IEC TS 62818-1

Edition 1.0 2024-12

TECHNICAL SPECIFICATION

colour inside

Conductors for overhead lines – Fiber reinforced composite core used as supporting member material –
Part 1: Polymeric matrix composite cores

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Conductors for overhead lines – Fiber reinforced composite core used as supporting member material – Part 1: Polymeric matrix composite cores

INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 1: Polymeric matrix composite cores

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IEC TS 62818-1 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
7/752/DTS	7/754/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- withdrawn, or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 variety of products used 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 lines 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, thermal tests, flexural under tension, etc.).

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

Part 1: Polymeric matrix composite cores

1 Scope

This part of IEC 62818, which is a Technical Specification, establishes a system of fiber reinforced composite core 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 polymeric 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 core with polymeric matrix,

– prescribing common methods and recommendations to characterize the properties of fiber reinforced composite core based on single or multi-wires with PMC (Polymeric Matrix Composite) used as 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 apply to 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*

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

ISO 4892-2:2013, *Plastics: Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

ISO 11358-1:2022, *Plastics – Thermogravimetry (TG) of polymers – Part 1: General principles*

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
polymer matrix composite
PMC
assembly of continuous fibers (such as carbon or glass fibers) embedded longitudinally in a polymer matrix (such as epoxy resin)

3.2
composite core
PMC 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 metallic or non-metallic material applied onto the PMC for the purpose of protecting it against external aggressions (such as corrosion, oxidation, etc.) and also acting as a protection against galvanic corrosion, if any

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 reinforcement
incorporation of continuous fibers within a polymeric matrix in order to increase its performance

Note 1 to entry: It is achieved through specific processes such as winding, moulding or pultrusion.

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

3.6
resin
matrix component of PMC

Note 1 to entry: There are two types of resin, namely thermosetting resin and thermoplastic resin.

3.7
thermoplastic resin
type of resin made of long polymer chains with weak bonding between them, which, when the resin is heated, break in a reversible way and make the material shapeable

Note 1 to entry: This is classified into two types by array of polymer chain. One is semi-crystalline resin and the other is amorphous resin.

3.8
thermosetting resin
type of resin made of a network of cross linked polymer chains

Note 1 to entry: The network is created by heating monomers which polymerized under high temperature.

3.9
porosity
measurement of the void fraction in the material over the total volume

Note 1 to entry: It results from a lack of matrix impregnation or from matrix degradation. It distinguishes itself from composite crack or fracture by that it's a lack of matrix or matrix deficiency but not a matrix mechanical fracture.

3.10
glass transition temperature
T_g
temperature where the PMC properties transition from a hard, glassy state to a rubbery state

Note 1 to entry: T_g of PMC is related to T_g of the polymer matrix but it can be different, depending on each technology and specific product design.

3.11
glass transition temperature onset
$T_{g,onset}$
temperature corresponding to the onset of the transition from the glassy state as defined by the intercept of the two tangent of the storage (E') modulus curve (see Annex C)

3.12
glass transition temperature loss modulus
$T_{g,LossModulus}$
temperature corresponding to the peak (maximum) in the loss (E'') modulus curve (see Annex C)

3.13
thermolysis temperature
$T_{onset\ thermolysis}$
temperature corresponding to the start of the polymeric matrix thermolysis, an irreversible reaction that breaks structures of resin (e.g. main chain, cross-link, etc.) and affects the lifetime of PMC

3.14
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. A lot may consist of part or all of a purchased quantity

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

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

3.15
production unit
coil, reel, spool or other package of individual composite core that represents a single usable length

3.16
sample
specimen(s) removed from a production unit(s) which is considered to have properties representative of a lot

3.17
specimen
length of composite core removed for test purposes

3.18
equivalent diameter
diameter of a circle which would have the same cross-sectional area as a given formed wire

4 Symbols and abbreviated terms

CTE	coefficient of thermal expansion (°C^{-1})
DC	direct current (A)
DMA	dynamic mechanical analysis
E_t	tensile modulus (GPa)
F_c	compressive load at break (N)
F_t	tensile load at break (N)
K_c	compressive stiffness ($K_c = F_c / \varepsilon_c$) (N)
RTS	rated tensile strength (kN)
SEM	scanning electron microscope
TGA	thermo-gravimetric analysis
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
ε_c	compressive strain at break (%)
ε_t	elongation at break (%)
σ_t	tensile stress at break (MPa)

5 Requirements

5.1 Composite core manufacturing

Composite core 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 or external imperfections (e.g. high porosity, inclusions, scratches, scrape, notch, holes, 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 parts. The fiber splicing is accepted in the protective layer. The purchaser may be informed upon request that splicing was used for protective layer.

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:

– Type test (T),
– Sample test (S),
– Routine test (R).

In order to ensure a 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 Table A.1 and described in Clause 8.

Laboratories and scheduling of tests shall be previously agreed between the purchaser and manufacturer. The ageing test being very long, a 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 type, matrix type, fiber volume ratio, ratio of carbon fiber composite to galvanic layer 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 system of 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 temperatures to be respected for a safe use of the complete conductor during the lifetime of the overhead line.

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

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

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

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

$T_{C,CORE}$ and $T_{P,CORE}$ shall be determined from the experimental result of the test described in 7.12.

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

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

This temperature is the maximum continuous temperature at which the composite core can be exposed, with deterioration acceptable in accordance with Annex B, for a duration equal (by definition) to its lifetime. The intended life expectancy of the core is typically 40 or 50 years.

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

This temperature is the maximum peak load temperature at which the composite core can be exposed, with deterioration acceptable in accordance with 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 1000 cumulative hours 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 Appearance

All the elements composing the core (composite wire(s), external protective layer(s), etc.) shall be free from any defect (ex: scratch, scrape notch hole, crack) significantly visible with the naked eye, normal or corrected. When removable external protective layer(s) is(are) present, it (they) shall be removed to allow the inspection of composite wire(s). A representative picture of a normal surface may be attached to official test report under purchaser request.

7.2 Diameter

7.2.1 Diameter measurement for single wire composite core

The diameter of the single wire (with the external 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 decimal places.

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

a) a continuous/online process measurement (online measurement), performed using a 2- or 3-axis caliper (laser or mechanical) with equal phase shifts in the same straight section. Minimum, maximum and average values shall be reported.

b) a direct/manual measurement, performed measuring the diameter on the cross-section of a cut sample in at least two directions, equally phase shifted. In this case, at least 2 samples shall be taken and tested from each length: one at the start and one at the end of the production unit. Each 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.

The manufacturer shall provide a specification for the required wire diameter and the permitted tolerance.

7.2.2 Diameter measurement for multi-wires composite core

Core diameter shall be measured by one of the following methods:

a) a continuous/online process measurement (online measurement), performed using a 2- or 3-axis caliper (laser or mechanical) with equal phase shifts in the same straight section. Minimum, maximum, and average values need to be reported.

b) a direct/manual measurement, performed measuring the diameter of a circumscribed circle (see Figure 1), and at least three directions within the same cross section shall be measured (with the external protective layer). At least 2 samples shall be taken and tested from each length: one at the start and one at the end of the production unit. All the above-mentioned dimensions of the complete core shall be verified on 1 sample at least 1 m long in the middle. Minimum, maximum and average values of diameter shall be reported for each sample.

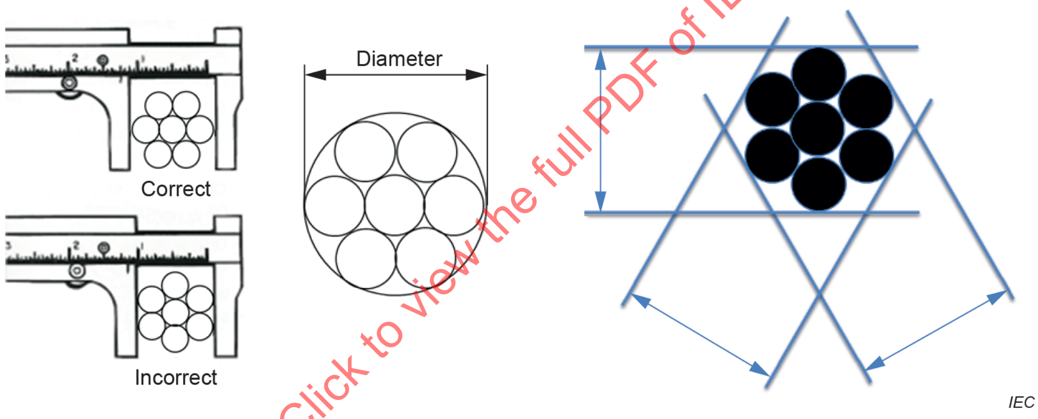


Figure 1 – Measurement of multi-wire core diameter

For non-circular wires (formed wires):

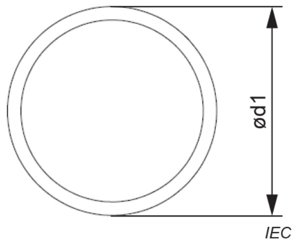
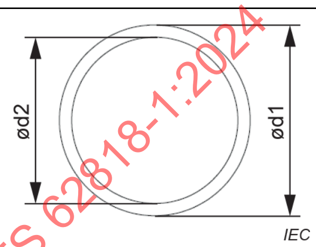
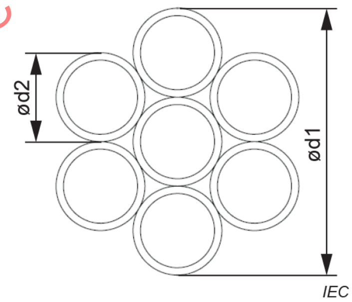
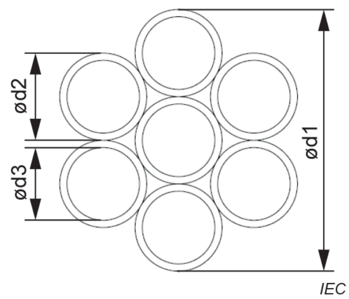
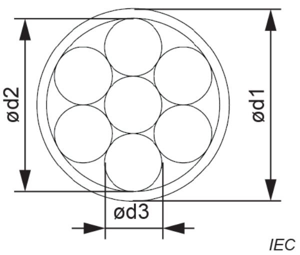
a) the wire shall be cut at 90° and polished in order to verify the compliance of the shape of the cross section with the designed shape. The measures shall be performed with a device (optical method system) with an accuracy of at least 0,01 mm,

b) for information, the section of the wire can be measured and the equivalent diameter calculated as the diameter of a round wire with the same cross-sectional area of the given formed wire.

In a multi-wire composite core, the diameter of each individual wire shall be measured as in 7.2.1 for type testing only. For cores with overall protective layer it is allowed to perform the Sample Test on samples of the stranded core picked before the application of the layer

The manufacturer shall provide a specification for the required stranded core diameter and the permitted tolerance. Table 1 defines the different diameter measurements for single and multi-wire cores.

Table 1 – Testing table for core diameter measurement by core type

Composite core	Protective layer	Test on	
Single wire	Unremovable (e.g. pultruded) or absent	Complete core, d1	
	Removable (e.g. pultruded)	Complete core, d1 Core without layer, d2	
Multi wire	Unremovable (e.g. pultruded) on each wire or absent	Complete core, d1 Wire (each type), d2	
	Removable (e.g. extruded) on each wire	Complete core, d1 Wire (each type), d2 Wire (each type) without layer, d3	
	Removable (e.g. extruded) on complete core	Complete core, d1 Core without layer, d2 Wire (each type), d3	

7.3 Lay length measurement for multi-wires composite core

The lay length of every layer of multi-wires composite core shall be measured and lay ratio calculated. The lay ratio of each layer shall be obtained through the ratio of the measured lay length to the external diameter of layer itself (7.2.2).

The manufacturer shall provide a specification for the required lay length for each respective layer as it applies.

7.4 Protective layer thickness

The protection layer thickness shall be expressed in millimeters to two decimal places. Minimum thickness value shall be measured by an apparatus (micrometric caliper or optical system) with an accuracy of at least 0,01 mm.

The manufacturer shall provide a specification for the required minimum protective layer thickness.

7.5 DC electrical resistance

DC electrical resistance shall be measured only on PMC with metallic layer, 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 measures taken on at least 1 sample. The length of each tested sample shall be at least 1 m.

The report shall include the mean value of resistance at 20 °C (Ω / m).

NOTE DC electrical resistance is not mandatory if the DC resistance value is not used in the calculation of conductor resistance.

7.6 Mass per unit length

Mass per unit length shall be tested using an apparatus with an accuracy of ±0,1 % on the composite core.

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

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 and the permitted tolerance.

7.7 Tensile test

The tensile test shall be performed, in accordance with ISO 527-5:2021, in order to define mechanical characteristics of composite core and single wires (for stranded cores, if possible, when the wires are straight not in a preformed shape) under tensile load:

– Ft: tensile load at break (N),
– εt: elongation at break (%),
– σt: tensile stress at break (MPa),
– $E_{t:}$ tensile modulus (GPa).

Clamping jaws for the tensile test (e.g. epoxy inclusions, conic clamps, bolted clamp) shall be correctly designed in order to minimize local flections, torsions or incisions, and stress concentrations on the sample and reach the right failure mode.

The minimum length of each sample shall be appropriate to avoid end effects to the extent that it is practically possible. For multi wires, sample length is linked to lay length; the longer the lay length, the longer the sample length. Load shall be gradually increased at a ramp of 1 mm/min to 10 mm/min, measuring the elongation with an extensometer or another equivalent device. As composite materials show an elastic behaviour, if the elongation measurement device risks being damaged at the break of the sample, elongation at break can be extrapolated by a linear interpolation of the load-elongation curve.

As measured breaking load values on composite wires are usually less repeatable than on metallic wires, at least 5 samples of complete core shall be tested in order to have a reliable mean value for type test. A single tensile test shall be applied on each wire of a stranded core (if not preformed).

For each sample, stress at break shall be calculated as the ratio between breaking load and section and tensile modulus as the ratio from the slope of the load-elongation curve. It is important to mention that the selected elongation range has an influence on tensile modulus final value. Tensile modulus is optional for the sample test.

The type test report shall include pictures of test setting, load-elongation curves, measured values and mean values of the characteristics above mentioned. For sample and routine tests, only the mean values of the characteristics mentioned above are to be reported. For multi wire composite core, tensile tests on each wires are optional depending on the design.

NOTE Composite wires are non-homogeneous materials with anisotropic properties, and the stress at break is understood as the nominal values of the whole composite core.

All composite cores shall have a tensile breaking load meeting at least the minimum specified RTS provided by the manufacturer.

7.8 Bending test

7.8.1 General

In order to assess bendability of the core during storage, transport, and installation, one of the following two tests shall be performed:

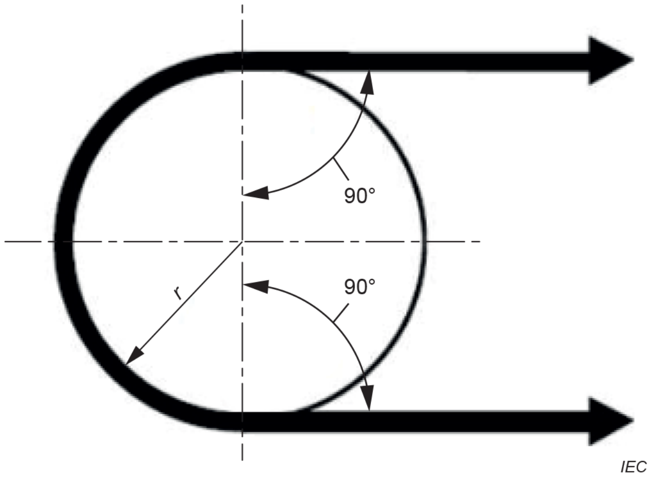
7.8.2 Mandrel test

The specimen of composite core (with external protective layer, if present) shall be wrapped around a cylindrical mandrel at 180°, as shown in Figure 2; and a mechanical load shall be applied for 1 min.

Minimum mandrel diameter and applied load shall be agreed by the purchaser and manufacturer in accordance with the core working conditions and core specifications. A testing load corresponding to 7,5 % RTS of the core is suggested.

After completion of the test, the composite core part in contact with the mandrel shall be tensile tested according to 7.7.

This test requires a special equipment. The device shall comprise a mandrel and a device to apply a mechanical load following the direction of the two arrows.



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.

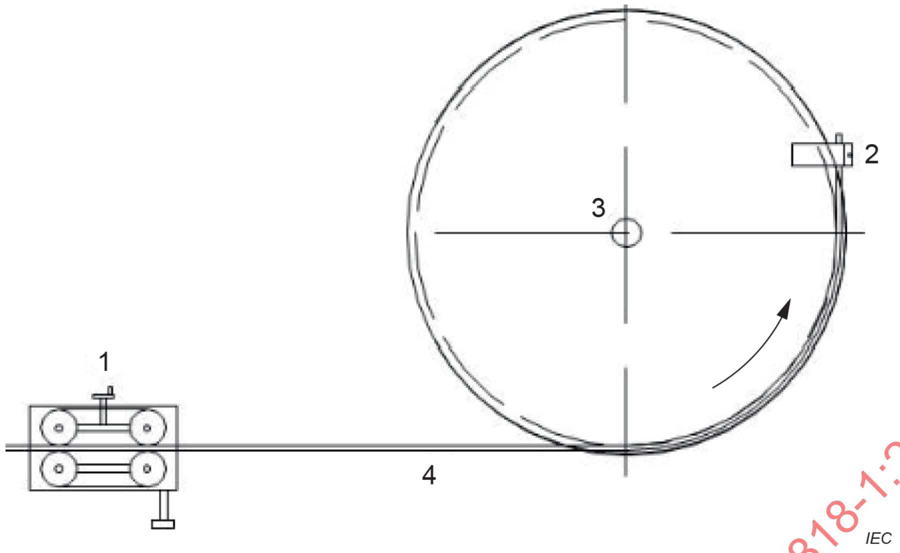
Figure 2 – Illustration of the mandrel test

7.8.3 Coiling test

The specimen shall be reeled around a cylindrical coiling reel as described in Figure 3. The minimum coiling reel diameter and the coiling speed shall be defined by the manufacturer in accordance with the core operating conditions and core specifications. Before starting the test, both the guide device and fastening device shall be tangent to the reel as shown in Figure 3. After a minimum of half a turn (core wrapped around reel 180°), the rotation is stopped for 1 min and the specimen is rewound at the same speed to the initial location. A testing load corresponding to 7,5 % RTS of the core is suggested. The composite core part in contact with the coiling reel is analysed.

After completion of the test, the specimen shall be tensile tested according to 7.7.

This test requires a special equipment. The device shall comprise a two-way tension gear (1), a fastening device (2) and a coiling reel (3).



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 coiling test.

Figure 3 – Illustration of the coiling test

7.9 Measurement of Glass transition temperature (by DMA)

The glass transition temperature (T_g) is measured in order to characterize the loss of PMC modulus versus temperature for PMC wires (Annex C). External protective layer may be removed if it is not the main strength member. The test shall be performed by Dynamic Mechanical Analysis (DMA), according to ISO 6721-5. For type test, 2 samples at the start and 2 samples at the end of the production unit shall be tested. If the sample is not tested immediately after production it may be dried prior to the test. Details of the testing requirements are shown in Table 2.

Table 2 – DMA testing specification

Frequency	1 Hz
Loading mode	Flexural
Heat rate	3 °C to 5 °C/min Heat rate to be agreed between purchaser and manufacturer, selected heat rate must be kept for all tests as a slight variation may occur between the different heating rates.
Sample shape **Thickness variation**	Test specimens of rectangular cross-section are recommended to facilitate load introduction when possible. Thickness variation shall be < 2 % (in accordance with ISO 6721-5). If not possible to machine small wires, wires can be tested as is with a tolerance in accordance with production process. Cutting method should prevent excessive temperatures and vibrations in the sample.
Clamp type	Dual cantilever or three-point bending. Clamp type to be agreed between purchaser and manufacturer, selected type must be kept for all tests as a slight variation may occur between the two methods. Clamp type may be a limitation based upon tooling available.

The report shall include, for each sample, the DMA results with both:

– the onset of the glass transition ($T_{g,onset}$),

– the $T_{g,LossModulus}$ measured from the maximum (highest value) of the loss modulus curve.

7.10 Coefficient of thermal expansion

7.10.1 Sample preparation

The heated section shall be a reasonable length, such as 10 m, to ensure adequate accuracy on elongation measurements. A schematic of a typical test set-up is shown in Figure 4.

The core can be heated by different ways: using for example a heating tape, an oven, aluminium tube or aluminium wires for a conductor sample where 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 sections may be used to create a more uniform temperature profile.

a) Install end fixtures onto the core and install the sample into the test frame.
b) Install extensometers on the core at the end 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).

7.10.2 Procedure

The coefficient of thermal expansion (CTE) of the PMC core with external protective layer shall be measured using the following procedure.

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.
b) Take first measurement point at ambient temperature.
c) Raise the sample temperature by equal intervals using 8 to 10 steps between room temperature and $T_{\mathrm{P,CORE}}$.
d) After reaching the steady state condition for 10 min at each target temperature (temperature tolerance ± 2 % with a minimum of ± 2 °C) core expansion and temperature shall be recorded.
e) Increase temperature further and repeat the previous steps until the target temperature of $T_{\mathrm{P,CORE}}$ 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}.

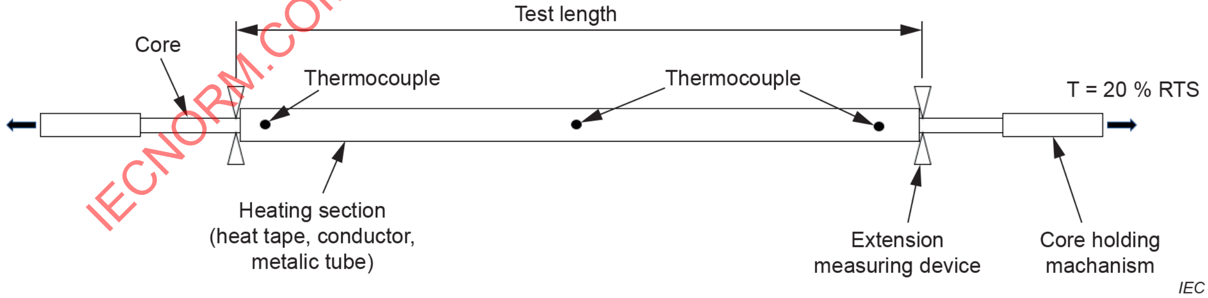


Figure 4 – CTE test setup

The manufacturer shall provide a specification for the required CTE and the permitted tolerance.

NOTE If agreed by the purchaser and manufacturer, TMA can be used for verification with consideration of the accuracy and precision of the measurement. 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.

In accordance with ISO 11359-1:2023 and ISO 11359-2:2021, at least 2 samples (repeatability) are randomly chosen and tested. The expansion is measured in the fiber direction (axial) between ambient temperature and $T_{P,CORE}$ with a slope of 3 °C.min^{-1}. The report presents 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, is considered to be the final result.

For a multi-wire composite core using the same material for all the wires, the center wire (straight wire) is typically used for measuring the CTE of the composite core and represents the full stranded core.

7.11 $T_{\text{onset Thermolysis}}$ determination

The measurement shall be performed using the TGA method, according to ISO 11358-1:2022. TGA measurement method offers reliable results only if the materials composing the PMC have different thermolysis temperatures. Depending on the purpose of the test, the gas used can change.

The TGA method is not applicable if:

a) fibers are less stable than the matrix at high temperature, or

b) matrix, fibers, coating and any other material used to realize the PMC have similar thermal decomposition temperatures.

In these cases, a different experimental method or theoretical calculation shall be agreed between manufacturer and purchaser. The fiber direction of the test specimen shall be perpendicular to the heating surface of the TGA instrument, and as far as is possible (as the sample are very small), each test specimen shall have the same mass.

The measurement shall be performed in nitrogen atmosphere (N_2 100 ml/min) with a heating rate of 1 °C/min to 2 °C/min up to the thermolysis of the matrix identified by a plateau of the weight curve by TGA curve (generally it should be in the range 600°C to 800°C).The heating rate has an important influence on the $T_{\text{onset thermolysis}}$; the lower the heating rate, the lower the $T_{\text{onset thermolysis}}$. It needs to be agreed between purchaser and manufacturer.

$T_{\text{onset thermolysis}}$ shall be determined by the interception point of the two tangents of the weight curve by TGA (see Figure 5) as mentioned in ISO 11358-1:2022.

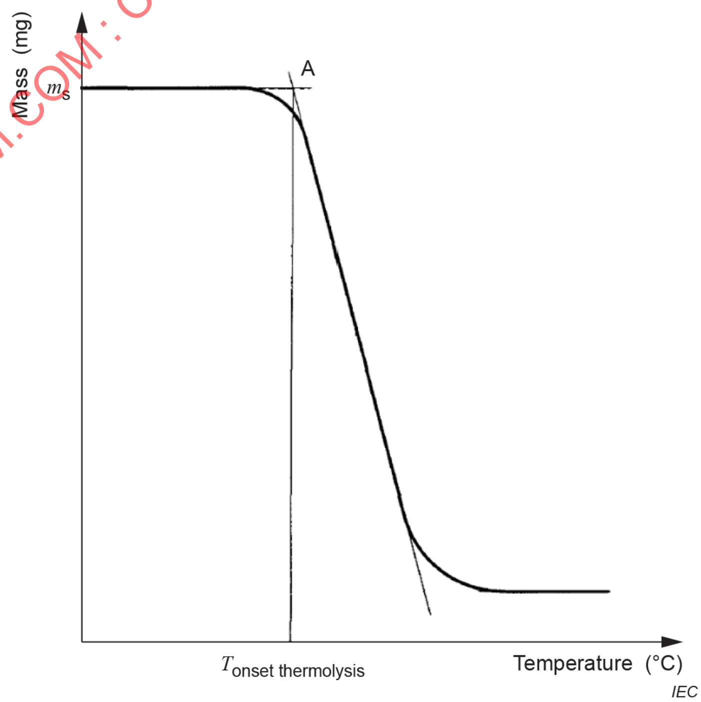


Figure 5 – Illustration for $T_{\text{onset thermolysis}}$ determination

7.12 Isothermal ageing

7.12.1 General

According to the definitions given in Clause 6, stability at $T_{C,CORE}$ and at $T_{P,CORE}$ shall be determined (or verified) by isothermal ageing tests in order to experimentally confirm that the physical parameters of composite cores are stable after a long-term exposition to high temperatures.

Both the tests described in 7.12.2 and 7.12.3 shall reproduce the same thermo-oxidation processes to which the core will be subjected during its lifetime; thus, the testing temperatures shall be kept below $T_{onset\ thermolysis}$ in order to avoid the activation of thermolysis processes and an irreversible degradation of the structure of the matrix and degradation paths different from the ones that will take place during the real use of the core.

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

Unless specific clamps are proven to be effective also on aged samples, to be able to properly clamp the ends, sample ends shall be placed outside the oven for a sufficient length.

Specimens shall be placed parallel to the bottom of oven and as close as possible to the thermocouple, avoiding the contact with the internal oven walls.

7.12.2 Product stability at $T_{C,CORE}$

During the holding time of a composite core at $T_{C,CORE}$, resin matrix is generally subjected to thermo-oxidation processes, and material properties could change.

As the composite core is designed to be the mechanical support or reinforcement of an overhead line conductor, it is required to maintain its properties 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 ageing procedures are practicable in order to demonstrate the durability of the core for the requested lifetime at a certain temperature.

The chosen accelerated ageing methodology must be justified by experimental results on composite wires, equivalent in composition (fiber, matrix, fiber volume ratio, protective layer) with composite wires to be tested.

The procedure for the accelerated ageing test, based on the Arrhenius curves method (IEC 60216-1:2013), is given in Annex B.

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

Once the reference lifetime is defined, $T_{C,\ CORE}$ shall be determined considering the lowest of the following values:

– T_{40y} an extrapolation of the experimental results of the thermal ageing test, as described in Annex B.

– T_g – 5 °C (per Annex C, the selection of T_g shall be agreed between purchaser and manufacturer) measured in accordance with 7.9.

NOTE Minus 5 °C is a margin to ensure that the core is not operating continuously at the T_g.

7.12.3 Product stability at $T_{P,CORE}$

According to the definition given in 6.3, the stability of the main physical properties of the core at the peak load temperature shall be determined or verified repeating the measurement already performed on samples in initial conditions after an isothermal ageing for a 400 h cumulative duration. As this temperature is related to the final use of the conductor for which the core will be used, a different time can be specified by the purchaser, if needed.

Therefore, as written above, the temperature $T_{P,TEST}$ for the 400 h exposition isothermal ageing phase shall be determined considering the lowest of the following values:

– $T_{onset\ thermolysis}$, in order to avoid the activation of thermolysis processes of irreversible degradation of the matrix,
– T_{400h}, the temperature corresponding to a 400 h exposure, identified on the Arrhenius curve,
– T_g, in order to describe the breaking load decay of samples with the matrix in vitreous phase, as during the real use as a strength member of an overhead conductors,
– $T_{critical}$, any other critical temperature that could limit the use of the core, imply an irreversible degradation of the materials, cause a different behaviour of the protection layer or change the degradation path from the one related to the real use of the core.

$$T_{P,TEST} \leq \min\left(T_g, T_{400h}, T_{onset\ thermolysis}, T_{critical}\right)$$

The specimens shall be exposed for 400 hours to the test temperature $T_{P,TEST}$ defined according to the limits described above.

After the holding time at $T_{P,TEST}$, samples shall be cooled until room temperature and subjected to: visual inspection (7.1), glass transition T_g (7.9) and tensile test (7.7).

The acceptance criteria shall be agreed between the purchaser and the manufacturer, depending on the specific characteristics of each composite material.

If the results of the tests performed on the aged samples show that the changes are within the tolerances, $T_{P,CORE}$ can be defined as:

$$T_{P,CORE} \leq T_{P,TEST} - 5\ °C$$

otherwise $T_{P,TEST}$ shall be reduced and the final tests repeated until all the results became compliant.

NOTE If the $T_{P,TEST}$ is defined by the T_{400h} the safety margin of −5 °C is not necessary. Minus 5 °C is a margin to ensure that the core is not operating continuously at the T_g, $T_{critical}$ or $T_{onset\ thermolysis}$.

8 Optional tests

8.1 Twisting test

The twisting test is utilized to demonstrate the core ability to handle rotation that could take place during conductor handling and installation activities.

The test shall be performed on the complete composite core (with the external protective layer, if applicable). A sufficient mechanical load shall be applied during the complete duration of the test to straighten the core.

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

a) turn the sample left at 360° (or lay direction for multi-wire core) per sample length,

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

c) turn in opposite direction the sample at 360° per sample length,

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

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

After the twisting cycles, samples shall be subjected to: appearance (7.1), tensile test (7.7).

This test requires a specific equipment according to Figure 6. The device shall comprise a clamping device (1), and the composite core (2); an optional stabilizer can be used if necessary (3). The torsion is performed perpendicularly to the tension load F.

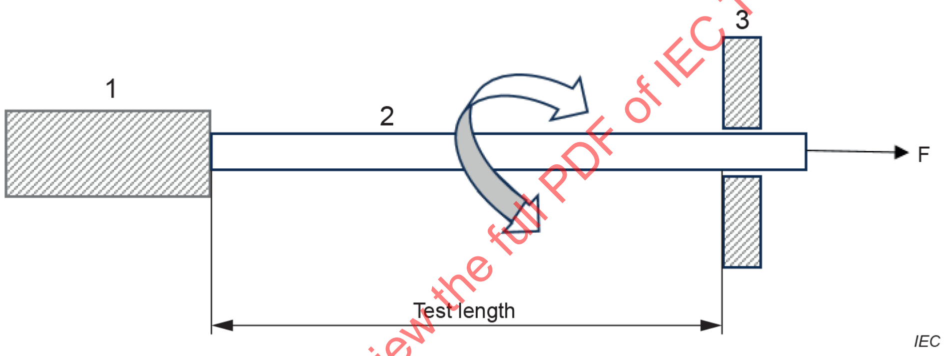


Figure 6 – Illustration of the twisting test

8.2 Crushing test

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

The test shall be performed on cores (with the external protective layer, if applicable), using a specific tension-compression machine with a test design defined by the laboratory.

According to Figure 7, the test shall be performed between two steel plates in contact with the sample on a 100 mm length and edges shall be rounded with 5 mm.

The range of crushing loads (kN) and the crushing speed shall be defined by the manufacturer. When the pressure is reached, a plateau is maintained during 1 min. The pressure is then released, and the compressed part is analysed.

At least 2 samples shall be tested.

After the crushing test, samples shall be subjected to: visual inspection (7.1) and tensile test (7.7)

Reduction of the characteristics of the aged samples shall be calculated referring to unaged samples experimental values.

The report shall include a description of the test design, the pictures of the composite core and the compressing test curves with the mean values of:

- the compressive load without break F_c (in N),
- the compressive strain without break ε_c (in %),
- the compressive stiffness K_c ($K_c = F_c / \varepsilon_c$) (in N).

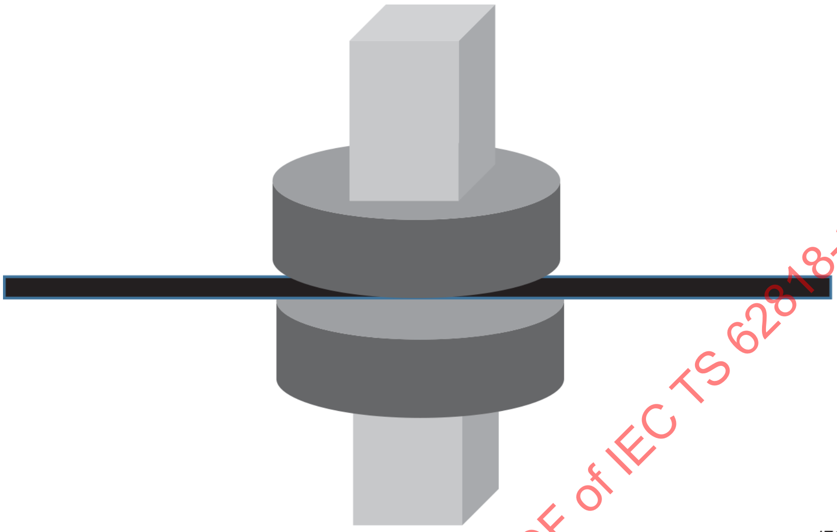


Figure 7 – Illustration of the crushing test

8.3 Salt fog test

The salt fog test of the composite core shall be performed only on cores with a metallic external protective layer 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 ageing phase, the samples shall be washed, dried at room temperature and subjected to visual inspection (7.1).

Any variation in the aspect shall be evaluated referring to the condition of unaged samples.

8.4 Fiber volume ratio

8.4.1 General

Fiber volume ratio shall be provided in one of two methods:

8.4.2 TGA method

According to ISO 11358-1:2022, following the method below. The volume density of polymeric matrix component shall be known in order to calculate the fiber volume ratio. If the volume density of components is not provided by the manufacturer, it shall be calculated according to ISO 11358-1:2022.

Using the TGA method, according to ISO 11358-1:2022, the weight loss versus temperature is measured for PMC wire for characterization and weight distribution among its main components which are matrix, fibers and possibly coating. A typical decomposition core is shown in Figure 8.

The method is based on the sequential decomposition of the main components of PMC wire through heating in two different atmospheres:

– nitrogen atmosphere at a flow rate of 100 ml/min, which produce pyrolyzation of components,
– air atmosphere at a flow rate of 100 ml/min, which produce combustion of components.

When the decomposition of a component is complete, and the specimen temperature is not sufficiently high to activate the decomposition of others, the specimen mass variation represents the mass of the component just decomposed.

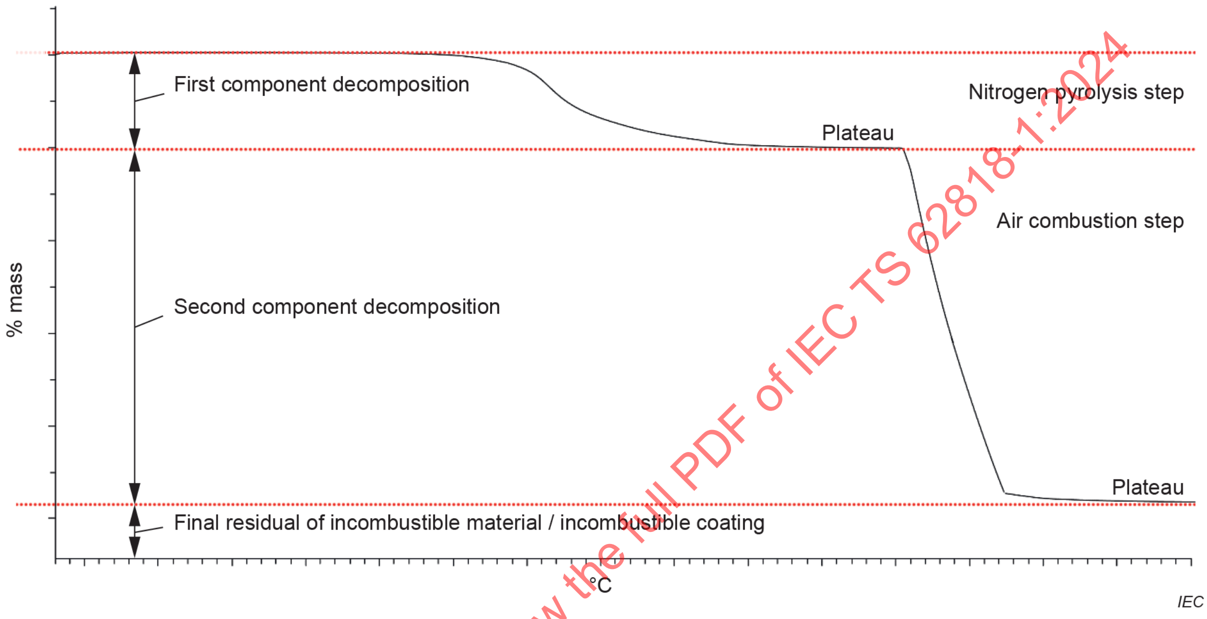


Figure 8 – TGA curve for the measurement of weight loss versus temperature

In order to decompose a component, a heating rate of 10 °C/min with 10 h isotherm step at the end of each temperature ramp is suggested to prove the complete pyrolysis or combustion of a component. A plateau in the TGA curve shall be clearly visible at the end of each isotherm step.

The matrix decomposition step shall be a temperature ramp with a pyrolyzation in nitrogen atmosphere followed by an isotherm permanence in nitrogen atmosphere. Fibers decomposition step shall be a temperature ramp with combustion in air atmosphere, followed by an isotherm permanence in air atmosphere.

When a wire has a non-metallic external protective layer or when other material than matrix and strengthening fibers is present, its decomposition step shall be a temperature ramp followed by an isotherm: a proper decomposition atmosphere shall be chosen between air, nitrogen or oxygen so that the TGA curves show a clearly identifiable mass loss. If this material has a decomposition temperature too high for the TGA equipment, or if its decomposition occurs at a temperature considerably higher than the one for matrix and fibers, its mass determination can be avoided or assumed as equal to a final mass residue of TGA measure.

Even when all the PMC components should have been decomposed, final residuals greater than 2 % may occur due to the presence of some incombustible material such as mineral charges, glass or even sub-products or carbonization of PMC components.

8.4.3 Calculated method

The fiber volume ratio can be calculated by using Formula (1) and Formula (2):

$$\text{fiber volume ratio} = \frac{A_f}{A_w} = \frac{W_f / \rho_f}{A_w} \tag{1}$$

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 fiber, expressed in kilograms per cubic meter (kg/m^3) (provided by the manufacturer).

$$\text{fiber volume ratio} = \frac{\rho_w - \rho_m}{\rho_f - \rho_m} \tag{2}$$

where

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

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

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

8.5 Porosity

A high porosity level will have a detrimental effect on mechanical and ageing properties. Despite mechanical and ageing tests usually being sufficient to determine the level of mechanical performance and thermal resistance of a composite core, this test can be optionally required by the purchaser for a deeper investigation of the inner structure of the composite material and its changes after a temperature ageing. Making mechanical and ageing tests shall be enough to determine the level of performance of the composite core. However, if the purchasers want further information on the core, they may ask for this test.

The porosity and fiber matrix repartition of the PMC wire may be measured using a micrographic observation of the core coupled with a computer-assisted measurement. It is suggested that at least 5 representative regions be analysed.

At least 3 samples of composite wire shall be tested. The wire shall be cut and polished in order to clearly observe the cross-section. The porosity measurement shall be performed using binarization software to differentiate the porosity from the matrix and from the fiber. Porosity shall be measured on pictures taken at a total magnification with a minimum of ×40 using an optical microscope. As an alternative, the SEM technique can be used. If with a single picture, at the chosen magnification factor, it were not possible to catch the required cross-section and/or achieve image focus, more than one picture shall be taken.

The report shall contain a global picture of the composite core cross section at a magnification ranging from ×10 to ×40 with a preferred value of ×10 in order to illustrate the core global aspect. In addition, porosity values in % measured from the pictures at magnification with a minimum of ×40 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 calculate porosity rate below 1 %. Porosity on unaged samples and porosity change during thermal ageing can strongly differ between different products, thus these values cannot be quantitatively linked to quality, mechanical performance or thermal stability.

8.6 UV ageing

The core can be subjected to UV if the core is stored on a reel for a significant amount of time outside without protection before stranding.

The UV ageing test of the composite core shall be performed in accordance with ISO 4892-2:2013 (Xenon). Method A, Cycle 1 is recommended to be used for a duration of 720 h (30 days) with an intermediate point at 360 h.

After the ageing phase, the samples shall be washed, dried and subjected to visual inspection (7.1) and glass transition T_g (7.9).

Reduction of the characteristics of the aged samples shall be calculated referring to unaged samples' experimental values.

Annex A
(normative)

Testing table

All the tests described in Clauses 7 and 8 are listed in Table A.1. For each test on PMC cores, 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**		
7.1	Appearance	T, S, R	10 % of drums, min. 2 per lot
7.2	Diameter	See Table 1	10 % of drums, min. 2 per lot
7.3	Lay length measurement for multi-wire	T, S, R	10 % of drums, min. 2 per lot
7.4	Protective layer thickness	T, S, R	10 % of drums, min. 2 per lot
7.5	DC electrical resistance [a]	T, S	10 % of drums, min. 2 per lot
7.6	Mass per unit length	T, S, R	10 % of drums, min. 2 per lot
7.7	Tensile test	T, S, R	10 % of drums, min. 2 per lot
7.8	Bending test	T	–
7.9	Glass transition temperature	T, S, R	10 % of drums, min. 2 per lot
7.10	Coefficient of thermal expansion	T	–
7.11	$T_{\text{onset Thermolysis}}$ determination	T	–
7.12	Isothermal ageing	T	–
	OPTIONAL TESTS		
8.1	Twisting test	T	–
8.2	Crushing test	T	–
8.3	Salt fog test [a]	T	–
8.4	Fiber volume ratio	T	–
8.5	Porosity	T	–
8.6	UV ageing [b]	T	–

[a] only for PMC with metallic protective layer

[b] only for PMC without metallic protective layer

If not differently specified in the subclause where the test is described (mean value from several measurements), the number of samples for each Type test is 1.

The number of pickings for each sample test is specified in the last column of Table A.1, referred as the percentage of drums to be picked from the production lot to be tested, with a minimum of two drums with one sample per drum. Some tests require a single sample for each picking; others more samples for each picking (repeatability) in order to give a mean value as a result.

Annex B
(normative)

Arrhenius thermal ageing test

B.1 General

The accelerated thermal ageing test, performed adopting the Arrhenius curve method, is finalized to extrapolate the theoretical temperature that, kept constant for the expected lifetime of the overhead line (normally 40 or 50 years), causes a reduction of the rated tensile strength or breaking load of the core in its initial conditions following IEC 60216-1:2013, 5.2 (to be agreed between manufacturer and purchaser).

The Arrhenius thermal ageing test takes a very long time to be prepared, run and analysed (2 years). It is a test of the material system and design (see 5.2.2).

B.2 Ageing temperatures, number of samples and picking frequency

B.2.1 Overview

The speed of breaking load reduction as a function of the temperature of exposition is strictly dependant on composition of the materials used as matrix and fibers for the composite core.

If no sufficient information is available on the composite core to be tested, preliminary exploratory tests are needed for evaluating the speed of decay at several temperatures and correctly define:

– number and values of temperature (T_{exp}) to which the samples shall be aged,
– a possible duration of each ageing phase,
– a sufficient number of samples to correctly draw the decay curves of the breaking load and to ensure the presence of spare samples for possible additional picking.

B.2.2 Definition of the testing plan

To define the testing plan, the following steps can be followed:

a) Definition of T_{exp} and its duration.

   There shall be at least 3 T_{exp} for which end point criterion can be reached (within 10 000 h).

   As a reduction of the duration of test is obtainable by an increase of T_{exp}, T_{exp} shall be carefully defined without exceeding:

   - $T_{onset\ thermolysis}$ in order to avoid the activation of thermolysis processes of irreversible degradation of the matrix,
   - any other critical temperature that could limit the use of the core, imply an irreversible degradation of the materials, cause a different behaviour of the protection layer or change the degradation path from the one related to the intended use of the core.

   A short duration of the isothermal ageing phase can be related to a high value of temperature without a relevant reduction in breaking load. Nevertheless, it is necessary to consider that a permanence at high temperatures could activate degradation processes different by the ones involved in the temperature range used for the Arrhenius test itself or to bring the matrix in a different state.

b) Definition of the picking frequency for each ageing.

Each picking establishes a single point on the "time – mean breaking load" graph (see Figure B.1), and the number of points shall be sufficient to describe correctly the decay curve for each temperature of exposition. The longer the duration of ageing, the higher the number of pickings.

The picking frequency shall be variable during the test and is highly dependent on T_{exp}, with an increase in the area where the decay curve is close to the end-point criterion (minimum of 5 samples is suggested similar to the blue data points in Figure B.1). Once a preliminary picking table has been defined according to the indications above, it shall be adjusted during the test, according to experimental results: reducing the picking frequency if the experimental mean breaking loads are decaying with a rate lower than expected and vice versa.

It can be observed that some PMC cores (as in Figure B.1) may show an initial increase in the mean breaking load curve, before the decay phase. The presence and the entity of this behaviour (mainly due to a final post-curing of the polymeric matrix) shall be properly evaluated during the exploratory tests in order to reduce the picking frequency in this phase, not relevant for the determination of the end-point.

c) Definition of the number of samples.

The number of samples to be prepared for each oven shall be defined considering that:

– the low repeatability of measured breaking load on composite core requires to test at least 5 samples for each picking in order to calculate a reliable mean value of breaking load,

– as a precise prevision of the duration and number of picking is difficult and ageing phase duration can be long, the preparation of extra samples as a spare to be added to the others is recommended. For cases in which the accuracy requires heat ageing at an additional temperature, as reference specimens, or some breaking test needs to be repeated.

B.3 Test method

For anything not specified in this Clause B.3, the simplified procedure described in IEC 60216-1:2013 shall be applied.

The samples are placed in the thermal aging ovens, set at the established exposure temperatures, and gradually removed, according to the picking plan (see Clause B.1).

Once removed from the oven, samples shall be cooled in still air to room temperature.

The composite cores shall be tensile tested, according to the procedure in 7.7 and the mean breaking load (or the equivalent tensile strength) shall be registered and drawn on a diagram as a function of exposure time (plotted on the X-axis in logarithmic scale), as represented in Figure B.1.