

7.3.6 Mechanical properties – tensile breaking load (stranded core)

The sample shall use resin cone terminations to act as end fittings.

The sample length, between end terminations, shall be at least 100 times the stranded core diameter. A shorter length may be agreed between the purchaser and manufacturer.

The breaking strength of the core shall be determined by pulling a core in a suitable tensile testing machine having an accuracy of at least ± 2 %. The rate of increase of load shall be 30 % RTS / min.

The breaking load of the core shall be determined by the maximum load attained. The test shall be considered satisfactory if 95 % of the rated load is achieved before final fracture. If fracture occurs within 15 cm of the end terminations before 95 % of the rated breaking load has been reached, the fracture shall be deemed to have been caused by the end termination and a retest is permitted if desired.

The manufacturer shall provide a specification for the minimum breaking load of the stranded core. It is required that the measured breaking load be ≥ 95 % of the specified minimum breaking load.

7.3.7 Holding ability of retaining means (tape)

If the stranded core uses a retaining means (for example a tape) to keep the wires in a stranded configuration, then the retaining means should be evaluated as follows.

Cut a 1 m length of stranded core. By hand, remove the retaining means over a length of 10 cm from one end. Typically, the wires in the region where the retaining means has been removed will expand and straighten due to the elastic behaviour of the wires.

Inspect the next 10 cm of the core that has the retaining means around it. The retaining means should remain tightly bound to the core and not permit the core to expand. If the retaining means loses the ability to hold, the retaining means will slip, and the core will expand and straighten.

Photographs shall be taken to document the transition region where the retaining means has been removed.

The retaining means should hold the stranding configuration of the core in the region 10 cm from the point where the retaining means has been removed.

7.3.8 Coefficient of thermal expansion (stranded core)

7.3.8.1 General

The CTE of the individual wire may also be measured (7.2.4), but it is suggested that only one of the measurements, the wire or the stranded core needs to be measured. This may be decided by agreement between the purchaser and the manufacturer.

The coefficient of thermal expansion (CTE) of the stranded core may be measured using the procedure in 7.3.8.2 and 7.3.8.3. The stranded core is held under constant tension, and heat is applied to the conductor and the extension of the core is measured as a function of temperature.

7.3.8.2 Sample preparation

The core can be heated by using a heating tape directly over the core or over an aluminium tube covering the core, an oven, or over aluminium wires (from a conductor sample) where the aluminium strands are peeled back exposing the core at both ends but keeping the aluminium strands over the core in the heated section. Multiple heating tape sections may be used to create a more uniform temperature profile. In samples that are electrically conductive, electric current may be passed through the core, to heat the sample.

The heated section shall be a reasonable length, such as 10 m (this can be adjusted to fit the test frame as needed), and to ensure adequate accuracy on elongation measurements.

a) Install end fixtures onto the core and install the sample into the test frame.
b) Install extensometers on the core at the ends of the heated section.
c) Install a minimum of 3 thermocouples in the heated section (one at each end and one at the middle). The thermocouples shall be touching the core (in case of conductor, thermocouples shall be wedged between the strands as close as possible to the core).

7.3.8.3 Procedure

The sequence of the test shall incorporate the following steps.

a) Tension the test sample to 20 % RTS of the core to keep the core sample straight and flat. Maintain constant tension during the test. Constant tension is critically important as small tension changes can have the same effect as large temperature changes. Figure 2 shows the test configuration.

b) Take the first extensometer measurement point at ambient temperature.

c) Raise the sample temperature by equal intervals using 8 to 10 steps between room temperature and $T_{P,CORE}$.

d) After reaching the steady state condition for 10 minutes at each target temperature (temperature tolerance to be ± 2 % with a minimum of ± 2 °C) the core extension and temperature shall be recorded.

e) Increase the temperature further and repeat the previous steps until the target temperature of $T_{P,CORE}$ is reached.

f) Determine the linear coefficient of thermal elongation by linear regression analysis of the experimental data. The report shall include the measured values of CTE in $°C^{-1}$.

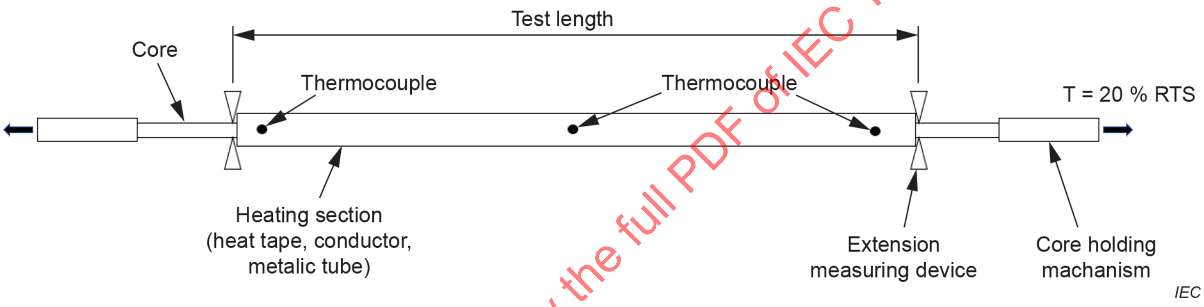

Figure 2 – CTE test setup

8 Optional tests for the stranded composite core characterization

8.1 Twisting test

A twisting test is performed to simulate torsion forces and behaviours that could take place during conductor handling and installation activities.

The test shall be performed on the stranded composite core (with the external protective layer, if applicable), using a specific torsion apparatus, in accordance with Figure 3. This test device shall comprise a clamping device (1), the composite core (2), an optional stabilizer if necessary (3), and a tensile load (F). The torsion is performed in a direction perpendicular to the tension load (3).

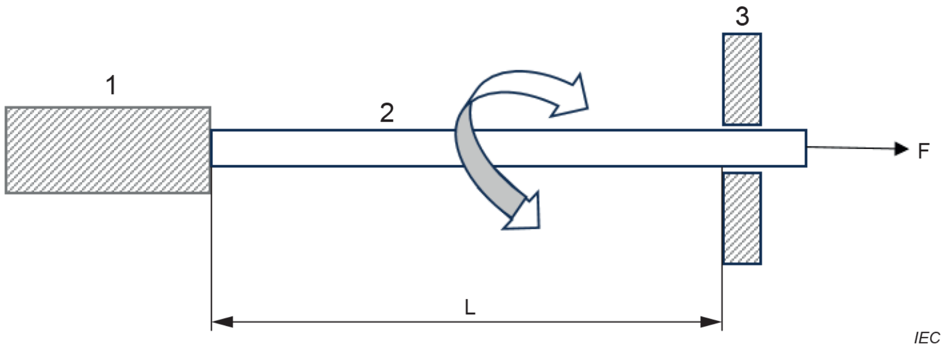

Figure 3 – Illustration of the twisting test

A sufficient mechanical load shall be applied during the complete duration of the test to straighten the core. The tension shall be noted.

The sample length shall be agreed by the purchaser and manufacturer in accordance with the core working conditions and it shall be tested accordingly to the following steps:

a) turn the sample left (counter-clockwise) at 360° per sample length,

b) keep the torsion for 1 min, then turn back to original position,

c) turn the sample right (clockwise) at 360° per sample length,

d) keep the torsion for 1 min, then turn back to original position.

After the twisting cycles, samples shall be subjected to a visual inspection (7.3.1), and a tensile breaking load test (7.3.6).

If a shorter sample length is chosen, a different twist ratio shall be used to complete the test (e.g. if the sample length being tested is half the core specification, then the core can be twisted to just 180° in both directions instead).

8.2 Crushing test

A crushing test is used to verify the ability of a loaded core to withstand radial compressive forces acting perpendicular to the core direction. This stress could take place during stranding, manufacturing, handling, installation, or during maintenance activities.

The test shall be performed using a suitable tension-compression machine. The test shall be performed between two steel plates in contact with the sample, with a 100 mm length, and the edges shall be rounded to a 5 mm radius. The test sample should be at least 300 mm long and positioned so that at least 100 mm of unsupported sample is present on either side of the steel plates. A schematic of a test configuration is shown in Figure 4.

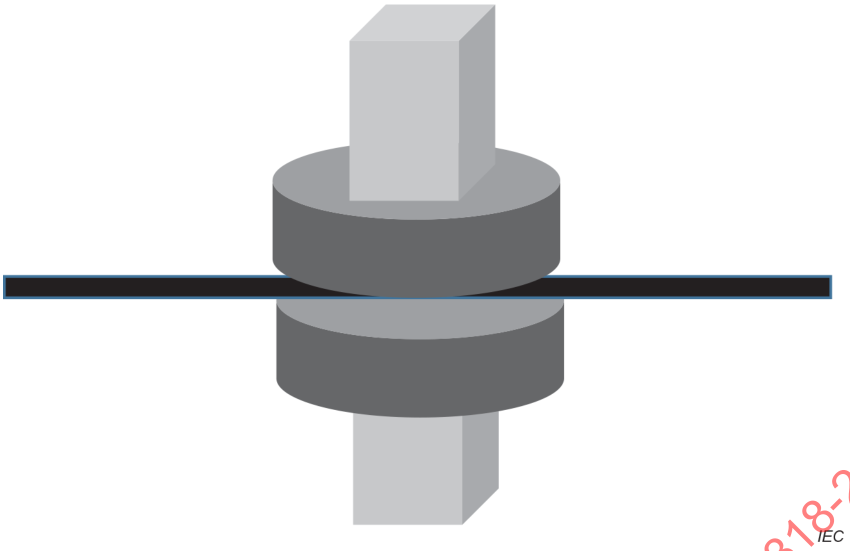

Figure 4 – Schematic of the crushing test

The range of compressive loads in kN and the compression speed shall be defined by the manufacturer. When the target load is reached, it is maintained for 1 minute. The load is then released, and the compressed sample is analyzed.

At least 2 samples shall be tested.

After the crush test, samples shall be separated into individual wires and subject to visual inspection (7.2.1), and breaking load of the individual wires (7.2.5).

Changes in the characteristics of the wires from the crushed sample shall be compared to a sample that was not crushed.

8.3 Salt fog test

The salt fog corrosion test of the stranded composite core (and the external protective layer if applicable) should be performed in accordance with IEC 60068-2-11:2021. The test duration is 672 h (28 days) with an intermediate point at 336 h.

After the aging phase, the wires from the stranded core shall be separated and the wires shall be washed, dried and subjected to visual inspection (7.2.1), and tensile breaking load (7.2.5).

Changes in the characteristics of the aged samples shall be compared to unaged samples.

8.4 Fiber volume ratio

The fiber volume ratio of individual wires can be calculated by using Formula (8) and Formula (9).

Formula (8) is for a single circular wire:

$$\text{fiber volume ratio} = \frac{A_f}{A_w} = \frac{W_f / \rho_f}{r_w^2 \times \pi} \tag{8}$$

where:

A_f is the area of fiber, expressed in square meters (m^2)

A_w is the area of wire, expressed in square meters (m^2)

W_f is the fiber weight per unit length, expressed in kilograms per meter (kg/m) (provided by the manufacturer)

ρ_f is the density of the fiber, expressed in kilograms per meter (kg/m) (provided by the manufacturer)

r_w is the radius of the wire, expressed in meters (m).

Formula (9):

$$\text{fiber volume ratio} = \frac{\rho_w - \rho_m}{\rho_f - \rho_m} \tag{9}$$

where:

ρ_f is the density of the fiber, expressed in kilograms per cubic meter (kg/m^3) (provided by the manufacturer)

ρ_w is the density of the wire, expressed in kilograms per cubic meter (kg/m^3)

ρ_m is the density of the matrix, expressed in kilograms per cubic meter (kg/m^3) (provided by the manufacturer)

8.5 Porosity

The porosity and fiber matrix integrity can be measured using a micrographic observation of a polished metallographic sample, coupled with a computer-assisted image analyzer.

At least 3 samples of composite wire shall be tested. The wire shall be cut and polished to clearly observe the cross-section. The porosity measurement shall be performed using binarization within image analysis software to differentiate the porosity from the matrix and from the fiber. Porosity shall be measured on pictures taken at a total magnification ranging from x40 to x1 000 with a preferred value dependent of the size of the porosity. Either an optical microscope or an SEM technique can be used. Five representative regions should be analyzed.

The report shall contain a global picture of the composite core cross section at a magnification ranging from x10 to x40 with a preferred value of x10 to illustrate the core global condition. In addition, porosity values (in area %) measured from the pictures at magnification ranging from x40 to x100 with a preferred value of x100 shall be provided. A mean value could be added to give a representative value of the core cross-section.

An alternative method using theoretical values of fiber volume ratio and densities can be used.

NOTE The described methods are not sensitive enough to reliably calculate porosity contents below 1 %.

Note that for metal matrix composites, porosity has very little effect on mechanical and aging properties. Performing mechanical and aging tests shall be enough to determine the level of performance of the composite core.

8.6 Bending test

This test is designed to validate the choice of internal diameter of a storage reel used for packaging of the stranded core.

Of concern is that no damage accumulates due to bending of the core around the reel diameter. When a composite wire undergoes bending, there are two different stresses created. Firstly, there is a tensile stress on the outer side of the bend radius (imagine the fibers need to stretch to sustain the bend). Secondly, there is a compressive stress on the inner side of the bend radius (imagine the fibers must shrink to sustain the bend).

For metal-matrix composites, the compressive breaking stress of the material is typically the same or greater than the tensile breaking stress. Therefore, the failure mode in bending is by a tensile failure of the outer side of the bend radius. Since the tensile properties are easily measured via simple tensile tests, the limits of bending can be reliably established from tensile test data.

Some materials, most notably many polymer-matrix composite systems, have a compressive breaking stress of the material lower than the tensile breaking stress. In this case during bending, the fibers can locally buckle on the compressive side in a process known as micro-buckling creating a feature known as kink-bands. Thus, damage can accumulate in the compression side. When the kink-band feature is then placed into tension (straightened and loaded), then the subsequent ability to carry tensile load can be reduced.

Thus, for the metal-matrix composite, a simple tensile test is sufficient to validate the choice of reel diameter to store the core. If a bending test is desired, then the following procedure may be followed.

The specimen of stranded composite core (with external protective layer, if present) shall be wrapped around a cylindrical mandrel for 180°, as shown in Figure 5 and a mechanical load shall be applied for 5 minutes. The device shall comprise a mandrel and a device to apply a mechanical load following the two arrows.

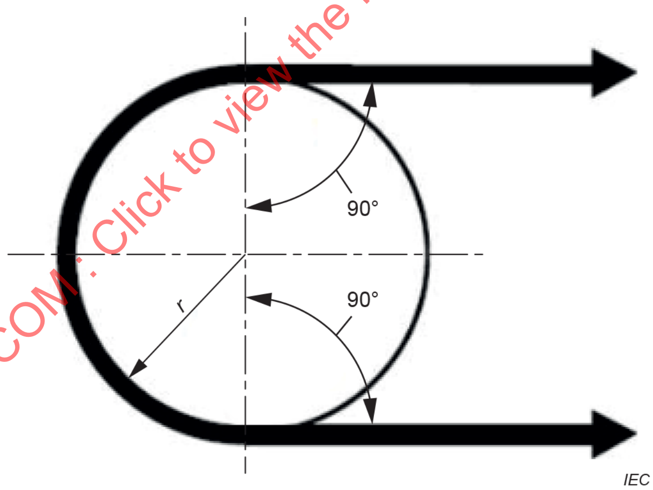

Figure 5 – Illustration of the mandrel test

The minimum mandrel diameter and applied load shall be agreed by the purchaser and manufacturer in accordance with the core size and packaging options. A testing load corresponding to 7,5 % RTS of the core is suggested. After the load hold, the specimen shall be tensile tested according to 7.3.6.

NOTE 7,5 % of RTS is a representative tension that can be seen during stringing, it is low enough to have a representative compression load during bending. It is also to ensure that the core will be in contact with the mandrel during the bending test.

Annex A
(normative)

Testing table

All the tests described in the previous clauses are listed in Table A.1. For each test, type tests (T), sample tests (S) and routine tests (R) are specified.

Table A.1 – Tests on composite core

Tests		Applicable tests	Sampling rate for S tests
Item	**Description**		
	Individual wire tests		
7.2.1	Appearance	T, S, R	10 % of drums, min. 2 per lot
7.2.2	Diameter	T, S, R	10 % of drums, min. 2 per lot
7.2.3	Mass per unit length	T	
7.2.4*	Coefficient of thermal expansion[a]	T	
7.2.5	Mechanical – tensile breaking load	T, S, R	10 % of drums, min. 2 per lot
7.2.6	Mechanical – flexural breaking load	T	
7.2.7	Isothermal ageing	T	
7.2.8	DC electrical resistivity (conductivity)	T, S, R	10 % of drums, min. 2 per lot
7.2.9	Thermal aging degradation test	T	
	Stranded core (multi-wire)		
7.3.1	Appearance	T, S, R	10 % of drums, min. 2 per lot
7.3.2	Diameter	T, S, R	10 % of drums, min. 2 per lot
7.3.3	Lay ratio (lay length)	T, S, R	10 % of drums, min. 2 per lot
7.3.4	Lay direction	T, S, R	10 % of drums, min. 2 per lot
7.3.5	Mass per unit length	T, S, R	10 % of drums, min. 2 per lot
7.3.6	Mechanical properties – tensile breaking load	T	
7.3.7	Holding ability of tape	T	
7.3.8*	Coefficient of thermal expansion [a]	T	
	OPTIONAL TESTS (Stranded core)		
8.1	Twisting test	T	
8.2	Crushing test	T	
8.3	Salt fog test	T	
8.4	Fiber volume ratio	T	
8.5	Porosity	T	
8.6	Bending test	T	

[a] Only one of the coefficient of thermal expansion tests is required, for either wire (7.2.4) or stranded core (7.3.8).

If not separately specified in the paragraph where the test is described (mean value from several measurements), the number of samples for each type test is one (1).

The sampling rate for each sample test is specified in the last column of Table A.1, expressed as the percentage of drums to be chosen from the production lot to be tested, with a minimum of two drums and one test sample per drum.