

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Magnetic materials –

Part 12: Methods of test for the assessment of the thermal endurance of surface insulation coatings on electrical steel strip and sheet

Matériaux magnétiques –

[IEC 60404-12:2023](#)

Partie 12: Méthodes d'essai pour l'évaluation de l'endurance thermique des revêtements isolants superficiels des bandes et tôles en acier électrique



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IEC Secretariat
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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IEC 60404-12 has been prepared by IEC technical committee 68: Magnetic alloys and steels. It is an International Standard.

This second edition cancels and replaces the first edition published in 1992. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) the method of test for adhesion has been modified to match to the method of bend test specified in ISO 1519 using a cylindrical mandrel of 32 mm in diameter instead of the 30 mm diameter mandrel specified in the first edition;
- b) the method of test for interlaminar insulation resistance has been modified to match to the method specified in IEC 60404-11 and the modified Franklin test has been removed;
- c) the method of test for compressibility has been modified to match to the method of test for stacking factor specified in IEC 60404-13;

- d) the concept of "resistance grades" has been removed;
- e) the clamping pressure to be used at temperature ratings above 500 °C has been reduced to $(0,01 \pm 0,001) \text{ N/mm}^2$;
- f) the testing for continuous exposure has been made a subject to an agreement between the manufacturer and the purchaser and the procedure has been moved to an informative Annex A.

The text of this International Standard is based on the following documents:

Draft	Report on voting
68/698/CDV	68/720/RVC

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 International Standard is English.

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.

A list of all parts in the IEC 60404 series, published under the general title *Magnetic materials*, can be found on the IEC website.

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,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The surface insulation coatings on electrical steel strip and sheet are sometimes exposed to elevated temperatures in service or during processing by the purchaser. Therefore, the thermal endurance of the surface insulation coating is important.

Physicochemical models postulated for the aging processes lead to the almost universal assumption of the Arrhenius equations to describe the rate of aging (see Annex A of this document and IEC 60216-1).

Since the measurement of the properties of surface insulation coatings at elevated temperatures is expensive and time-consuming, the thermal endurance of a coating is usually assessed by evaluating the change of a specified coating property, at an ambient temperature, due to a heat treatment.

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MAGNETIC MATERIALS –

Part 12: Methods of test for the assessment of the thermal endurance of surface insulation coatings on electrical steel strip and sheet

1 Scope

This part of IEC 60404 is applicable to surface insulation coatings on electrical steel strip and sheet classified in IEC 60404-1-1.

This document defines the general principles and technical details of the tests for the assessment of the thermal endurance of surface insulation coatings on electrical steel strip and sheet.

The assessment is made by evaluating the change of a specified property of the surface insulation coating due to a heat treatment at a specified temperature up to 850 °C for a specified duration time up to 2 500 h. The specified property is measured at an ambient temperature of (23 ± 5) °C both without heat treatment and after heat treatment.

This document is applicable to the following properties of surface insulation coatings:

- adhesion;
- surface insulation resistance;
- stacking factor.

This document is not applicable to other properties of surface insulation coatings, e.g. welding properties, or to other effects, e.g. discoloration and off-gassing, which can be caused by exposure to elevated temperatures.

NOTE Some of the tests take a very long time to perform and therefore they are often not appropriate for acceptance tests of material supplied on a specific order.

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 60050-121, *International Electrotechnical Vocabulary – Part 121: Electromagnetism*

IEC 60050-221, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components*

IEC 60404-1-1, *Magnetic materials – Part 1-1: Classification – Surface insulations of electrical steel sheet, strip and laminations*

IEC 60404-11, *Magnetic materials – Part 11: Methods of measurement of the surface insulation resistance of electrical steel strip and sheet*

IEC 60404-13, *Magnetic materials – Part 13: Methods of measurement of resistivity, density and stacking factor of electrical steel strip and sheet*

ISO 1519, *Paints and varnishes – Bend test (cylindrical mandrel)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-121, IEC 60050-221 and the following apply.

ISO and IEC maintain terminological 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

temperature/time performance designation T/t

designation consisting of a temperature T , expressed in °C, and a duration of time t , expressed in hours, of a heat treatment that a surface insulation coating can withstand with respect to a specified coating property

EXAMPLE The designations 200/2500 and 800/2 mean that the surface insulation coating can withstand heat treatments at 200 °C for 2 500 h and 800 °C for 2 h, respectively, with respect to a specified coating property.

Note 1 to entry: This designation serves for rating of the thermal endurance of a surface insulation coating with respect to specified coating properties.

Note 2 to entry: More than one designation can be assigned to a coating.

4 General principles

4.1 General

The thermal endurance of a surface insulation coating shall be assessed by evaluating changes of specified coating properties due to a heat treatment at a specified temperature T °C for a specified duration time t h. The coating properties shall be measured at an ambient temperature of (23 ± 5) °C.

The thermal endurance for the following coating properties shall be assessed separately:

- adhesion;
- surface insulation resistance;
- stacking factor.

4.2 Preparation of clamped stacks of test specimens

4.2.1 Procedure of stacking test specimens

The test specimens shall be stacked between two similar sized or larger sheets made of the same material as the test specimens. The stack shall then be clamped between two steel pressure plates. The dimensions of the steel pressure plates shall be larger than the size of the part of the test specimens to be tested, e.g. it is permitted to clamp only the part of the test specimens that will be bent at the bend test (see 6.3).

4.2.2 Clamping stacks for temperature ratings up to 500 °C

The stack of test specimens shall be clamped homogeneously between the two steel pressure plates under a pressure of $(1 \pm 0,1)$ N/mm². Figure 1 illustrates an example of clamped stack for 100 mm square test specimens for temperature rating up to 500 °C.

The pressure shall be applied using suitable calibrated equipment such as a press, a tensile test machine or hydraulic jacks. The bolts shall be tightened while applying the pressure. The disk-springs, the bolts, the nuts and the steel pressure plates shall be made of suitable materials which can maintain a substantially constant pressure while the test specimens are subjected to the heat treatment.

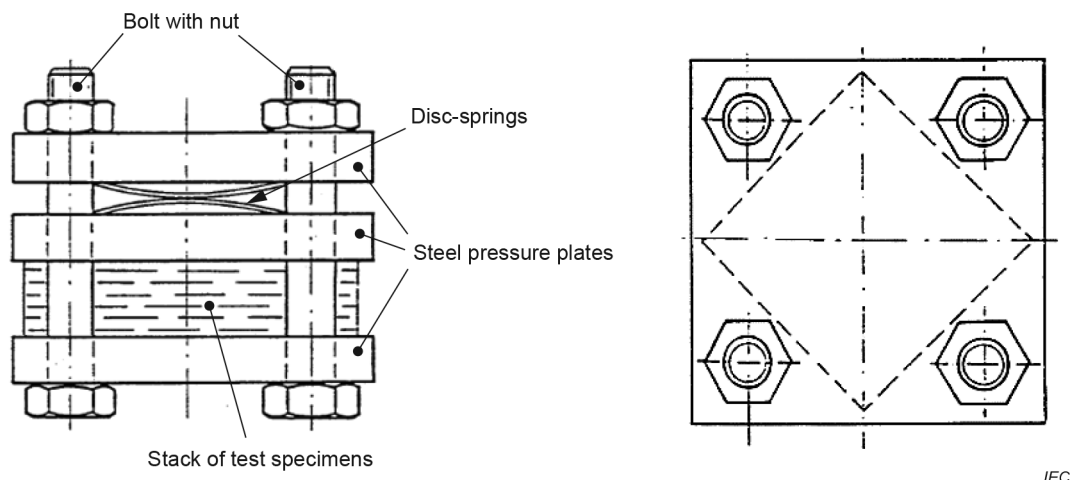


Figure 1 – Example of clamped stack for 100 mm square test specimens

In case the clamping method using screws causes problems during the test, the manufacturer and the purchaser can agree at the time of enquiry and order on using the clamping method for above 500 °C described in 4.2.3.

4.2.3 Clamping stacks for temperature ratings above 500 °C

The stack of test specimens shall be clamped homogeneously between the two steel pressure plates under a pressure of $(0,01 \pm 0,001) \text{ N/mm}^2$.

The pressure shall be applied by using a dead weight or by an externally applied force transmitted by suitable thermally insulated rods from the outside of the furnace used for the heat treatment.

4.3 Heat treatment

4.3.1 For time ratings up to 2 500 h

The clamped stack shall be placed in a furnace at near ambient temperature. The furnace shall be heated to the temperature T °C within $\pm 1,5$ % with a heating rate not exceeding 200 °C/h.

When the furnace reaches the temperature T °C, this temperature shall be held for a specified duration time of t h within ± 1 %, where T and t constitute the temperature/time performance designation T/t .

The furnace shall have enough power and heating capacity to ensure that the surface of the clamped stack reaches at least 2,5 % below the temperature T °C when the furnace reaches the temperature T °C. The furnace capacity shall be confirmed, e.g. by means of a thermocouple applied to the clamped stack. A furnace with forced atmosphere convection is recommended.

After the duration time t h, the clamped stack is removed from the furnace and allowed to cool to ambient temperature.

For temperatures up to 500 °C, the heat treatment shall take place in air. For temperatures above 500 °C, other atmospheres, e.g. inert atmosphere, are recommended to avoid oxidation of the steel.

4.3.2 For continuous exposure

If agreed between the manufacturer and the purchaser at the time of enquiry and order, the assessment of the thermal endurance for continuous exposure to elevated temperatures can, as a guide, be carried out according to the procedure described in Annex A.

5 Standard temperature/time performance designations T/t

The recommended standard temperature/time performance designations T/t are:

150/168, 180/168, 200/168, 250/168, 150/2500, 180/2500, 200/2500, 250/2500, 400/6, 500/0,5, 750/2, 800/2 and 850/2.

6 Method of the test for adhesion

6.1 General

The test for assessment of the thermal endurance for adhesion shall be made by the method of bend test in accordance with ISO 1519 using the test apparatus with a mandrel with $(32 \pm 0,1)$ mm diameter specified in ISO 1519 at an ambient temperature of (23 ± 5) °C.

The manufacturer and the purchaser can agree at the time of enquiry and order to use a different diameter of the mandrel, e.g. 30 mm to comply with the requirements according to the first edition of IEC 60404-12 (IEC 60404-12:1992), or a smaller diameter to increase the severity of the test.

6.2 Test specimens

The test specimens shall be at least 30 mm in width, 280 mm to 320 mm in length. They shall be cut parallel to the rolling direction of the strip or sheet, and adjacent to each other, without causing damage to the coating. Four test specimens shall be cut from the strip or sheet at least 40 mm away from the edges of the strip or sheet.

NOTE A test applied to coated electrical steel sheets of one nominal thickness can be considered to be representative of the coated electrical steel sheets of other nominal thicknesses.

6.3 Procedure of test

Two of the four test specimens shall be tested without heat treatment. One test specimen shall be bent with one of the surfaces against the mandrel and another test specimen shall be bent with the opposite surface against the mandrel.

The test specimens shall be examined immediately after bending by the naked eye under sufficient illumination. There shall be no cracking and/or detachment of the coating from the base material visible to the naked eye, ignoring the surface of the coating within 2 mm from the edges of the test specimen.

The remaining two test specimens shall be stacked and clamped in accordance with 4.2, and then heat-treated at a specified temperature T °C for a specified duration time t h in accordance with 4.3.

After cooling the test specimens to $(23 \pm 5) ^\circ\text{C}$, the test specimens shall be removed from the clamping device and tested in the same way as the first two test specimens are tested. If there is no cracking and/or detachment of the coating from the base material visible to the naked eye, ignoring the surface of the coating within 2 mm from the edges of the test specimen, the coating has a temperature/time performance designation T/t with respect to adhesion.

6.4 Test report

The test report for each temperature/time performance designation T/t shall include the following as applicable:

- a) the description of the surface insulation coating, including the coating thickness, and the type of base material (e.g. a steel name specified in IEC 60404-8-4);
- b) the number of this document (IEC 60404-12), including the year of publication;
- c) the diameter of the mandrel used for the bend test if different from the specified $(32 \pm 0,1)$ mm;
- d) the atmosphere used during the heat treatment;
- e) the description of any cracks or detachment of the coating from the base material without heat treatment and after the heat treatment, ignoring the surface of the coating within 2 mm from the edges of the test specimen;
- f) the temperature/time performance designation T/t with respect to adhesion.

7 Method of the test for surface insulation resistance

7.1 General

The test for assessment of the thermal endurance for surface insulation resistance shall be made in accordance with IEC 60404-11 at an ambient temperature of $(23 \pm 5) ^\circ\text{C}$.

7.2 Test specimens

A sufficient number of test specimens shall be prepared to provide a total area enabling 10 measurements of surface insulation resistance to fulfil the requirements of IEC 60404-11. Two sets of such test specimens shall be prepared.

7.3 Procedure of test

The first set of test specimens shall be tested without heat treatment. The value of the coefficient of the insulation resistance shall be calculated from 10 measurements (five measurements per side for materials coated on both sides).

The second set of test specimens shall be stacked and clamped in accordance with 4.2, and then heat-treated at a specified temperature $T ^\circ\text{C}$ for a specified duration time t h in accordance with 4.3.

After cooling the test specimens to $(23 \pm 5) ^\circ\text{C}$, the second set of test specimens shall be removed from the clamping device and the value of the coefficient of the surface insulation resistance shall be measured in the same way as the first set of test specimens was measured.

If the value of the coefficient of the surface insulation resistance has not decreased by more than 30 % due to the heat treatment, the coating has a temperature/time performance designation T/t with respect to surface insulation resistance.