IEC 62899-201

Edition 1.1 2018-11

CONSOLIDATED VERSION

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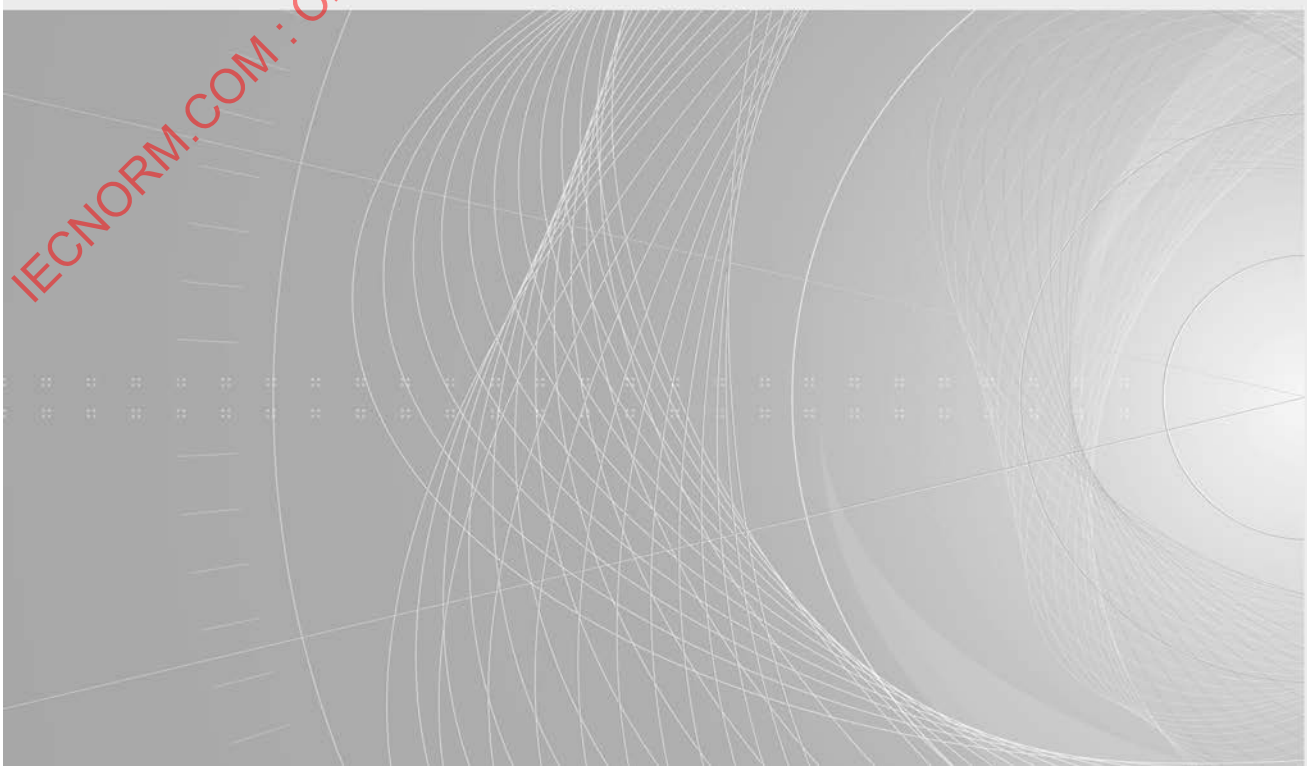
Printed electronics –
Part 201: Materials – Substrates



IEC 62899-201:2016-02+AMD1:2018-11 CSV(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

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

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Printed electronics –
Part 201: Materials – Substrates

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.035.01; 31.180

ISBN 978-2-8322-6279-5

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IEC 62899-201

Edition 1.1 2018-11

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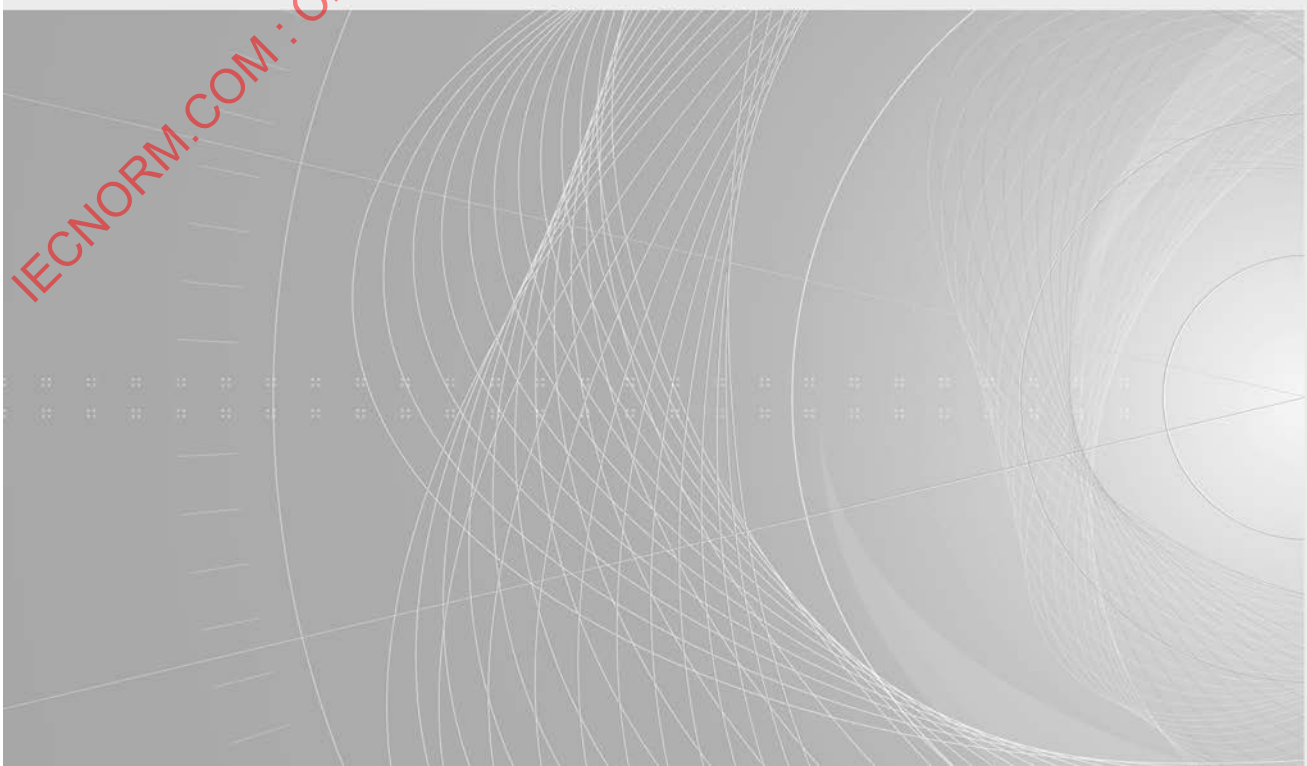
Printed electronics –
Part 201: Materials – Substrates



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PRINTED ELECTRONICS –

Part 201: Materials – Substrates

FOREWORD

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This Consolidated version of IEC 62899-201 bears the edition number 1.1. It consists of the first edition (2016-02) [documents 119/87/FDIS and 119/100A/RVD] and its amendment 1 (2018-11) [documents 119/189/CDV and 119/206A/RVC]. The technical content is identical to the base edition and its amendment.

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 62899-201 has been prepared by IEC technical committee 119: Printed electronics.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The IEC 62899-20x series relates mainly to evaluation methods for materials of printed electronics. The series also includes storage methods, packaging and marking, and transportation conditions.

The IEC 62899-20x series is divided into parts for each material. Each part is prepared as a generic specification containing fundamental information for the area of printed electronics.

The IEC 62899-20x series consists of the following parts:

Part 201: Materials – Substrates

Part 202: Materials – Conductive ink

Part 203: Materials – Semiconductor ink[1]

(Subsequent parts will be prepared for other materials.)

Furthermore, sectional specifications, blank detail specifications, and detail specifications for each material will follow these parts.

This part of IEC 62899 is prepared for substrate used in printed electronics and contains the test conditions, the evaluation methods and the storage conditions.

[1] Under consideration.

PRINTED ELECTRONICS –

Part 201: Materials – Substrates

1 Scope

This part of IEC 62899 defines the terms and specifies the evaluation method for substrates used in the printing process to form electronic components/devices. This international standard is also applied to the substrates which make surface treatment in order to improve their performance.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at www.electropedia.org)

IEC 60093:1980, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

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

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1:* Ageing *ovens – Single-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60216-6, *Electrical insulating materials – Thermal endurance properties – Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method*

IEC 60243-1:2013, *Electric strength of insulating materials – Test methods – Part 1: Tests at power frequencies*

IEC 60674-2:1988, *Specification for plastic films for electrical purposes – Part 2: Methods of* test
IEC 60674-2:1988/AMD1:2001

IEC 60674-3-1:1998, *Plastic films for electrical purposes – Part 3: Specifications for individual materials – Sheet 1: Biaxially oriented polypropylene (PP) films for capacitors*
IEC 60674-3-1/AMD1:2011

IEC 60695-11-10, *Fire hazard testing – Part11-10: Test flames – 50W horizontal and vertical flame test methods*

IEC 60721-3-1, *Classification of environmental conditions – Part 3 Classification of groups of environmental parameters and their severities – Section 1: Storage*

IEC 60721-3-2, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

IEC 61189-2:2006, *Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 2: Test methods for materials for interconnection structures*

IEC 61189-3:2007, *Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 3: Test methods for interconnection structures (printed boards)*

IEC 62321-3-1, *Determination of certain substances in electrotechnical products – Part 3-1: Screening – Lead, mercury, cadmium, total chromium and total bromine using X-ray fluorescence spectrometry*

IEC 62899-202-5, *Printed electronics – Part 202-5: Materials – Conductive ink – Mechanical bending test of a printed conductive layer on an insulating substrate*

ISO 5-2, *Photography and graphic technology – Density measurements – Part 2: Geometric conditions for transmittance density*

ISO 5-3, *Photography and graphic technology – Density measurements – Part 3: Spectral conditions*

ISO 62, *Plastics – Determination of water absorption*

ISO 175:2010, *Plastics – Methods of test for the determination of the effects of immersion in liquid chemicals*

ISO 187, *Paper, board and pulps – Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples*

ISO 216, *Writing paper and certain classes of printed matter – Trimmed sizes – A and B series, and indication of machine direction*

ISO 217, *Paper – Untrimmed sizes – Designation and tolerances for primary and supplementary ranges, and indication of machine direction*

ISO 291, *Plastics – Standard atmospheres for conditioning and testing*

ISO 472, *Plastics – Vocabulary*

ISO 489:1999, *Plastics – Determination of refractive index*

ISO 527-1:2012, *Plastics – Determination of tensile properties – Part 1: General principles*

ISO 527-2, *Plastics – Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics*

ISO 527-4, *Plastics – Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

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

ISO 534, *Paper and board – Determination of thickness, density and specific volume*

ISO 535, *Paper and board – Determination of water absorptiveness – Cobb method*

ISO 536, *Paper and board – Determination of grammage*

ISO 868, *Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness)*

ISO 1924-2, *Paper and board – Determination of tensile properties – Part 2: Constant rate of elongation method (20 mm/min)*

ISO 1924-3, *Paper and board – Determination of tensile properties – Part 3: Constant rate of elongation method (100 mm/min)*

ISO 1974, *Paper – Determination of tearing resistance – Elmendorf method*

ISO 2039-1, *Plastics – Determination of hardness – Part 1: Ball indentation method*

ISO 2039-2, *Plastics – Determination of hardness – Part 2: Rockwell hardness*

ISO 2471, *Paper and board – Determination of opacity (paper backing) – Diffuse reflectance method*

ISO 2493-1, *Paper and board – Determination of bending resistance – Part 1: Constant rate of deflection*

ISO 2493-2, *Paper and board – Determination of bending resistance – Part 2: Taber-type tester*

ISO 2578:1993, *Plastics – Determination of time-temperature limits after prolonged exposure to heat*

ISO 2758, *Paper – Determination of bursting strength*

ISO 2759, *Board – Determination of bursting strength*

ISO 3274, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

ISO 3664, *Graphic technology and photography – Viewing conditions*

ISO 3696, *Water for analytical laboratory use – Specification and test methods*

ISO 3781, *Paper and board – Determination of tensile strength after immersion in water*

ISO 3783, *Paper and board – Determination of resistance to picking – Accelerated speed method using the IGT-type tester (electric model)*

ISO 4287, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*

ISO 4288:1996, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture*

ISO 5626, *Paper – Determination of folding endurance*

ISO 5635, *Paper – Measurement of dimensional change after immersion in water*

ISO 6383-1, *Plastics – Film and sheeting – Determination of tear resistance – Part 1: Trouser tear method*

ISO 6383-2, *Plastics – Film and sheeting – Determination of tear resistance – Part 2: Elmendorf method*

ISO 6507-1, *Metallic materials – Vickers hardness test – Part 1: Test method*

ISO 6588-1, *Paper, board and pulps – Determination of pH of aqueous extracts – Part 1: Cold extraction*

ISO 6588-2, *Paper, board and pulps – Determination of pH of aqueous extracts – Part 2: Hot extraction*

ISO 7991, *Glass – Determination of coefficient of mean linear thermal expansion*

ISO 8791-2, *Paper and board – Determination of roughness/smoothness (air leak methods) – Part 2: Bendtsen method*

ISO 8791-4, *Paper and board – Determination of roughness/smoothness (air leak methods) – Part 4: Print-surf method*

ISO 9220:1988, *Metallic coatings – Measurement of coating thickness – Scanning electron micro-scope method*

ISO 9773:1998, *Plastics – Determination of burning behaviour of thin flexible vertical specimens in contact with a small-flame ignition source*
ISO 9773:1998/AMD1:2003

ISO 11359-2:1999, *Plastics – Thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

ISO 11556, *Paper and board – Determination of curl using a single vertically suspended test piece*

ISO 11664-4, *Colorimetry – Part 4: CIE 1976 $L^*a^*b^*$ Colour space*

ISO 11798, *Information and documentation – Permanence and durability of writing, printing and copying on paper – Requirements and test methods*

ISO 12192, *Paper and board – Determination of compressive strength – Ring crush method*

ISO 13468-1:1996, *Plastics – Determination of the total luminous transmittance of transparent materials – Part 1: Single beam instrument*

ISO 13468-2:1999, *Plastics – Determination of the total luminous transmittance of transparent materials – Part 2: Double-beam instrument*

ISO 13565-2:1996, *Geometrical Product Specification (GPS) – Surface texture: Profile method; Surfaces having stratified functional properties – Part 2: Height characterization using the linear material ratio curve*

ISO 13655, *Graphic technology – Spectral measurement and colorimetric computation for graphic arts images*

ISO 14782, *Plastics – Determination of haze for transparent materials*

ISO 15105-1, *Plastics – Film and sheeting – Determination of gas-transmission rate – Part 1: Differential-pressure methods*

ISO 15105-2:2003, *Plastics – Film and sheeting – Determination of gas-transmission rate – Part 2: Equal-pressure method*

ISO 15106-1, *Plastics – Film and sheeting – Determination of water vapour transmission rate – Part 1: Humidity detection sensor method*

ISO 15106-2, *Plastics – Film and sheeting – Determination of water vapour transmission rate – Part 2: Infrared detection sensor method*

ISO 15106-3, *Plastics – Film and sheeting – Determination of water vapour transmission rate – Part 3: Electrolytic detection sensor method*

ISO 15106-4, *Plastics – Film and sheeting – Determination of water vapour transmission rate – Part 4: Gas-chromatographic detection sensor method*

ISO 15184, *Paints and varnishes – Determination of film hardness by pencil test*

ISO 15512, *Plastics – Determination of water content*

ISO 15359, *Paper and board – Determination of the static and kinetic coefficients of friction – Horizontal plane method*

ISO 15754, *Paper and board – Determination of z-directional tensile strength*

ISO 15989, *Plastics – Film and sheeting – Measurement of water-contact angle of corona-treated films*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050, IEC 60695-11-10, ISO 472, ISO 4287, as well as the following apply.

3.1
bow and twist
distortion in the dimensions of a plastic object which occurs after moulding or processing

Note 1 to entry: See Figure 1 for an example of bow and Figure 2 for an example of twist.

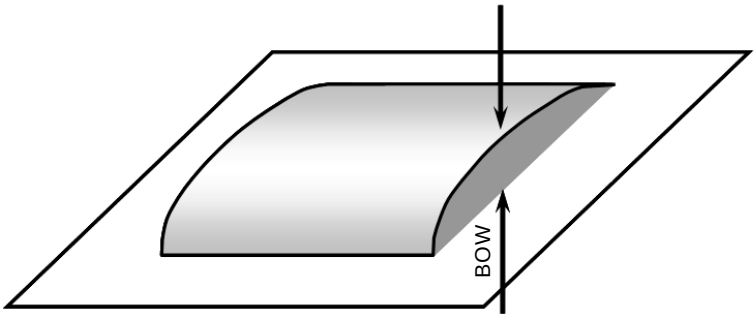

Figure 1 – Example of bow

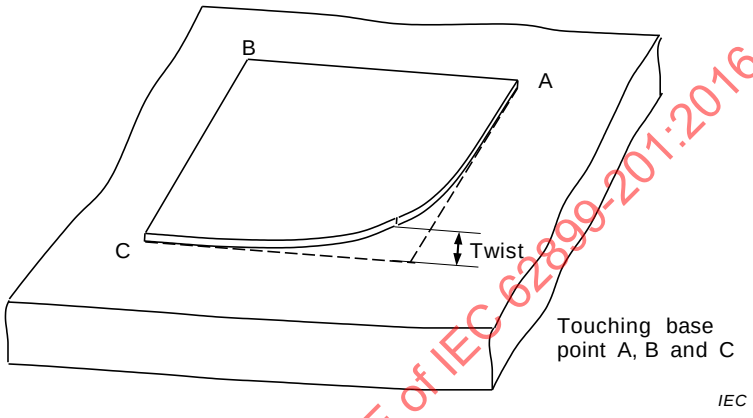

Figure 2 – Example of twist

3.2
roughness
surface property of a substrate which indicates a high-frequency component of irregular elements in the profile curve

Note 1 to entry: Roughness is obtained as a roughness curve by subtracting noise and micro-waviness (see 3.3) from the profile curve measured with a profile filter and phase compensation filter.

3.3
micro-waviness
surface property of a substrate which indicates a low-frequency component of irregular elements in the profile curve

Note 1 to entry: Micro-waviness is obtained from the average line (from the deviation curve) of the measured profile curve.

3.4
foreign substance on surface
substance which is located on the surface of the substrate and can be removed easily by washing off with water, alcohols, cleaning agents, etc., or ultrasonic cleaning

3.5
foreign inclusion
substance which is completely embedded in the substrate or partially exposed on the surface of the substrate, and cannot be removed by cleaning

3.6
edge condition
state of the edges of the substrate which indicates the presence of distortion, waviness, scratches, fracture, burrs, or foreign substances

3.7
minimum bending radius
smallest limit bending radius for which permanent structural change does not occur

3.8
tear strength
force required to rip test specimens apart

Note 1 to entry: The unit of tear strength is newton (N).

3.9
tear propagation resistance
tear strength (see 3.8) divided by thickness

Note 1 to entry: The unit of tear propagation resistance is newton/millimetre (N/mm).

3.10
gas transmission
ease of gas which passes through a unit area of a substrate per unit time under specified temperature and humidity conditions

3.11
water vapour transmission
amount of water vapour which passes through a unit area of a substrate per unit time under specified temperature and humidity conditions

Note 1 to entry: Water vapour transmission is generally expressed as the mass of water vapour which passes through an area of 1 m^2 in 24 h ($g/m^2 \cdot d$).

3.12
oxygen gas transmission
amount of oxygen which passes through a unit area of substrate per unit time and unit partial pressure between both sides of the substrate under specified temperature and humidity conditions

3.13
electric strength
quotient of the maximum voltage applied without breakdown, by the distance between conducting parts under prescribed test conditions

[SOURCE: IEC 60050-212:2010, 212-11-37]

3.14
temperature index
numerical value corresponding to the temperature, in degrees Celsius, derived from the thermal endurance relationship at a given time (normally 20 000 h)

[SOURCE: ISO 2578:1993, 3.1, modified – “numerical value” is used instead of “number”.]

3.15
relative temperature index
temperature index (see 3.14) of a test material, obtained at the time which corresponds to the known temperature index of a reference material when both materials are subjected to the same ageing and diagnostic procedures in a comparative test

[SOURCE: ISO 2578:1993, 3.2, modified – the reference to “temperature index” has been added.]

3.16
chip
<glass substrates> place from which a small piece of glass has been removed from the glass surface

3.17
crack
<glass substrates> lines on the surface of the central or edge of glass where it has broken but not split into separate parts

3.18
scratch
<glass substrates> shallow grooves on a glass surface which are made during handling

Note 1 to entry: A scratch may be accompanied by a crack.

3.19
paper
material without conductivity in the form of a coherent sheet or web, excluding sheets or laps of pulp as commonly understood for paper-making or paper-dissolving purposes and non-woven products, made by deposition of vegetable, mineral, animal or synthetic fibres, or their mixtures, from a fluid suspension onto a suitable forming device, with or without the addition of other substances

Note 1 to entry: There are also a number of synthetic products with paper-like qualities that are applicable as substrates for printed electronics. For the purposes of this document these can be treated as paper for testing as substrates.

[SOURCE: ISO 21067-1:2016, A.1.1, modified – “without conductivity“ and NOTE have been added.]

3.20
board
paper (3.19) of a relatively high rigidity

Note 1 to entry: The term “paper” may be used for both paper and board. Materials of grammage less than 225 g/m^2 are generally considered to be paper, and materials of grammage of 225 g/m^2 or more to be board.

[SOURCE: ISO 5127:2017, 3.3.5.2.02]

3.21
pinhole
small hole in a printed feature that is a result of a surface inhomogeneity on the substrate

Note 1 to entry: This can be a consequence of a number of causes, and potential examples are listed below:

- a small hole in the surface of the substrate;
- a hole large enough to permit the transfer of an applied functional ink;
- a local variation in the wetting properties of the surface that results in uneven wetting of an applied functional ink.

4 Materials, structures and dimensions

4.1 Base materials

Base materials are used in the printing process to form electronic components/devices that are polymer, glass and other materials such as ceramics, metal, paper, etc.

4.2 Structures of substrates

The substrate shall have a monolithic structure of one of the materials specified in 4.1, a composite structure of several of those materials, or a reinforced composite structure strengthened with fibres or particles. The surface of the substrate may be treated to enhance the wettability, adhesive property, gas transmission, smoothness, and electric insulation.

For paper substrates, all paper and paper board substrates may be used. For example, uncoated or coated one-layer paper, as well as similarly uncoated or coated multilayer paperboards can be used, and laminated papers/boards, polymer coating papers/boards, and papers/boards coating with extrusion/dispersion can also be used.

4.3 Dimensions of substrates

4.3.1 Outline

Substrates made of the material(s) specified in 4.1 and with a structure specified in 4.2 shall be supplied in the form of (rigid or flexible) sheets or rolls.

The preferred area dimensions (width and length) of the substrate are shown below. The preferred thickness is specified in 4.3.4. The dimensions of the substrate shall be agreed between user and supplier, and described in the product specifications.

4.3.2 Sheet dimensions

The recommended standard area dimensions (width and length) of a sheet are shown below. The tolerance of width and length is ±1 mm.

370 mm × 470 mm, 550 mm × 650 mm, 680 mm × 880 mm, and 1 100 mm × 1 300 mm

4.3.3 Width and length (roll supply)

4.3.3.1 Polymer substrates

Preferred substrate widths are 800 mm and 1 600 mm with a tolerance of ±1 mm. The test method for substrate width shall be as specified in IEC 60674-2:1988, Clause 5.

The substrate winding length on a roll shall be as agreed between user and supplier.

The inner diameter of a roll winding core shall be 7,62 cm (3 inches) or 15,24 cm (6 inches). The core shape shall be cylindrical. The core material may be any material which can be used in a level 100 clean room.

The winding condition on a roll shall be evaluated by referring to IEC 60674-2:1988, Clause 6. The sum of the curvature and sag shall be 10 mm or less.

The roll winding misalignment of the roll (the difference between the roll width and the maximum substrate width) shall comply with Table 1.

Table 1 – Winding misalignment of the roll

Dimensions in millimetres

Substrate width	Winding misalignment
less than 150	0,5 or less
150 to less than 300	1,0 or less
300 or more	2,0 or less

4.3.3.2 Glass substrates

Preferred substrate widths are 300 mm, 600 mm, 800 mm and 1 600 mm with a tolerance of ±5 mm. Substrate winding length on a roll shall be as agreed between user and supplier.

The inner diameter of the roll winding core, core material, roll winding condition and roll winding misalignment should be as specified in the stipulations regarding the polymer substrate.

4.3.3.3 ~~Other materials~~ Paper substrate

~~Under consideration.~~

When paper substrate is used as a sheet, the dimensions of the sheets shall be as specified in ISO 216. Designation and tolerances for primary and supplementary ranges, and indication of machine direction shall be as specified in ISO 217.

When paper substrate is supplied by a roll, the standard widths of the roll shall be according to ISO 217. Winding length on a roll shall be as agreed between user and supplier.

4.3.4 Substrate thickness

4.3.4.1 Polymer substrates

Substrate nominal thickness shall be selected from 5 μm, 7,5 μm, 10 μm, 12,5 μm, 20 μm, 25 μm, 30 μm, 38 μm, 50 μm, 75 μm, 100 μm, 125 μm, 150 μm, 188 μm, 200 μm or 250 μm. The tolerance of the nominal thickness shall be ±10%.

4.3.4.2 Glass substrates

Substrate nominal thickness should be selected from 5 μm, 10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 70 μm, 100 μm, 125 μm, 150 μm, 200 μm, 250 μm, 300 μm, 400 μm, 500 μm, 600 μm, 700 μm, 800 μm or 1 000 μm. The tolerance of the nominal thickness should be ±10 %.

4.3.4.3 ~~Other materials~~ Paper substrate

~~Under consideration.~~

The thickness of substrates is not limited. It shall be as agreed between user and supplier. The method for measuring thickness shall be according to ISO 534.

Determination of grammage shall be according to ISO 536.

5 General descriptions of evaluation tests

5.1 Sampling

~~Under consideration.~~

In case paper substrates are used, the test methods in this document may be applied to the evaluation of a single sheet or to the set of sheets. When the test methods are applied to the set of sheets, the sheet shall be sampled randomly with no replacement. In cases where the results of the tests are reported for a set of sheets, the total number of sheets in the set to be tested and the number of sheets measured shall be reported.

5.2 Preparation of test specimens

The substrate shall be in its original form, or cut into the appropriate size for testing.

Care should be taken not to touch the test specimens with fingers, etc. The specimens shall not be cleaned unless otherwise specified.

5.3 Atmospheric conditions for evaluation test

The temperature and humidity conditions for evaluation tests shall be at a temperature of 23 °C ± 1 °C and relative humidity of (50 ± 5) % according to ISO 291 unless otherwise specified.

The paper and paper board substrates shall be tested under standard atmospheric conditions, at a temperature of 23 °C ± 1 °C and a relative humidity of (50 ± 2) %.

NOTE These are the standard atmospheric conditions as specified by ISO 187.

5.4 Conditioning

5.4.1 Polymer substrates

Polymer substrates need conditioning. Unless otherwise specified, the test specimens to be evaluated shall be stored at a temperature of 23 °C ± 1 °C and relative humidity of (50 ± 5) % for 48 h or more.

5.4.2 Glass substrates

Since glass substrates have no hygroscopicity, conditioning is generally not necessary.

5.4.3 Other materials

~~Under consideration.~~

Paper and paper board substrates need conditioning. Unless otherwise specified, the test specimens to be evaluated shall be conditioned according to ISO 187.

6 Characteristics and evaluation method of polymer substrates

6.1 Surface properties

6.1.1 Surface defects

6.1.1.1 General characteristics

The surface of a substrate shall not have the following defects. However, since the maximum permissible size of defects depends on the purpose, the defect condition shall be agreed upon between user and supplier.

– Pinholes, hollows, blisters, pimples, fish-eyes, speckles, cracks, fractures, wrinkles, detachment and creep

6.1.1.2 Detection method

The surface defects of a substrate shall be detected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine such as a stylus-based profilometer, or WLI (white light interferometry).

6.1.1.3 Report of the results

The report shall include the following items. For defect(s) not exceeding the permissible size, items b) through f) may be omitted:

a) type of defects;

b) length of each defect;

c) width of each defect;

d) depth or height of each defect;

e) number of defects;

f) position of each defect.

6.1.2 Flatness

6.1.2.1 Bow and twist

6.1.2.1.1 Test method

Bow and twist are expressed as the bow ratio and twist ratio according to IEC 61189-3:2007, 9.4 (test 3M04).

The permissible bow ratio and twist ratio shall be agreed upon between user and supplier as required. This agreement should consider the actual use on products as well as the manufacturing process.

6.1.2.1.2 Report of the results

The report shall include the bow ratio and twist ratio.

6.1.2.2 Surface roughness

6.1.2.2.1 Procedure of measurement and calculation

Surface roughness is expressed as the arithmetic mean roughness (Ra). However, unevenness (extrusions) which exceeds the level difference (Rk) at the core shall be treated as protrusions.

Ra shall be obtained as follows.

Measurement shall be made using a contact (stylus) instrument specified in ISO 3274 and a roughness parameter shall be calculated according to ISO 4288:1996, 7.2. From the profile curve obtained, stylus strain and noise are removed with a profile filter and the form deviation curve (waviness curve) is extracted. The cut-off value (wavelength) of the phase compensation filter used to distinguish the waviness curve shall be the wavelength at an amplitude transmission rate of 50 %. The high-frequency component (short-wavelength component) curve obtained is treated as a surface roughness curve, from which the arithmetic mean roughness (Ra) is calculated.

For protrusions, Rk shall be obtained according to ISO 13565-2:1996, Clause 4; unevenness exceeding this value is treated as protrusions, and the number of protrusions per unit area is calculated.

6.1.2.2.2 Report of the results

The report shall include the following items:

a) measuring instruments;

b) sampling method and place, and specimen size;

c) result of Ra measurement;

d) number of protrusions.

6.1.2.3 Micro-waviness

6.1.2.3.1 Procedure of measurement and calculation

Micro-waviness is expressed as the arithmetic mean waviness (Wa). Wa is obtained as follows.

Measurement shall be made using a stylus (contact) instrument specified in ISO 3274 and a roughness parameter shall be calculated according to ISO 4288:1996, 7.2. From the profile curve obtained, stylus strain and noise are removed with a profile filter and the roughness curve is extracted. The cut-off value (wavelength) of the phase compensation filter used to distinguish the roughness curve shall be the wavelength at an amplitude transmission rate of 50 %. The low-frequency component (long-wavelength component) curve obtained is treated as a form deviation curve (waviness curve), from which the arithmetic mean waviness (Wa) is calculated.

6.1.2.3.2 Report of the results

The report shall include the following items:

a) measuring instruments;

b) sampling method and place, and specimen size;

c) result of Wa measurement.

6.1.3 Surface condition

6.1.3.1 Contact angle

6.1.3.1.1 Test method

The contact angle shall be measured as specified in ISO 15989, using water or some other solvent which does not affect the substrate.

6.1.3.1.2 Report of the results

The report shall include the following items:

a) sampling method and place;

b) substrate and water or other solvent;

c) test conditions (temperature and humidity);

d) mean contact angle.

6.1.3.2 Foreign substances on the surface

6.1.3.2.1 Principle

Regarding foreign substances on the surface of the substrate, those which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier shall be detected.

6.1.3.2.2 Inspection method

Foreign substances shall be detected with normal or corrected vision (6/6 or better), with a microscope, edge light, or with a surface inspection machine. There shall be no foreign substances which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier.

6.1.3.2.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) no foreign substances which are equal to or greater than a certain size (maximum diameter).

6.1.3.3 Foreign inclusions

6.1.3.3.1 Principle

For foreign substances and voids which are included in the substrate, those which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier shall be detected.

6.1.3.3.2 Inspection method

Foreign substances shall be detected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine.

Since the permissible state of inclusion of foreign substances depends on the purpose, the allowable size shall be agreed between user and supplier.

Regarding the inclusion of foreign substances which cause unevenness on the surface, the allowable height shall be agreed between user and supplier.

6.1.3.3.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) no foreign substances which are equal to or greater than a certain size (maximum diameter).

6.1.4 Edge condition

6.1.4.1 General characteristics

To evaluate the condition of the edge of the substrate, specific cracks, scratches, unevenness, and foreign substances shall be detected as mutually agreed upon between user and supplier.

6.1.4.2 Inspection method

Edge conditions shall be inspected with the normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine. Adhesive tape is used to detect foreign substances. There shall be no foreign substances on the tape.

6.1.4.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) specific cracks, scratches, unevenness, and foreign substances.

6.2 Mechanical properties

6.2.1 Elongation at break

6.2.1.1 Outline

Rupture elongation is expressed as the tensile strain at break or nominal tensile strain at break, to which ISO 527-1 and the following shall be applied.

6.2.1.2 Test speeds

Test speeds shall be selected from ISO 527-1:2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.1.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, or ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.1.4 Report of the results

The report shall include the following items:

a) testing machine;
b) test speed (mm/min);
c) specimen size (mm);
d) test environment (temperature and humidity);
e) tensile strain at break or nominal tensile strain at break (dimensionless ratio or %).

6.2.2 Tensile strength

6.2.2.1 Outline

Tensile strength is expressed as the stress at which the specimen breaks, to which ISO 527-1 and the following shall be applied.

6.2.2.2 Test speeds

Test speeds shall be selected from ISO 527-1:2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.2.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, or ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.2.4 Report of the results

The report shall include the following items:

a) testing machine;
b) test speed (mm/min);
c) specimen size (mm);
d) test environment (temperature and humidity);
e) tensile strength (MPa).

6.2.3 Tensile modulus

6.2.3.1 Test method

ISO 527-1 and the following shall be applied to tensile modulus.

6.2.3.2 Recommended test speeds

A test method is selected from ISO 527-2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.3.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.3.4 Report of the results

The report shall include the following items:

a) testing machine;
b) test speed (mm/min);
c) specimen size (mm);
d) test environment (temperature and humidity);
e) tensile modulus (MPa).

6.2.4 Minimum bending radius

6.2.4.1 Principle

When the substrate is bent beyond the minimum bending radius, permanent structural changes (creases or cracks) occur on the substrate at a certain radius.

Subclause 6.2.4 defines the method for obtaining the minimum bending radius below which no permanent structural changes occur on the substrate. One test method uses a flex resistance tester and the other a fracture resistance tester. An appropriate test method shall be selected according to the material of the substrate, and shall be described in the product specifications.

6.2.4.2 Measurement equipment

6.2.4.2.1 General

The measurement equipment shall be a flex resistance tester (also known as a U-shaped flex tester) or a fracture resistance tester (also known as a two-sided fracture tester).

6.2.4.2.2 Flex resistance tester

A flex resistance tester has the structure shown in Figure 3 near the part where the specimen is attached, and shall satisfy the following requirements:

– The two flat plates are parallel. The distance d between the flat plates can be adjusted and measured.
– Each flat plate has a mechanism to hold the side of the specimen so that no part of the specimen protrudes when it is bent in a U shape.

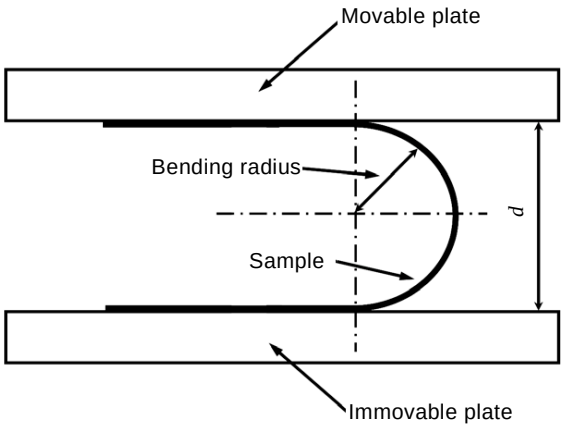

Figure 3 – Structure of the flex resistance tester near the part where the specimen is attached

6.2.4.2.3 MIT instrument

The MIT instrument which is described in the ISO 5626 is used. This instrument has the structure shown in Figure 4.

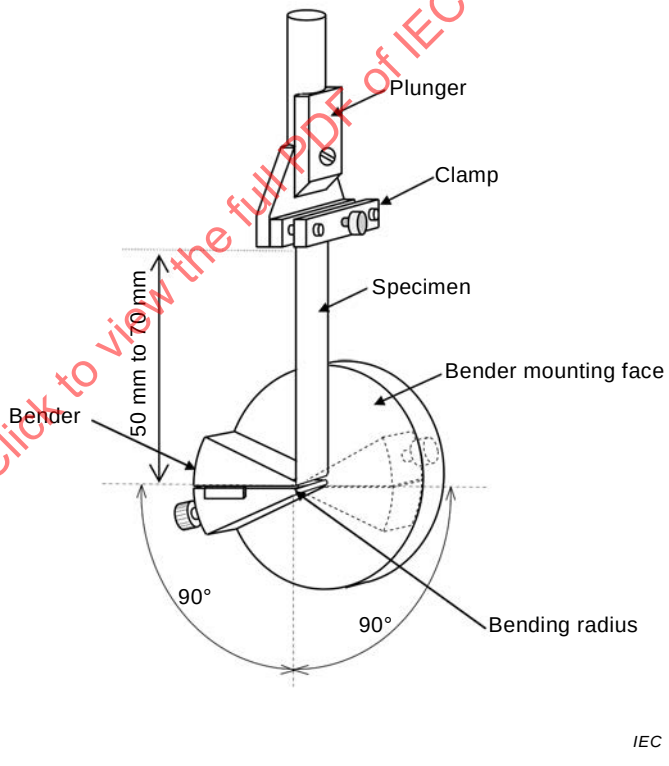

Figure 4 – Structure of the MIT instrument

The MIT instrument has a movable part which holds the specimen and bends it by 180º (90º on both sides of the vertical direction), a bending part for applying constant curvature to the specimen, and a mechanism for applying constant tension to the specimen. This instrument shall satisfy the following requirements.

– It can apply the tension specified in the product specifications to the specimen, and measure and display the tension.

– It can conduct tests at radiuses of curvature greater than that specified in the product specifications.

– It has a power unit that applies rotational motion at the speed specified in the product specifications to the bending device.

6.2.4.3 Test specimens

The specimen shall be in its original form, and of the size specified in the product specifications.

6.2.4.4 Measurement procedure

6.2.4.4.1 Flex resistance test

As shown in Figure 3, the specimen is bent in a U shape and fixed to both parallel plates. The distance d between the parallel plates shall be sufficiently larger than twice the minimum bending radius of the specimen. Then d shall be set to four times the minimum bending radius and kept for the time specified in the product specifications. When the test is completed, increase d, detach the specimen, and perform the inspection after testing.

The test shall be repeated with d reduced each time until permanent structural change is detected according to 6.2.4.4.2.

6.2.4.4.2 MIT instrument

The tension applied to the specimen, bending speed, and hold time shall be according to the product specifications.

Fix the plunger with locking screws and apply to the plunger the force equal to the tension applied to the specimen. Accurately attach the specimen to the clamp connected to the plunger and the bender so that it is kept flat and does not touch the mounting face of the bender. The specimen shall be attached to the clamp and the bender without rotating the bender or causing deflection to the specimen. Loosen the locking screws on the plunger to apply tension to the specimen. If the reading of the indicator changes, adjust the tension to the specified level.

Rotate the bender 90º from the vertical direction at the specified bending speed and keep it for the specified time. Then rotate the bender back to the original position and rotate it 90º in the opposite direction. When the test is completed, detach the specimen, and perform the inspection after testing.

Repeat the test by gradually reducing the radius of the curvature at the bender from approximately twice the minimum bending radius of the specimen specified in the product specifications to the level specified in the product specifications.

The test shall be repeated by reducing the bending radius from twice the minimum bending radius to the one specified in the product specification, until permanent structural change is detected according to 6.2.4.4.2.

6.2.4.4.3 Inspection after test

To evaluate whether permanent structural changes occurred or not (creases or cracks), the specimen shall be inspected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine.

6.2.4.5 Expression of the results

The minimum bending radius at which no permanent structural change occurs to the specimen is the minimum bending radius.

6.2.4.6 Report of the results

The report shall include the following items:

a) test method (flex resistance tester or MIT instrument);
b) type and thickness of the specimens;
c) number of specimens;
d) conditioning (temperature, humidity, and kept time);
e) test environment (temperature and humidity);
f) minimum bending radius.

6.2.5 Tear strength and tear propagation resistance

6.2.5.1 Test method

Tear strength shall be measured and calculated using the trouser tear method specified in ISO 6383-1 or the Elmendorf tear method specified in ISO 6383-2. Either method can be used to measure tear strength. An appropriate test method depends on the stiffness and deformation (extent) of the material to be tested. The test method shall be as specified in IEC 60674-3-1, or the test method as agreed between user and supplier.

As the tear properties change according to the thickness, tear speed, and measuring atmosphere, if a data comparison is required, these conditions shall be accurately controlled.

6.2.5.2 Test specimens

When comparing tear strength between different materials, adjust the specimen so that the difference in thickness is no more than 10 %. In addition, since the dependency on tear speed might greatly differ between materials, care shall be taken when comparing the results.

6.2.5.3 Expression of the results

The tear property obtained is the tear propagation resistance in newton per millimetre (N/mm), which is calculated by dividing the force required to tear the specimen (tear strength) in newton (N) by the thickness of the specimen.

6.2.5.4 Report of the results

The report shall include the following items:

a) thickness of the specimen;
b) tear speed;
c) measuring atmosphere;
d) tear propagation resistance (tear strength may be accompanied).

6.2.6 Edge strength

Under consideration.

6.2.7 Hardness

6.2.7.1 Test method

Hardness shall be measured as pencil hardness according to ISO 15184. If required, Shore hardness (see ISO 868) or ball indentation hardness (see ISO 2039-1 and ISO 2039-2) can be used.

6.2.7.2 Report of the results

The report shall include the following items:

a) test method;
b) thickness of the specimen;
c) temperature and humidity during the test;
d) brand of the pencil used (for pencil hardness), durometer type (for Shore hardness), or Rockwell hardness scale (for ball indentation hardness);
e) test result;
f) difference from the specified test method (if applicable).

6.3 Chemical properties

6.3.1 Resistance to chemicals

6.3.1.1 Test method

ISO 175 and the following shall apply to the resistance to chemicals.

6.3.1.2 Selection of test conditions

The properties of the specimen soaked in the liquid such as mass, size, and colour are selected from ISO 175 as agreed between user and supplier, and described in the product specification.

The liquid used for the test shall be an acid solution, an alkaline solution, or an organic solvent, which should preferably be selected from Table A.1 (reagents) and Table A.2 (various liquid products) in ISO 175:2010. However, depending on the target material and the process used, other liquids may be used as agreed between user and supplier.

6.3.1.3 Test specimens

The size and preparation of test specimens shall follow ISO 175 and be described in the product specification.

6.3.1.4 Report of the results

The report shall include the following items:

a) test method;
b) test conditions;
c) test specimen;
d) test environment (temperature and humidity);
e) resistance to chemicals.

6.3.2 Halide contents

6.3.2.1 Test method

Mass fraction (10^{-6}) shall be obtained using the method in IEC 61189-2:2006, 8.12 (test 2C12).

6.3.2.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass fraction (10^{-6}).

6.3.3 Volatile content

6.3.3.1 Test method

The test method shall be the mass reduction in a high-temperature oven as specified in IEC 61189-2:2006, 8.4 (test 2C04).

For materials which are not specified in IEC 61189-2:2006, 8.4 (test 2C04), the oven shall follow the instruction of the material manufacture.

6.3.3.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass fraction (10^{-6}).

6.3.4 Gas transmission

6.3.4.1 Water vapour transmission

6.3.4.1.1 Test method

Water vapour transmission shall be measured using the humidity detection sensor method specified in ISO 15106-1, infrared sensor method specified in ISO 15106-2, gas chromatographic method specified in ISO 15106-4, or electrolytic sensor method specified in ISO 15106-3. However, as agreed upon between user and supplier, another method may be used. The test method selected shall be described in the product specification.

6.3.4.1.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass of water vapour which passes through an area of 1 m^2 in 24 h (g/m^2 d).

6.3.4.2 Oxygen gas transmission

6.3.4.2.1 Test method

Oxygen gas transmission shall be measured using the differential pressure method (pressure sensor method) specified in ISO 15105-1 or isopiestic method (electrolytic sensor method or gas chromatographic method) specified in ISO 15105-2. However, as agreed upon between user and supplier, another method may be used. The test method selected shall be described in the product specification.

The gas transmission and gas transmission coefficient (gas permeability) can be obtained as test results. The properties used for the evaluation shall be described in the product specification as agreed between user and supplier.

6.3.4.2.2 Test specimens

Since both sides of the specimen may have different properties, a method for distinguishing each side shall be determined and the side which is exposed to the test gas shall be recorded.

6.3.4.2.3 Report of the results

The report shall include the following items:

a) test method;
b) test conditions;
c) test specimen (method for distinguishing sides and the side exposed to the test gas);
d) test environment (temperature and humidity);
e) gas transmission and gas transmission coefficient (gas permeability).

6.3.5 Moisture absorption

6.3.5.1 Test method

The test is conducted using the D method (exposing the specimen to a relative humidity of 50 % and measuring the amount of water absorption) specified in ISO 62.

The change in the amount of water in the substrate before and after moisture absorption is obtained according to the method for determining water content specified in ISO 15512.

6.3.5.2 Report of the results

The report shall include the following items:

a) test method;
b) test environment (temperature and humidity);
c) test conditions (exposure time);
d) test specimen (area size and thickness);
e) water absorption coefficient (mass fraction in percentage: %).

6.4 Electrical properties

6.4.1 Measurement at ambient temperature

6.4.1.1 Volume resistance and surface resistance

6.4.1.1.1 Outline

Volume resistance is expressed in Ohm centimetre (Ω cm). Surface resistance is expressed in Ohm (Ω).

6.4.1.1.2 Test method

Volume resistance and surface resistance shall be measured as specified in IEC 60093.

6.4.1.1.3 Measurement equipment

Measurement equipment shall be as specified in IEC 60093. The dimensions of the measuring electrode described in IEC 60093:1980, Clause 6, are: d_1 = 50 mm, d_2 = 60 mm,

and d_3 = 80 mm (see Figure 5). However, the other electrode dimensions of d_1 = 50 mm, d_2 = 70 mm, d_3 = 80 mm, may be used.

6.4.1.1.4 Applied voltage

Applied voltage shall be selected from the voltage listed in IEC 60093:1980, Clause 4.

6.4.1.1.5 Test specimens

The shape, dimensions and preparation of the test specimen shall be as specified in IEC 60093:1980, Clause 6.

6.4.1.1.6 Calculation of the results

Volume resistivity shall be calculated in accordance with IEC 60093:1980, 11.1, from the measurement results. Surface resistivity is calculated in accordance with IEC 60093:1980, 11.2, from the measurement results.

6.4.1.1.7 Report of the results

The report shall include:

a) volume resistance and/or surface resistance;

b) shape and dimensions of the specimen: length × width or diameter (mm), and thickness (μm);

c) treatment and conditioning for the specimen (application of cleaning and method, conditioning atmosphere, etc.);

d) test atmosphere (temperature and relative humidity);

e) electrode dimensions (d_1, d_2 and d_3) and material;

f) applied voltage (V).

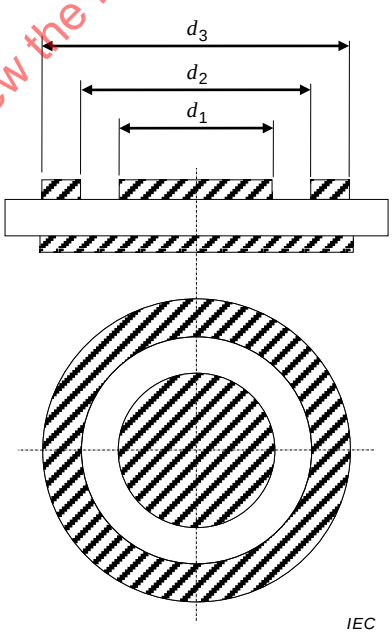

Figure 5 – Example of a measuring electrode

6.4.1.2 Electrical strength

6.4.1.2.1 Outline

Breakdown voltage is measured in the direction perpendicular to the surface of the substrate. Electric strength is the quotient of the breakdown voltage by the distance between the electrodes under specified test conditions.

6.4.1.2.2 Test method

Breakdown voltage shall be measured by the test method as specified in IEC 60243-1 with the following details:

a) the specimen shall be as specified in 5.2;

b) the specimen shall be conditioned as specified in 5.3;

c) the temperature and humidity of the test shall be as specified in 5.3;

d) the surrounding medium should be air. If the specimens have high breakdown values, they may be tested in insulating liquid as agreed between user and supplier;

e) the electrodes are unequal electrodes;

f) the frequency of the applied voltage is selected between 48 Hz and 62 Hz;

g) the test voltage is increased according to IEC 60243-1:2013, 10.1 (short time test), with a rising rate of 500 V/s.

6.4.1.2.3 Report of the results

The report shall include:

a) measured electric strength in kV/mm (minimum, maximum and median), preferably in conjunction with breakdown mode and location;

b) dimensions of the specimen (length × width or diameter (mm), and thickness (μm));

c) treatment and conditioning for the specimen (application of cleaning and method, conditioning atmosphere, etc.);

d) test atmosphere (surrounding medium: air or insulation liquid, temperature and relative humidity);

e) electrode dimensions (d_1, d_2 and d_3) and material;

f) mode of increasing voltage.

6.4.1.3 Relative permittivity

Under consideration.

6.4.1.4 Dissipation factor

Under consideration.

6.4.2 Measurement at high temperature

6.4.2.1 Surface resistance

Under consideration.

6.4.2.2 Volume resistance

Under consideration.

6.5 Thermal properties

6.5.1 Glass transition temperature

6.5.1.1 Test method

Glass transition temperature shall be measured using the DSC method specified in IEC 61189-2:2006, 9.10 (test 2M10), or the TMA method specified in IEC 61189-2:2006, 9.11 (test 2M11).

6.5.1.2 Report of the results

The report shall include:

a) measurement method;

b) rate of temperature rise;

c) glass transition temperature.

6.5.2 Coefficient of linear thermal expansion

6.5.2.1 Test method

The coefficient of linear thermal expansion shall be measured using the method as specified in ISO 11359-2 or an equivalent method.

6.5.2.2 Measurement conditions

Measurement conditions such as the measuring of the temperature range, heating rate, surrounding atmosphere, gas flow rate, are dependent on the specimen characteristics, and shall be specified in the product specification.

6.5.2.3 Conditioning atmosphere

According to ISO 11359-2:1999, 6.2, the conditioning atmosphere shall be as specified in ISO 291. However, if a modification of the condition is required to the characteristics of the material, the conditioning atmosphere may be determined by agreement between user and supplier.

6.5.2.4 Report of the results

The report shall include the following items:

a) coefficient of linear thermal expansion;

b) conditioning atmosphere;

c) measuring temperature range;

d) heating rate;

e) surrounding atmosphere;

f) gas flow rate, etc.

6.5.3 Dimensional stability

6.5.3.1 Dimensional stability (heating)

6.5.3.1.1 Test method

Dimensional stability (heating) shall be measured using the method specified in IEC 61189-2:2006, 12.1 (test 2X02) or the method agreed between user and supplier.

6.5.3.1.2 Test conditions

Test conditions shall be as specified in IEC 61189-2:2006, 12.1 (test 2X02). Processing temperature and time may be modified as agreed between user and supplier.

6.5.3.1.3 Report of the results

The report shall include:

a) results of the dimensional stability;

b) specimen dimensions;

c) processing temperature and processing time.

6.5.3.2 Dimensional stability (humidity)

Under consideration.

6.5.4 Relative temperature index (RTI)

6.5.4.1 Test method

The relative temperature index (RTI) shall be determined by the procedures as specified in IEC 60216-5 and IEC 60216-3, using the data obtained by the method defined in IEC 60216-1. If there is agreement between user and supplier, the method specified in IEC 60216-6 shall be used.

NOTE The method specified in IEC 60216-2 is called the "temperature fixed method", and the method specified in IEC 60216-6 is called the "time fixed sampling method". There is almost no difference between the results obtained by each measuring method.

According to the recommendation described in IEC 60216-2, the property to determine RTI shall be specified in the product specification. Tensile strength and/or electric strength should be selected to determine RTI. Unless otherwise specified, the evaluation method of the selected property (properties) shall be the respective method specified in this document. If special conditioning is necessary, the product specification shall specify the conditions.

The reference material shall be selected according to ISO 2578:1993, 4.4.

6.5.4.2 Test apparatus

The ageing oven shall be as specified in IEC 60216-1:2013, 5.6, or it shall be able to hold the exposure temperature within the tolerance as specified in the product specification. Unless otherwise specified, the oven type as specified in IEC 60216-4-1 shall be used.

6.5.4.3 Test conditions

According to the requirements specified in IEC 60216-1:2013, 5.5, the exposure temperatures shall be selected as appropriate to the specimen and shall be specified in the product specification.

The exposure temperatures should be four or more. The lowest temperature shall be selected so that time to end-point will be more than 5 000 h. The highest temperature shall be selected so that time to end-point will be less than 500 h.

The atmospheric conditions during exposure shall be according to IEC 60216-1:2013, 5.7.2. However, if special atmospheric conditions are required depending on the characteristics of the specimen, the atmospheric conditions shall be as specified in the product specification.

The method of determining the end-point shall be according to IEC 60216-1:2013, 5.2.

If the product specification so specifies, the evaluation shall be made before reaching the end-point or at the time the end-point is reached.

6.5.4.4 Test specimens

Specimen preparation shall be as specified in the product specification.

6.5.4.5 Conditioning atmosphere

The conditioning atmosphere shall be as specified in the product specification.

6.5.4.6 Test conditions

The test conditions shall follow the product specifications.

Atmospheric conditions during ageing shall be as specified in the product specification.

6.5.4.7 Calculation and expression of RTI

The relative temperature index shall be calculated using the formula TIr + (T_A – T_B) from the temperatures obtained by extending the degradation function of the material to be evaluated (regression line) and the degradation function of the reference material for the time required in practice (20 000 h, 60 000 h, 100 000 h, etc.) (with T_A indicating the temperature of the material to be evaluated and T_B indicating the temperature of the reference material), and from the temperature index (TIr) of the reference material.

The relative temperature index shall be obtained using the temperatures (T_A for the specimen and T_B for the reference material) which are obtained by extrapolating the practical time (20 000 h, 60 000 h, 100 000 h) to the degradation function (regression line) of the specimen and the reference material, and temperature index of the reference material (TIr) as expressed by the formula TIr + (T_A – T_B).

6.5.4.8 Report of the results

The report shall include:

a) relative temperature index (RTI);

b) extrapolated temperatures;

c) property(ies) for determining the relative temperature index.

6.6 Optical properties

6.6.1 Method of testing the colour of the substrates

6.6.1.1 Outline

Subclauses 6.6.1.2 through 6.6.1.5 shall apply to transparent or nearly transparent materials.

6.6.1.2 Luminous transmittance

6.6.1.2.1 Measuring method

Luminous transmittance is expressed as total luminous transmittance, and shall be measured using the single-beam method as specified in ISO 13468-1, or the double-beam method as specified in ISO 13468-2, with the following details. If agreed upon between user and supplier (supplier and purchaser), another method which is recognized as equivalent may be used.

6.6.1.2.2 Measuring equipment

Measuring equipment shall be as specified in ISO 13468-1:1996, Clause 4, or ISO 13468-2:1999, Clause 4, as appropriate. Measuring equipment according to ISO 13655 and/or ISO 5-2 may be used.

6.6.1.2.3 Wavelength or wavelength range used in the test

Luminous transmittance shall be measured either at a particular wavelength or at a wavelength range, as agreed between user and supplier considering factors such as the material characteristics and application.

6.6.1.2.4 Report of the results

The report shall include the following items:

a) measuring method;

b) measuring wavelength;

c) specimen thickness;

d) luminous transmittance.

6.6.1.3 Chromaticity

6.6.1.3.1 Outline

According to ISO 11664-4, chromaticity is presented as the CIE (1976) $L^*a^*b^*$ colour space.

6.6.1.3.2 Measuring method

The measuring method shall be the reflected light method or the transmitted light method, depending on the application and the purpose.

If the reflected light method is used, a reflecting diffuser shall be placed on both the surface to be measured and the other surface, with the specimen in between.

The product specification shall specify the measuring method.

The reflecting diffuser shall be a perfect reflecting diffuser or a reference diffuser used for calibrating measuring equipment.

6.6.1.3.3 Measuring equipment and auxiliaries

The measuring equipment and light source shall be in accordance with at least one of the following: ISO 5-2, ISO 5-3, ISO 3664 or ISO 13655, and shall be specified in the product specification.

NOTE There is a measuring instrument which conforms to ISO 14981.

6.6.1.3.4 Expression of the results

The results shall be presented as the numerical values of each of the $L^*a^*b^*$ coordinate axes, or shall be plotted in the $L^*a^*b^*$ colour space. If agreed between user and supplier, the results may be presented instead by the numerical value of a specific coordinate axis or the numerical values of two specific coordinate axes of the $L^*a^*b^*$ colour space. In this case, the coordinate axis or axes concerned shall be clearly stated.

6.6.1.3.5 Report of the results

The report shall include the following items:

a) measuring instrument and light source;

b) measurement method (reflected light or transmitted light);

c) chromaticity (numerical values of each of the $L^*a^*b^*$ coordinate axes, plotted in the $L^*a^*b^*$ colour space, or the numerical value of a specific coordinate axis or numerical values of two specific coordinate axes of the $L^*a^*b^*$ colour space).

6.6.1.4 Uniformity of colour

6.6.1.4.1 Principle

Colour differences are obtained at 10 points on the specimen, and their average is evaluated by the difference between the standard chromaticity and standard deviation.

6.6.1.4.2 Measuring equipment

According to 6.6.1.3.

6.6.1.4.3 Illuminant

According to 6.6.1.3.

6.6.1.4.4 Measuring method

According to 6.6.1.3, chromaticity shall be measured at 10 points on a single specimen using the same instrument and under the same conditions. Five or more pairs of points are selected so that all 10 points are chosen. From the colour difference between each pair of points, the mean colour difference, the difference between the reference chromaticity and the mean, and the standard deviation are calculated.

6.6.1.4.5 Calculation of colour difference

Colour difference is calculated using the colour difference formula based on the numerical values of each of the $L^*a^*b^*$ coordinate axes, or using the colour difference formula based on lightness, chroma, and hue.

The colour difference based on the $L^*a^*b^*$ colour system is calculated according to the following formula:

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2}$$

where:

ΔE^*_{ab} is the colour difference based on the $L^*a^*b^*$ colour system;

ΔL^*, Δa^*, Δb^* are the difference in L^* and the difference in the colour coordinates a^* and b^* of the chromaticity between a pair of points obtained in 6.6.1.3.

The colour difference based on the luminosity, chroma, and hue is calculated according to the following formula:

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2 \right]^{1/2}$$

where:

ΔE^*_{ab} is the colour difference based on the $L^*a^*b^*$ colour system;

ΔL^* is the difference in luminosity L^* of the chromaticity between a pair of points obtained in 6.6.1.3;

ΔC^*_{ab} is the difference in ab chroma of the chromaticity between a pair of points obtained in 6.6.1.3;

ΔH^*_{ab} is the difference in ab hue of the chromaticity between a pair of points obtained in 6.6.1.3.

The colour difference formula in CIE DE2000 (see CIE Publication No. 142) may also be used for calculating colour difference.

6.6.1.4.6 Report of the results

The report shall include the following items:

a) measuring instruments;

b) measurement method (reflected light or transmitted light);

c) standard chromaticity;

d) difference between the standard chromaticity and the mean, and standard deviation.

6.6.1.5 Spectrophotometric characteristics

6.6.1.5.1 Outline

Spectrophotometric characteristics are indicated as changes in the energy of the transmitted light or the reflected light against the wavelength of light. For example, they are represented in a chart with wavelength plotted on the horizontal axis and relative energy value at each wavelength on the vertical axis.

6.6.1.5.2 Measuring equipment

Spectrophotometric characteristics shall be measured using an instrument which conforms to one or more of the following: ISO 5-2, ISO 5-3, ISO 3664, or ISO 13655. A similar measuring instrument may be used. It is also possible to measure the total luminous flux using an integrating sphere, in which case, the measuring instrument specified in ISO 13468-1 or ISO 13468-2 or a similar instrument shall be used.

6.6.1.5.3 Measuring method

Transmitted light or reflected light may be used for measurement. The details of the measuring method shall be described in the product specifications.

6.6.1.5.4 Report of the results

The report shall include the following items:

a) measuring instruments;

b) measurement method (reflected light or transmitted light);

c) chart plotting the changes in the energy of the transmitted light and the reflected light against the wavelength (with the wavelength on the horizontal axis and relative energy at each wavelength on the vertical axis). The vertical axis may be used as an index which represents the distribution of light energy at different wavelengths. The vertical axis shall be labeled with the index used.

6.6.2 Refractive index

6.6.2.1 Measuring method

The refractive index shall be measured using method A (for measuring the refractive index using a refractometer) specified in ISO 489 or some other method.

6.6.2.2 Contacting liquid

A contacting liquid with a refractive index higher than that of the measured object and with a substrate which does not swell or dissolve as listed in ISO 489:1999, Table 1, shall be used.

6.6.2.3 Conditioning

Conditioning shall be performed at a temperature of 23 °C ± 2 °C and a relative humidity of (50 ± 10) % for 88 h or longer.

6.6.2.4 Report of the results

The report shall include the following items:

a) refractometer used, and the type of light source and wavelength;

b) refractive index;

c) dispersion (if applicable).

6.6.3 Retardation

Under consideration.

6.6.4 Luminous reflectance

6.6.4.1 Principle

Luminous reflectance is measured relative to a perfect white diffuser or the reference diffuser used for calibrating the measuring instrument.

NOTE Theoretically, measurement on a translucent plate which absorbs little light in the visible region results in the sum of the total luminous transmittance and the total luminous reflectance being almost 100 %. If such an ideal state is attained, the reflectance can be obtained by subtracting luminous transmittance from 100 % in 6.6.1.2. Subclause 6.6.4 specifies a method for measuring reflectance independently.

6.6.4.2 Measuring equipment

Luminous reflectance shall be measured using an equipment which conforms to one or more of the following: ISO 5-3, ISO 3664, and ISO 13655.

6.6.4.3 Illuminant

The illuminant shall be specified in the product specifications.

6.6.4.4 Measuring method

The measuring method shall be specified in the product specifications.

6.6.4.5 Report of the results

The report shall include the following items:

a) measuring instrument and light source;

b) reflectance.

6.6.5 Haze

6.6.5.1 Measuring method

Haze is measured using the method specified in ISO 14782. A similar method may be used as agreed between user and supplier.

6.6.5.2 Report of the results

The report shall include the following items:

a) thickness of the specimen;

b) type of light source;

c) haze.

6.7 Flammability

6.7.1 Outline

Flammability is evaluated in the vertical burning test. The vertical burning test is defined by method B specified in IEC 60695-11-10 or as follows. An evaluation method which has been confirmed to be equivalent may be used.

6.7.2 Test method

In principle, method B specified in IEC 60695-11-10 shall be used. However, if it cannot hold the specimen vertically and/or the specimen is off the flame due to insufficient thickness, deformation, or contraction, or the specimen bursts into flame up to the clamp, the vertical burning test for easily bent materials specified in ISO 9773 or a method which has been confirmed to be equivalent may be used to evaluate the specimen.

6.7.3 Report of the results

The report shall include the following items:

a) thickness of the specimen;

b) conditioning (for tests in conditions different from the specifications in IEC 60695-11-10);

c) cutting, finishing, and processing other than conditioning;

d) lingering flame time after the 1st flame contact (t_1), lingering flame time after the 2nd flame contact (t_2), afterglow time (t_3), and (t_2+t_3) for each specimen;

e) total lingering time (t_1) of a group of five specimens for each of the two types of conditioning;

f) whether flaming objects fall, and whether the marking absorbent cotton catches fire;

g) applicable combustibility class (V-0, V-1, or V-2).

7 Characteristics and evaluation method of glass substrates

7.1 Surface properties

7.1.1 Surface roughness

Usually an arbitrarily selected area on the surface of the substrate is measured using a surface analyzer.

The test should follow 6.1.2.2. It may also use a method with an atomic force microscope (AFM) or a method which has been confirmed to be equivalent. The test method shall be described in the product specifications.

7.1.2 Chips and cracks

7.1.2.1 Inspection method

Chips and cracks shall be detected with normal or corrected vision (6/6 or better) in a darkroom, or by image inspection.

7.1.2.2 Inspection environment

The inspection light source shall be reflected light from a halogen lamp, or reflected or transmitted light from a fluorescent lamp. It may also use other light sources with similar illumination. The conditions for inspection including the type of light source and illumination shall be described in the product specifications.

7.1.2.3 Report of the results

If chips or cracks exist, the allowed types and sizes of the defects shall be described in the product specifications as agreed between user and supplier. However, the permissible types and sizes shall not exceed the visually recognized level.

7.1.3 Foreign inclusions

7.1.3.1 Inspection method

Foreign inclusions shall be detected with the normal or corrected vision (6/6 or better) in a darkroom, or by image inspection.

7.1.3.2 Inspection environment

The inspection light source shall be reflected light from a halogen lamp, or reflected or transmitted light from a fluorescent lamp. It may also use other light sources with similar illumination. The conditions for inspection including the type of light source and illumination shall be described in the product specifications.

7.1.3.3 Report of the results

The permissible type and size of foreign inclusions shall be described in the product specifications as agreed upon between user and supplier. However, the permissible types and sizes shall not exceed the visually recognized level.

7.1.4 Foreign substances on surface

7.1.4.1 Inspection method

Foreign substances shall be detected with normal or corrected vision (6/6 or better) in a darkroom, or by image inspection.

7.1.4.2 Inspection environment

The inspection light source shall be reflected light from a halogen lamp, or reflected or transmitted light from a fluorescent lamp. It may also use other light sources with similar illumination. The conditions for inspection including the type of light source and illumination shall be described in the product specifications.

7.1.4.3 Report of the results

The permissible type and size of foreign substance on the surface shall be described in the product specifications as agreed upon between user and supplier. However, the permissible types and sizes shall not exceed the visually recognized level.

7.1.5 Scratches

7.1.5.1 Inspection method

Scratches shall be detected with normal or corrected vision (6/6 or better) in a darkroom, or by image inspection.

7.1.5.2 Inspection environment

The inspection light source shall be reflected light from a halogen lamp, or reflected or transmitted light from a fluorescent lamp. It may also use other light sources with similar illumination. The conditions for inspection including the type of light source and illumination shall be described in the product specifications.

7.1.5.3 Report of the results

The permissible type and size of scratches shall be described in the product specifications as agreed between user and supplier. However, the permissible types and sizes shall not exceed the visually recognized level.

7.2 Mechanical properties

7.2.1 Young's modulus and Poisson's ratio

Young's modulus and Poisson's ratio shall be measured using the method specified in ISO 17561 or a method which has been confirmed to be equivalent.

7.2.2 Density

Density shall be measured using the method specified in ISO 2738 or a method which has been confirmed to be equivalent.

7.2.3 Hardness

Hardness shall be expressed as Vickers hardness and is measured using the method specified in ISO 6507-1. Knoop hardness may be used if necessary.

7.3 Chemical properties

7.3.1 Resistance to chemicals

Under consideration.

7.3.2 Gas transmission

Subclause 6.3.4 applies to gas transmission.

7.4 Thermal properties

7.4.1 Coefficient of linear thermal expansion

The coefficient of linear thermal expansion shall be measured using the method specified in ISO 7991 or a method which has been confirmed to be equivalent.

7.4.2 Strain point

7.4.2.1 Outline

The strain point is the temperature at which the internal stresses in a glass are substantially relieved in a matter of hours (see the ISO 7884-1). The temperature shall be measured using the beam bending method (the method specified in ISO 7884-7), the fiber elongation method, or a method which has been confirmed to be equivalent.

7.4.2.2 Beam bending method

The beam bending method is specified in ISO 7884-7.

7.4.2.3 Fiber elongation method

7.4.2.3.1 Principle

The principle of the strain point by the fiber elongation method is basically based on ISO 7884-3. The strain point is determined by an extrapolation with the annealing point. The annealing point is determined by measuring the rate of viscous elongation of a simply loaded glass fiber.

7.4.2.3.2 Test method

7.4.2.3.2.1 Apparatus

The strain point shall be measured using the following apparatus or apparatus which has been confirmed to be equivalent.

- Furnace – the furnace shall be about 370 mm long and approximately 120 mm in diameter and shall contain a core about 300 mm long and 30 mm in outside diameter, with an inside diameter of 6 mm.
- Temperature measuring – the alumina-insulated platinum-10 % rhodium/platinum (type S according to IEC 60584-1) thermocouples, or platinum-13 % rhodium/platinum (type R according to IEC 60584-1) thermocouples, nickel-chromium/nickel (type K according to IEC 60584-1) thermocouples shall exhibit low thermal inertia (the diameter of the wires should not be greater than 0,5 mm).
- Elongation measuring – the fiber elongation rate shall be measured with an apparatus which has an uncertainty not greater than 0,01 mm.
- Micrometer – the fiber diameter shall be measured by a micrometer with a least count of 0,005 mm.

7.4.2.3.2.2 Preparation

For a fiber sample specimen, the fiber cross section shall be of a diameter of 0,65 mm ± 0,10 mm, and be uniform ±0,015 mm. Fiber length shall be 100 mm to 350 mm and have two balls at the both ends. If the length of the fiber is shorter than the furnace length, the fiber shall be supported by a metal rod.

7.4.2.3.3 Procedure

The specimen shall be held at the upside ball and not touch the furnace inner wall, and the the 1 kg load shall hang on the lower side. The furnace shall establish a cooling rate of 4 °C/min ±1 °C/min. The elongation rate at the annealing point is approximately 0,14 mm/min. The strain point is determined by extrapolation of the annealing point data and is the temperature at which the viscous elongation rate is 0,031 6 times that observed at the annealing point. The strain point shall be obtained following a specified procedure after direct calibration of the apparatus using reference glasses having a known strain point.

7.4.2.3.4 Report of the results

The report shall include:

a) test method;

b) strain point in degree Celsius;

c) description of the sample;

d) calibration reference and correction applied.

7.5 Optical properties

7.5.1 Refractive index

The refractive index shall be measured using the minimum deviation angle method, critical angle method, or a method which has been confirmed to be equivalent. The test condition shall be described in the product specifications.

For the minimum deviation method, a prism spectrometer or a V-block refractometer with similar accuracy may be used. For the critical angle method, an Abbe refractometer may be used.

7.5.2 Luminous transmittance

Luminous transmittance shall be measured by obtaining a spectral transmission factor with a single-beam or double-beam spectrophotometer. The test condition shall be described in the product specifications.

8 Characteristics and evaluation method of ~~other materials (ceramics, metal, paper, others)~~ paper substrates

~~Under consideration.~~

8.1 General

The paper and paper board substrates used in printed electronics (PE) shall be tested according to the methods specified in Table 2. Unless there is a prior agreement between the user and supplier these test methods shall be applied without modification. In cases where the test has been modified, the changed condition shall be described in the report.

Table 2 – Test methods for paper and paper board substrates used in PE

Items		Standards that each test method is defined
Surface condition	Surface roughness	Subclause 8.2 in this document
	Flatness (curl)	ISO 11556
	Defects	Subclause 8.3 in this document
	Coefficient of friction	ISO 15359
	Contact angle	Subclause 8.4 in this document
	Surface pH	Subclause 8.5 in this document
	Composition of surface	Subclause 8.6 in this document
	Thickness of coating layer	Subclause 8.7 in this document
Mechanical properties	Bursting strength	ISO 2758 (for paper), ISO 2759 (for paper board)
	Tensile strength	Constant rate of elongation method: ISO 1924-2 (for 20 mm/min) ISO 1924-3 (for 100 mm/min) ISO 3781 (for after immersion in water) z-directional tensile strength: ISO 15754
	Young's modulus	ISO 1924-3
	Bending radius	(IEC 62899-202-5)
	Tearing resistance	ISO 1974 (Elmendorf method)
	Bending resistance (bending stiffness)	ISO 2493-1 (constant rate of deflection) ISO 2493-2 (taber-type) ISO 5626 (folding endurance) ISO 11798 (mechanical strength)
	Resistance to picking	ISO 3783

	Compressive strength	ISO 12192 (ring crush method)
Chemical properties	pH of aqueous extracts	ISO 6588-1 (cold extraction) ISO 6588-2 (hot extraction)
	Water vapour transmission rate	ISO 15106-2
	Oxygen gas transmission rate	ISO 15105-2
	Water absorptiveness	ISO 535 (Cobb method)
	Dimensional stability (humidity)	ISO 5635
Electrical properties	Volume resistance and surface resistance	IEC 62899-201
	Electrical strength	IEC 62899-201
Optical properties	Opacity	ISO 2471 (diffuse reflectance)

8.2 Surface roughness

8.2.1 General

The surface roughness of paper substrates is classified according to the following three classes:

class (a) optical roughness at < 1 µm;

class (b) micro roughness at 1 µm to 100 µm;

class (c) macro roughness at >100 µm

In traditional technology, class (a) was not recognized as an important area. However, the progress of the technology requires the region of class (a) to be considered, whereas the importance of class (c) might be reduced in comparison. The measurement methods for classes (a) and (b) are specified in this document.

8.2.2 Measurement method for class (a)

8.2.2.1 General

The gloss method or the white light interferometry (WLI) shall be used in the detection of optical roughness (< 1 µm). The method which is used in this measurement may be decided according to prior agreement between the user and supplier.

NOTE The WLI is used for high smoothness glossy paper such as a uniformly nanoparticle-coated product.

When the 60° gloss is over 65 or the average roughness (Ra) is less than 0,6 µm, the distinctness of image (DOI) measurement may be used.

8.2.2.2 Gloss method

The 60° gloss shall be used in this measurement. The appropriate gloss meter may be used, but the measurement method should be according to ISO 2813.

NOTE The equipment which is specified in ISO 8254-1 is also used widely in the paper industry. However, the method of ISO 8254-1 is limited to 75° gloss. When the equipment is able to measure the 60° gloss, it will be possible to use it in this measurement.

Since the value of specular reflection light intensity which is obtained during the measurement of gloss and the surface roughness have a relation in Formula (1), the surface roughness (R_q (RMS)) is calculated by Formula (2). The value of specular reflection light intensity can also be obtained by dividing the value of the glossiness by the specularly reflected light intensity of the glass surface with the refractive index n = 1,567.

$$\frac{I}{I_0} = F\exp\left[-\left(\frac{4\pi\sigma\cos\theta}{\lambda}\right)^2\right] \quad (1)$$

$$\sigma = \frac{\lambda}{4\pi\sigma\cos\theta}\sqrt{-\ln\left(\frac{I}{I_0 F}\right)} \quad (2)$$

where

I is the specular reflection light intensity;

I_0 is the incident light intensity;

F is the Fresnel coefficient;

σ is the surface roughness (R_q);

θ is the measurement angle (60˚); and

λ is the wavelength.

8.2.2.3 WLI method

The WLI method shall be used with following requirements:

a) the inclination of the sample shall be corrected by tilt-stage before measurement;

b) the measurement equipment shall be placed on an anti-vibration table;

c) enough data shall be collected to achieve statistical significance over the roughness length scale of the substrate.

R_a and R_k shall be calculated according to the method described in 6.1.2.2.1.

8.2.2.4 DOI method

The wave scan DOI meter shall be used. The equipment shall use a laser light source to illuminate the substrate surface at a 60° angle. The image clarity value (C, %) is obtained as the result of the measurement, and R_a shall be calculated using the C value.

NOTE The DOI meter which is described in ASTM D5767 can be used in this measurement.

8.2.3 Measurement method for class b)

The method specified in ISO 8791-2 (Bendtsen method) or ISO 8791-4 (PPS (ParkerPrint-surf)) shall be used as the measurement of surface roughness of class (b).

8.2.4 Calculation

R_a and R_k shall be calculated as the parameters on the surface roughness according to the method described in 6.1.2.2.1.

8.2.5 Report of the results

The report shall include the following items:

a) measurement method and measurement equipment used;

b) measuring place and measurement size;

c) number of the sampling data;

d) result of R_a or R_q measurement;

e) result of R_k and number of protrusions (if detected).

8.3 Defects (pinholes) of coating layer

8.3.1 General

In many cases, paper substrates and paper board substrates are coated with polymeric layers. It may be possible to detect defects of the polymeric layer using the method described in 8.2. However, it would be necessary to examine the defects in a wider area on the surface of the paper substrate. In particular, pinholes are the defect which has a negative impact such as disconnection of the circuit. The method for detecting these defects is specified in 8.3. This method is applicable to all kinds of polymeric coated paper and paper board substrates.

It should be noted that there may be a case where it is not possible to detect all pinholes. It is necessary to pay particular attention in the case where the ink to be used has a large difference on the wettability from the ethanol solution.

8.3.2 Test specimens

At least five specimens shall be tested.

Except by prior agreement between the user and supplier, the size of the specimens shall be 12 cm x 12 cm.

In some cases the size of the specimens may be adjusted based on the size of the test equipment, in such cases a prior agreement between the user and supplier shall be made and the size of the test sample used shall be reported.

8.3.3 Colour solution

A solution of 0,5 % (weight per volume) of dyestuff ethanol shall be prepared. E131 Blue (CAS 3536-49-0) or Crossing Scarlet MOO (CAS 5413-75-2) shall be used as dyestuff. When insoluble matters are observed in the solution, the solution should be filtered before use.

8.3.4 Procedure

The specimen shall be placed on an appropriate plane. The colour solution shall be poured onto the surface of the specimen, covering it completely. After 5 min, the colour solution shall be poured off and wiped off the surface with some tissue paper or a sheet of unprinted kitchen roll. The number of coloured pinholes shall be counted and expressed by the number of pinholes in the sample per square metre. This procedure is repeated against five specimens. The five results shall be averaged.

8.3.5 Report of the results

The report shall include:

a) type of substrate, sample identification;

b) area of the test piece;

c) result of the test (averaged value).

8.4 Contact angle

8.4.1 General

When a droplet of liquid is dropped on the surface of a paper substrate, in many cases the droplet is absorbed into the substrate. In other words, the contact angle between the droplet and the substrate changes depending on the time. In the case of paper substrates where the surface is coated with a polymer and the contact angle does not change, the contact angle may be measured by the method specified in ISO 15989. However, for most paper substrates where the droplet of liquid is absorbed into the substrate, the contact angle shall be measured by the following method.

8.4.2 Outline of the measurement method

A drop with a specified volume of liquid is automatically applied to the surface of the paper substrate. Images of the contact angle between the droplet and the surface are captured by a video camera at specified time intervals. The contact angles at various time intervals are determined by image analysis techniques. The contact angles are determined at specified check points, and other related parameters such as the rate of change for the contact angles and the droplet volume can be determined by this method.

NOTE A meaningful property of the test liquid is that it has low to medium viscosity (e.g. below 100 mPa·s), and it has a boiling point above for example 60 °C.

8.4.3 Parameters

Parameters related to the contact angle shall be defined as in Figure 6.

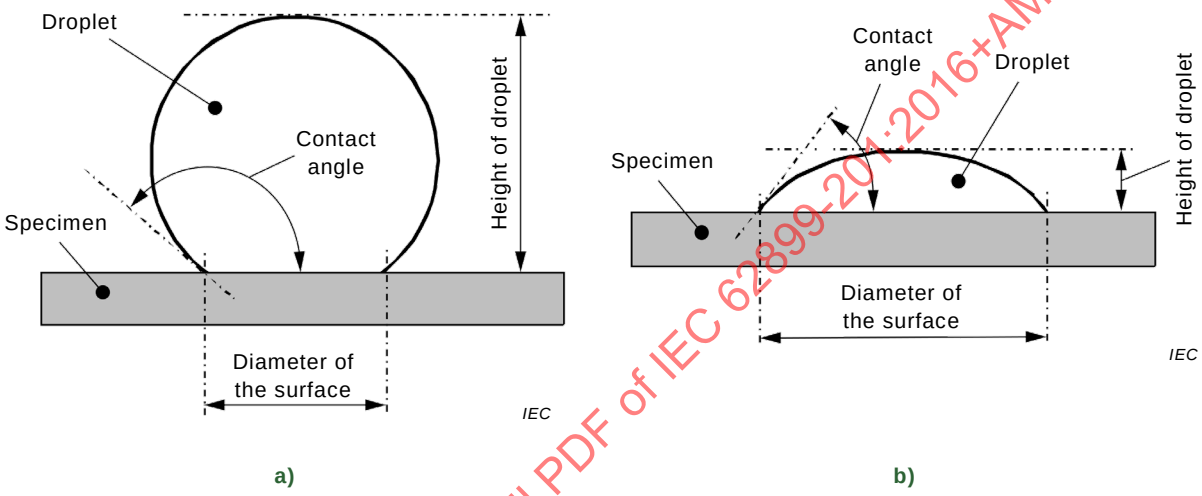

Figure 6 – Parameters related to the contact angle

8.4.4 Test apparatus

An automated contact angle tester shall comprise the following components:

- a light source,
- a video camera,
- a specimen stage,
- a liquid delivery system, and
- a computer with appropriate software.

The lamp housing shall be constructed so that the heat generated during lamp operation does not reach the test specimen or the droplet. The instrument shall have a contact angle precision of ±1° and a time precision of ±0,1 ms.

The specimen stage shall be designed so that the surface of the specimen becomes flat. The specimen is positioned horizontally with respect to the video camera, and shall be supported sufficiently to withstand the influence of capillary forces.

The drop volume should be in the range from 1 µl to 4 µl. It shall be possible to set the measurements start to the moment when the drop touches the substrate. The time resolution of the measurement should be 1 ms or better. The time stamp should be contained within the captured image with an accuracy of ±2 ms. A minimum of fifty video images shall be captured during the first second. After the first second, the images may be captured less frequently.

The inner wall of the dispensing system should be hydrophobic, for example by applying a PTFE coating.

The adjustment, calibration, and maintenance of the apparatus shall be performed following the instructions from the manufacturer.

The contact angle and the volume of the droplet shall be calculated as a function of time. The contact angle and the volume at any specified time (check points) should be calculated, and an average contact angle and volume should be calculated.

8.4.5 Test method

Except by prior agreement between trade partners, water with a purity of grade 3 or better as specified in ISO 3696 shall be used in this test.

Care shall be taken not to touch the surface of the specimen. The specimen shall not be cleaned unless otherwise specified. In some cases the wetting characteristics are different between the machine and cross directions. Care should be taken with the direction of the substrate. The size of the specimen shall be determined in accordance with the test apparatus. When the specimen curls it may be fixed by adhesive tape or other means in order to achieve a flat surface.

The test begins from the time when the droplet was dropped on the surface of the substrate by a trigger from the sync pulse from the video camera. Except by prior agreement between the trading partners, images shall be captured for at least 15 s.

At least three check points shall be set in the test. Except by prior agreement between the trading partners, the check points shall be either 0,1 s, 1,0 s and 2,0 s, or 0,1 s, 1,0 s and 10 s. The test shall be repeated ten times, changing the specimen position each time. The results (contact angles and droplet volumes) at each check point shall be averaged.

8.4.6 Report of the results

The report shall include the following items:

a) identification of the test specimen(s);
b) test liquid (if other than reagent water);
c) initial droplet volume (if other than standard volume);
d) centre-to-centre distance between two consecutive droplets applied on the same specimen surface;
e) stroke applied;
f) selected check points (seconds);
g) average contact angle and coefficient of variation at the selected check points;
h) average droplet volume and coefficient of variation at the selected check points.

8.5 Surface pH

8.5.1 General

For a pH measurement of paper, an aqueous extracts method is generally used. Since the surface pH of paper substrates affects printability directly this becomes one of most important factors in printing technology. In 8.5, the measurement of surface pH is specified.

8.5.2 Test specimens

The paper substrate to be measured shall be used as it is without any processing. It may be cut to the appropriate size for testing. Care should be taken not to touch the surface of the

test specimens. The specimens shall not be cleaned unless otherwise specified by the manufacturer.

8.5.3 Measurement

The pH meter to be used for this measurement shall be equipped with a composite glass electrode with a flat head. The electrode shall be a single electrode formed by integrating the glass electrode and the reference electrode, and shall be soaked in a small amount of water. The pH meter shall be calibrated by standard buffers of pH 4,01 and pH 6,86. When a surface pH of greater than 8,0 is anticipated, the pH meter should be calibrated by a standard buffer of pH 9,18. The electrode shall be used after immersion into distilled water for at least 30 min.

The surface pH shall be measured as the pH of a wetting liquid where one or two drops have been placed onto the substrate. Distilled or deionised water, or 0,1 mol/L of KCl aqueous solution shall be used as the wetting liquid. The pH of the distilled or deionised water shall be in the range of 6,2 pH to 7,3 pH.

NOTE 1 If the variation of the measured pH becomes large, it is possible to use 0,1 mol/L of KCl aqueous solution to decrease the variation.

The pH value shall be measured after sufficient time has passed for the pH measured to reach equilibrium.

NOTE 2 In general, it often takes around 1 min or 2 min to reach equilibrium.

The electrode shall be washed with distilled water prior to each measurement.

The surface pH shall be measured for at least five sheets. The measured pH value shall be averaged to obtain the result value.

8.5.4 Report of the results

The report shall include:

a) identification of the test specimen(s);

b) number of measured sheets;

c) result of surface pH measurement (average of measured value).

8.6 Composition of surface (screening of metal composition)

The X-ray fluorescence spectrometry (XRF) shall be used in the screening of the metal composition on paper substrates and paper board substrates. The method (non-destructive approach) specified in IEC 62321-3-1 shall be used. In this measurement, at least Ca, Si, Al, and Ti shall be examined.

If quantification by the XRF method is necessary, the Ca and Ti content can be measured by the methods specified in ISO 10716 and ISO 5647, respectively.

The results of the screening shall be reported, including the following items:

a) type of substrate, sample identification;

b) detected metal composition, amount of metal(s);

c) Ca and/or Ti content measured by other methods (if necessary).

8.7 Thickness of coating layer

8.7.1 General

The thickness of any coating layer shall be evaluated by observation with a scanning electron microscope (SEM). It is necessary to prepare cross-sections for observation with a SEM. The requirements and procedure are specified in 8.7.

8.7.2 Instrumentation

The requirements of the apparatus (SEM), magnification, and calibration shall be according to ISO 9220.

8.7.3 Preparation of cross-sections

Various methods may be used for the preparations of cross-sections. Irrespective of how they are created, cross-sections shall meet the following requirements:

a) the cross-section shall be perpendicular to the plane of the coating layer;

b) the entire thickness of the coating image shall be simultaneously in focus at the magnification to be used for the measurement;

c) all material deformed by cutting or cross-sectioning shall be removed;

d) the boundaries of the coating cross-section shall be sharply defined by no more than contrasting appearance, or by a narrow, well-defined line.

NOTE If the plane of the cross-section is not perpendicular to the plane of the coating, the measured thickness will be greater than the true thickness. For example, an inclination of 10° to the perpendicular plane will contribute a 1,5 % error.

8.7.4 Measurement

The thickness of the coating layer is determined from the SEM image. The thickness of the coating layer shall be measured as the distance between the boundary lines of the coating layer in the image. The measurement shall be repeated in at least three different locations at least 3 mm apart on the image to determine the average thickness.

The SEM should be operated and the cross-section should be recorded in accordance with the manufacturer's instructions. Appropriate attention should be given to the factors listed in ISO 9220:1988, Clause 6.

8.7.5 Report of the results

The report shall include:

a) identification of the test specimen(s);

b) thickness of coating layer (measured value);

c) location of the measurements on the test specimen and the magnification.

9 Storage

9.1 Storage conditions

9.1.1 Climatic conditions

Class 1k1 of IEC 60721-3-1 and the following shall apply.

It is preferable to store substrate materials at a temperature of +20 °C to +25 °C and humidity of 30 % to 60 %. Even if it is impossible to keep substrate materials at a constant temperature, they shall be stored at a temperature of +0 °C to 30 °C and humidity of 30 % to 60 %, without

dew condensation, before use. In addition, substrate materials shall be stored out of direct sunlight.

9.1.2 Chemically active substances

Class 1C1 of IEC 60721-3-1 shall apply.

9.1.3 Mechanically active substances

Class 1S2 of IEC 60721-3-1 shall apply.

9.1.4 Other conditions

Storage conditions shall be agreed between user and supplier.

9.2 Storage period

If the specimens are stored unopened in an environment at a temperature of +20 °C to +25 °C and at relative humidity of 30 % to 60 % as described in 6.1, the storage period is 3 months after reaching the client. However, if there are special circumstances, the storage period may be determined by agreement between user and supplier.

10 Packaging and marking

10.1 Packaging

Substrate materials shall be packaged so that no breakage or degradation occurs due to climatic and mechanical conditions during transportation, and climatic conditions during storage.

10.2 Marking

Under consideration.

10.3 Traceability

Under consideration.

11 Transportation

11.1 Transportation conditions

11.1.1 Climatic conditions

Class 2K2 of IEC 60721-3-2 and the following shall apply.

It is preferable to transport substance materials in an environment at a temperature of 0 °C to 30 °C and relative humidity of 30 % to 60 %. Dew concentration shall be prevented even during transportation between the inside and outside of a building.

11.1.2 Chemically active substances

Class 2C2 of IEC 60721-3-2 shall apply. However, the substrate materials shall be protected against salt air by packaging or by the means of transportation.

11.1.3 Mechanically active substances

Class 2S2 of IEC 60721-3-2 shall apply.

11.1.4 Mechanical condition

Class 2M1 or 2M2 of IEC 60721-3-2 shall apply.

11.1.5 Other conditions

Preferably, transportation conditions should be agreed between user and supplier.

11.2 Means of transportation

Under consideration.

11.3 Vibration resistance

Under consideration.

11.4 Impact resistance

Under consideration.

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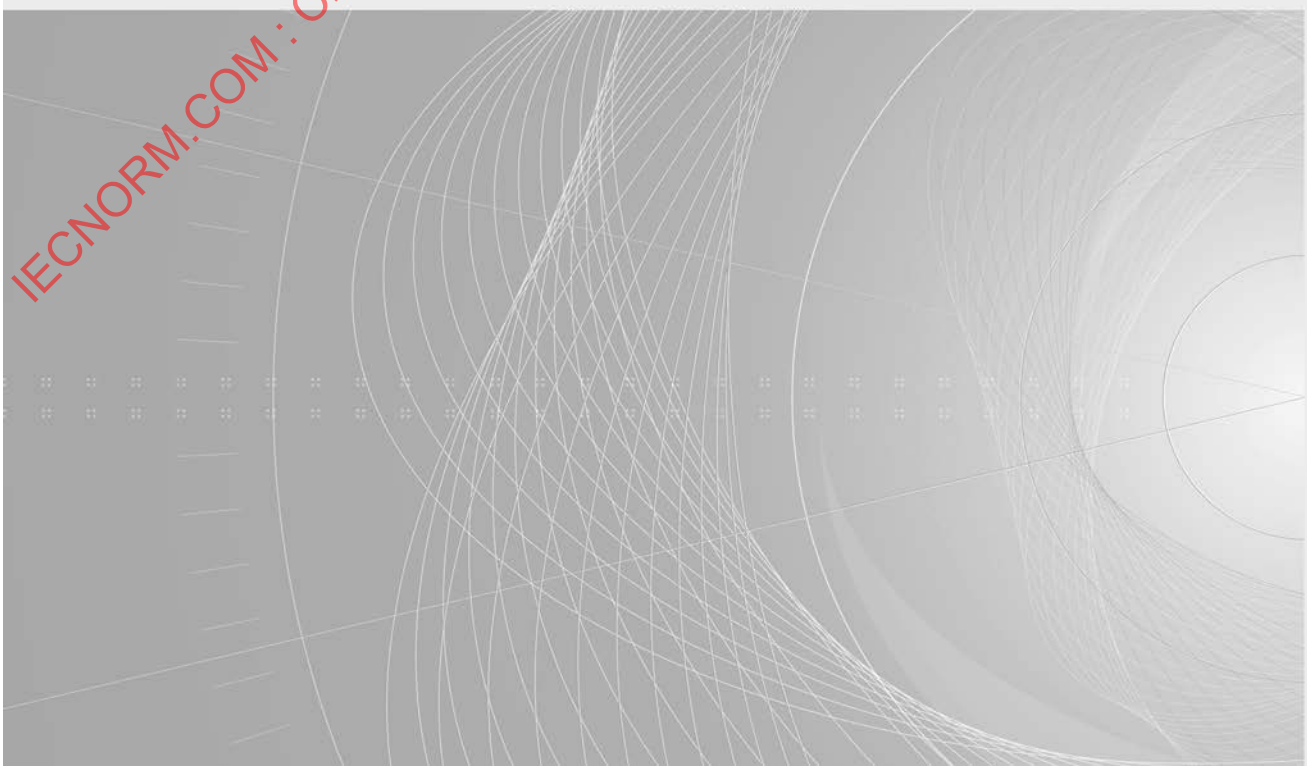
IEC 62899-201

Edition 1.1 2018-11

FINAL VERSION

Printed electronics –
Part 201: Materials – Substrates



IEC 62899-201:2016-02+AMD1:2018-11 CSV(en)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PRINTED ELECTRONICS –

Part 201: Materials – Substrates

FOREWORD

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This Consolidated version of IEC 62899-201 bears the edition number 1.1. It consists of the first edition (2016-02) [documents 119/87/FDIS and 119/100A/RVD] and its amendment 1 (2018-11) [documents 119/189/CDV and 119/206A/RVC]. The technical content is identical to the base edition and its amendment.

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 62899-201 has been prepared by IEC technical committee 119: Printed electronics.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The IEC 62899-20x series relates mainly to evaluation methods for materials of printed electronics. The series also includes storage methods, packaging and marking, and transportation conditions.

The IEC 62899-20x series is divided into parts for each material. Each part is prepared as a generic specification containing fundamental information for the area of printed electronics.

The IEC 62899-20x series consists of the following parts:

Part 201: Materials – Substrates

Part 202: Materials – Conductive ink

Part 203: Materials – Semiconductor ink[1]

(Subsequent parts will be prepared for other materials.)

Furthermore, sectional specifications, blank detail specifications, and detail specifications for each material will follow these parts.

This part of IEC 62899 is prepared for substrate used in printed electronics and contains the test conditions, the evaluation methods and the storage conditions.

[1] Under consideration.

PRINTED ELECTRONICS –

Part 201: Materials – Substrates

1 Scope

This part of IEC 62899 defines the terms and specifies the evaluation method for substrates used in the printing process to form electronic components/devices. This international standard is also applied to the substrates which make surface treatment in order to improve their performance.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1:* Ageing *ovens – Single-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

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IEC 60674-2:1988/AMD1:2001

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IEC 60695-11-10, *Fire hazard testing – Part11-10: Test flames – 50W horizontal and vertical flame test methods*

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ISO 5-3, *Photography and graphic technology – Density measurements – Part 3: Spectral conditions*

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ISO 175:2010, *Plastics – Methods of test for the determination of the effects of immersion in liquid chemicals*

ISO 187, *Paper, board and pulps – Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples*

ISO 216, *Writing paper and certain classes of printed matter – Trimmed sizes – A and B series, and indication of machine direction*

ISO 217, *Paper – Untrimmed sizes – Designation and tolerances for primary and supplementary ranges, and indication of machine direction*

ISO 291, *Plastics – Standard atmospheres for conditioning and testing*

ISO 472, *Plastics – Vocabulary*

ISO 489:1999, *Plastics – Determination of refractive index*

ISO 527-1:2012, *Plastics – Determination of tensile properties – Part 1: General principles*

ISO 527-2, *Plastics – Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics*

ISO 527-4, *Plastics – Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

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

ISO 534, *Paper and board – Determination of thickness, density and specific volume*

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ISO 2758, *Paper – Determination of bursting strength*

ISO 2759, *Board – Determination of bursting strength*

ISO 3274, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

ISO 3664, *Graphic technology and photography – Viewing conditions*

ISO 3696, *Water for analytical laboratory use – Specification and test methods*

ISO 3781, *Paper and board – Determination of tensile strength after immersion in water*

ISO 3783, *Paper and board – Determination of resistance to picking – Accelerated speed method using the IGT-type tester (electric model)*

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ISO 11556, *Paper and board – Determination of curl using a single vertically suspended test piece*

ISO 11664-4, *Colorimetry – Part 4: CIE 1976 $L^*a^*b^*$ Colour space*

ISO 11798, *Information and documentation – Permanence and durability of writing, printing and copying on paper – Requirements and test methods*

ISO 12192, *Paper and board – Determination of compressive strength – Ring crush method*

ISO 13468-1:1996, *Plastics – Determination of the total luminous transmittance of transparent materials – Part 1: Single beam instrument*

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ISO 15106-2, *Plastics – Film and sheeting – Determination of water vapour transmission rate – Part 2: Infrared detection sensor method*

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ISO 15512, *Plastics – Determination of water content*

ISO 15359, *Paper and board – Determination of the static and kinetic coefficients of friction – Horizontal plane method*

ISO 15754, *Paper and board – Determination of z-directional tensile strength*

ISO 15989, *Plastics – Film and sheeting – Measurement of water-contact angle of corona-treated films*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050, IEC 60695-11-10, ISO 472, ISO 4287, as well as the following apply.

3.1
bow and twist
distortion in the dimensions of a plastic object which occurs after moulding or processing

Note 1 to entry: See Figure 1 for an example of bow and Figure 2 for an example of twist.

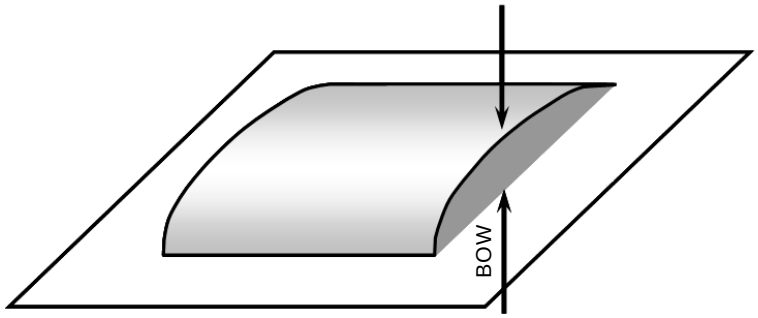

Figure 1 – Example of bow

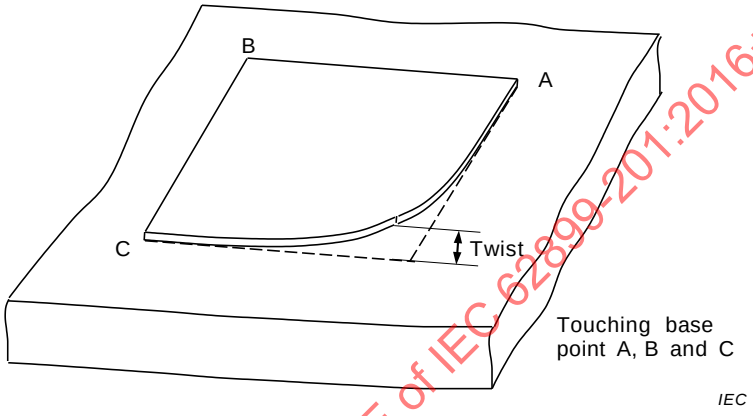

Figure 2 – Example of twist

3.2
roughness
surface property of a substrate which indicates a high-frequency component of irregular elements in the profile curve

Note 1 to entry: Roughness is obtained as a roughness curve by subtracting noise and micro-waviness (see 3.3) from the profile curve measured with a profile filter and phase compensation filter.

3.3
micro-waviness
surface property of a substrate which indicates a low-frequency component of irregular elements in the profile curve

Note 1 to entry: Micro-waviness is obtained from the average line (from the deviation curve) of the measured profile curve.

3.4
foreign substance on surface
substance which is located on the surface of the substrate and can be removed easily by washing off with water, alcohols, cleaning agents, etc., or ultrasonic cleaning

3.5
foreign inclusion
substance which is completely embedded in the substrate or partially exposed on the surface of the substrate, and cannot be removed by cleaning

3.6
edge condition
state of the edges of the substrate which indicates the presence of distortion, waviness, scratches, fracture, burrs, or foreign substances

3.7
minimum bending radius
smallest limit bending radius for which permanent structural change does not occur

3.8
tear strength
force required to rip test specimens apart

Note 1 to entry: The unit of tear strength is newton (N).

3.9
tear propagation resistance
tear strength (see 3.8) divided by thickness

Note 1 to entry: The unit of tear propagation resistance is newton/millimetre (N/mm).

3.10
gas transmission
ease of gas which passes through a unit area of a substrate per unit time under specified temperature and humidity conditions

3.11
water vapour transmission
amount of water vapour which passes through a unit area of a substrate per unit time under specified temperature and humidity conditions

Note 1 to entry: Water vapour transmission is generally expressed as the mass of water vapour which passes through an area of 1 m^2 in 24 h ($g/m^2 \cdot d$).

3.12
oxygen gas transmission
amount of oxygen which passes through a unit area of substrate per unit time and unit partial pressure between both sides of the substrate under specified temperature and humidity conditions

3.13
electric strength
quotient of the maximum voltage applied without breakdown, by the distance between conducting parts under prescribed test conditions

[SOURCE: IEC 60050-212:2010, 212-11-37]

3.14
temperature index
numerical value corresponding to the temperature, in degrees Celsius, derived from the thermal endurance relationship at a given time (normally 20 000 h)

[SOURCE: ISO 2578:1993, 3.1, modified – “numerical value” is used instead of “number”.]

3.15
relative temperature index
temperature index (see 3.14) of a test material, obtained at the time which corresponds to the known temperature index of a reference material when both materials are subjected to the same ageing and diagnostic procedures in a comparative test

[SOURCE: ISO 2578:1993, 3.2, modified – the reference to “temperature index” has been added.]

3.16
chip
<glass substrates> place from which a small piece of glass has been removed from the glass surface

3.17
crack
<glass substrates> lines on the surface of the central or edge of glass where it has broken but not split into separate parts

3.18
scratch
<glass substrates> shallow grooves on a glass surface which are made during handling

Note 1 to entry: A scratch may be accompanied by a crack.

3.19
paper
material without conductivity in the form of a coherent sheet or web, excluding sheets or laps of pulp as commonly understood for paper-making or paper-dissolving purposes and non-woven products, made by deposition of vegetable, mineral, animal or synthetic fibres, or their mixtures, from a fluid suspension onto a suitable forming device, with or without the addition of other substances

Note 1 to entry: There are also a number of synthetic products with paper-like qualities that are applicable as substrates for printed electronics. For the purposes of this document these can be treated as paper for testing as substrates.

[SOURCE: ISO 21067-1:2016, A.1.1, modified – “without conductivity“ and NOTE have been added.]

3.20
board
paper (3.19) of a relatively high rigidity

Note 1 to entry: The term “paper” may be used for both paper and board. Materials of grammage less than 225 g/m^2 are generally considered to be paper, and materials of grammage of 225 g/m^2 or more to be board.

[SOURCE: ISO 5127:2017, 3.3.5.2.02]

3.21
pinhole
small hole in a printed feature that is a result of a surface inhomogeneity on the substrate

Note 1 to entry: This can be a consequence of a number of causes, and potential examples are listed below:

- a small hole in the surface of the substrate;
- a hole large enough to permit the transfer of an applied functional ink;
- a local variation in the wetting properties of the surface that results in uneven wetting of an applied functional ink.

4 Materials, structures and dimensions

4.1 Base materials

Base materials are used in the printing process to form electronic components/devices that are polymer, glass and other materials such as ceramics, metal, paper, etc.

4.2 Structures of substrates

The substrate shall have a monolithic structure of one of the materials specified in 4.1, a composite structure of several of those materials, or a reinforced composite structure strengthened with fibres or particles. The surface of the substrate may be treated to enhance the wettability, adhesive property, gas transmission, smoothness, and electric insulation.

For paper substrates, all paper and paper board substrates may be used. For example, uncoated or coated one-layer paper, as well as similarly uncoated or coated multilayer paperboards can be used, and laminated papers/boards, polymer coating papers/boards, and papers/boards coating with extrusion/dispersion can also be used.

4.3 Dimensions of substrates

4.3.1 Outline

Substrates made of the material(s) specified in 4.1 and with a structure specified in 4.2 shall be supplied in the form of (rigid or flexible) sheets or rolls.

The preferred area dimensions (width and length) of the substrate are shown below. The preferred thickness is specified in 4.3.4. The dimensions of the substrate shall be agreed between user and supplier, and described in the product specifications.

4.3.2 Sheet dimensions

The recommended standard area dimensions (width and length) of a sheet are shown below. The tolerance of width and length is ±1 mm.

370 mm × 470 mm, 550 mm × 650 mm, 680 mm × 880 mm, and 1 100 mm × 1 300 mm

4.3.3 Width and length (roll supply)

4.3.3.1 Polymer substrates

Preferred substrate widths are 800 mm and 1 600 mm with a tolerance of ±1 mm. The test method for substrate width shall be as specified in IEC 60674-2:1988, Clause 5.

The substrate winding length on a roll shall be as agreed between user and supplier.

The inner diameter of a roll winding core shall be 7,62 cm (3 inches) or 15,24 cm (6 inches). The core shape shall be cylindrical. The core material may be any material which can be used in a level 100 clean room.

The winding condition on a roll shall be evaluated by referring to IEC 60674-2:1988, Clause 6. The sum of the curvature and sag shall be 10 mm or less.

The roll winding misalignment of the roll (the difference between the roll width and the maximum substrate width) shall comply with Table 1.

Table 1 – Winding misalignment of the roll

Dimensions in millimetres

Substrate width	Winding misalignment
less than 150	0,5 or less
150 to less than 300	1,0 or less
300 or more	2,0 or less

4.3.3.2 Glass substrates

Preferred substrate widths are 300 mm, 600 mm, 800 mm and 1 600 mm with a tolerance of ±5 mm. Substrate winding length on a roll shall be as agreed between user and supplier.

The inner diameter of the roll winding core, core material, roll winding condition and roll winding misalignment should be as specified in the stipulations regarding the polymer substrate.

4.3.3.3 Paper substrate

When paper substrate is used as a sheet, the dimensions of the sheets shall be as specified in ISO 216. Designation and tolerances for primary and supplementary ranges, and indication of machine direction shall be as specified in ISO 217.

When paper substrate is supplied by a roll, the standard widths of the roll shall be according to ISO 217. Winding length on a roll shall be as agreed between user and supplier.

4.3.4 Substrate thickness

4.3.4.1 Polymer substrates

Substrate nominal thickness shall be selected from 5 μm, 7,5 μm, 10 μm, 12,5 μm, 20 μm, 25 μm, 30 μm, 38 μm, 50 μm, 75 μm, 100 μm, 125 μm, 150 μm, 188 μm, 200 μm or 250 μm. The tolerance of the nominal thickness shall be ±10%.

4.3.4.2 Glass substrates

Substrate nominal thickness should be selected from 5 μm, 10μm, 20 μm, 30 μm, 40 μm, 50 μm, 70 μm, 100 μm, 125 μm, 150 μm, 200 μm, 250 μm, 300 μm, 400 μm, 500 μm, 600 μm, 700 μm, 800 μm or 1 000 μm. The tolerance of the nominal thickness should be ±10 %.

4.3.4.3 Paper substrate

The thickness of substrates is not limited. It shall be as agreed between user and supplier. The method for measuring thickness shall be according to ISO 534.

Determination of grammage shall be according to ISO 536.

5 General descriptions of evaluation tests

5.1 Sampling

In case paper substrates are used, the test methods in this document may be applied to the evaluation of a single sheet or to the set of sheets. When the test methods are applied to the set of sheets, the sheet shall be sampled randomly with no replacement. In cases where the results of the tests are reported for a set of sheets, the total number of sheets in the set to be tested and the number of sheets measured shall be reported.

5.2 Preparation of test specimens

The substrate shall be in its original form, or cut into the appropriate size for testing.

Care should be taken not to touch the test specimens with fingers, etc. The specimens shall not be cleaned unless otherwise specified.

5.3 Atmospheric conditions for evaluation test

The temperature and humidity conditions for evaluation tests shall be at a temperature of 23 °C ± 1 °C and relative humidity of (50 ± 5) % according to ISO 291 unless otherwise specified.

The paper and paper board substrates shall be tested under standard atmospheric conditions, at a temperature of 23 °C ± 1 °C and a relative humidity of (50 ± 2) %.

NOTE These are the standard atmospheric conditions as specified by ISO 187.

5.4 Conditioning

5.4.1 Polymer substrates

Polymer substrates need conditioning. Unless otherwise specified, the test specimens to be evaluated shall be stored at a temperature of 23 °C ± 1 °C and relative humidity of (50 ± 5) % for 48 h or more.

5.4.2 Glass substrates

Since glass substrates have no hygroscopicity, conditioning is generally not necessary.

5.4.3 Other materials

Paper and paper board substrates need conditioning. Unless otherwise specified, the test specimens to be evaluated shall be conditioned according to ISO 187.

6 Characteristics and evaluation method of polymer substrates

6.1 Surface properties

6.1.1 Surface defects

6.1.1.1 General characteristics

The surface of a substrate shall not have the following defects. However, since the maximum permissible size of defects depends on the purpose, the defect condition shall be agreed upon between user and supplier.

– Pinholes, hollows, blisters, pimples, fish-eyes, speckles, cracks, fractures, wrinkles, detachment and creep

6.1.1.2 Detection method

The surface defects of a substrate shall be detected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine such as a stylus-based profilometer, or WLI (white light interferometry).

6.1.1.3 Report of the results

The report shall include the following items. For defect(s) not exceeding the permissible size, items b) through f) may be omitted:

a) type of defects;

b) length of each defect;

c) width of each defect;

d) depth or height of each defect;

e) number of defects;

f) position of each defect.

6.1.2 Flatness

6.1.2.1 Bow and twist

6.1.2.1.1 Test method

Bow and twist are expressed as the bow ratio and twist ratio according to IEC 61189-3:2007, 9.4 (test 3M04).

The permissible bow ratio and twist ratio shall be agreed upon between user and supplier as required. This agreement should consider the actual use on products as well as the manufacturing process.

6.1.2.1.2 Report of the results

The report shall include the bow ratio and twist ratio.

6.1.2.2 Surface roughness

6.1.2.2.1 Procedure of measurement and calculation

Surface roughness is expressed as the arithmetic mean roughness (Ra). However, unevenness (extrusions) which exceeds the level difference (Rk) at the core shall be treated as protrusions.

Ra shall be obtained as follows.

Measurement shall be made using a contact (stylus) instrument specified in ISO 3274 and a roughness parameter shall be calculated according to ISO 4288:1996, 7.2. From the profile curve obtained, stylus strain and noise are removed with a profile filter and the form deviation curve (waviness curve) is extracted. The cut-off value (wavelength) of the phase compensation filter used to distinguish the waviness curve shall be the wavelength at an amplitude transmission rate of 50 %. The high-frequency component (short-wavelength component) curve obtained is treated as a surface roughness curve, from which the arithmetic mean roughness (Ra) is calculated.

For protrusions, Rk shall be obtained according to ISO 13565-2:1996, Clause 4; unevenness exceeding this value is treated as protrusions, and the number of protrusions per unit area is calculated.

6.1.2.2.2 Report of the results

The report shall include the following items:

a) measuring instruments;
b) sampling method and place, and specimen size;
c) result of Ra measurement;
d) number of protrusions.

6.1.2.3 Micro-waviness

6.1.2.3.1 Procedure of measurement and calculation

Micro-waviness is expressed as the arithmetic mean waviness (Wa). Wa is obtained as follows.

Measurement shall be made using a stylus (contact) instrument specified in ISO 3274 and a roughness parameter shall be calculated according to ISO 4288:1996, 7.2. From the profile

curve obtained, stylus strain and noise are removed with a profile filter and the roughness curve is extracted. The cut-off value (wavelength) of the phase compensation filter used to distinguish the roughness curve shall be the wavelength at an amplitude transmission rate of 50 %. The low-frequency component (long-wavelength component) curve obtained is treated as a form deviation curve (waviness curve), from which the arithmetic mean waviness (Wa) is calculated.

6.1.2.3.2 Report of the results

The report shall include the following items:

a) measuring instruments;

b) sampling method and place, and specimen size;

c) result of Wa measurement.

6.1.3 Surface condition

6.1.3.1 Contact angle

6.1.3.1.1 Test method

The contact angle shall be measured as specified in ISO 15989, using water or some other solvent which does not affect the substrate.

6.1.3.1.2 Report of the results

The report shall include the following items:

a) sampling method and place;

b) substrate and water or other solvent;

c) test conditions (temperature and humidity);

d) mean contact angle.

6.1.3.2 Foreign substances on the surface

6.1.3.2.1 Principle

Regarding foreign substances on the surface of the substrate, those which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier shall be detected.

6.1.3.2.2 Inspection method

Foreign substances shall be detected with normal or corrected vision (6/6 or better), with a microscope, edge light, or with a surface inspection machine. There shall be no foreign substances which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier.

6.1.3.2.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) no foreign substances which are equal to or greater than a certain size (maximum diameter).

6.1.3.3 Foreign inclusions

6.1.3.3.1 Principle

For foreign substances and voids which are included in the substrate, those which are equal to or greater than the specified size (maximum diameter) agreed between user and supplier shall be detected.

6.1.3.3.2 Inspection method

Foreign substances shall be detected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine.

Since the permissible state of inclusion of foreign substances depends on the purpose, the allowable size shall be agreed between user and supplier.

Regarding the inclusion of foreign substances which cause unevenness on the surface, the allowable height shall be agreed between user and supplier.

6.1.3.3.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) no foreign substances which are equal to or greater than a certain size (maximum diameter).

6.1.4 Edge condition

6.1.4.1 General characteristics

To evaluate the condition of the edge of the substrate, specific cracks, scratches, unevenness, and foreign substances shall be detected as mutually agreed upon between user and supplier.

6.1.4.2 Inspection method

Edge conditions shall be inspected with the normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine. Adhesive tape is used to detect foreign substances. There shall be no foreign substances on the tape.

6.1.4.3 Report of the results

The report shall include the following items:

a) detection method;

b) inspection method (100 % or sampling), sampling method and place, and specimen size;

c) specific cracks, scratches, unevenness, and foreign substances.

6.2 Mechanical properties

6.2.1 Elongation at break

6.2.1.1 Outline

Rupture elongation is expressed as the tensile strain at break or nominal tensile strain at break, to which ISO 527-1 and the following shall be applied.

6.2.1.2 Test speeds

Test speeds shall be selected from ISO 527-1:2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.1.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, or ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.1.4 Report of the results

The report shall include the following items:

a) testing machine;
b) test speed (mm/min);
c) specimen size (mm);
d) test environment (temperature and humidity);
e) tensile strain at break or nominal tensile strain at break (dimensionless ratio or %).

6.2.2 Tensile strength

6.2.2.1 Outline

Tensile strength is expressed as the stress at which the specimen breaks, to which ISO 527-1 and the following shall be applied.

6.2.2.2 Test speeds

Test speeds shall be selected from ISO 527-1:2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.2.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, or ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.2.4 Report of the results

The report shall include the following items:

a) testing machine;
b) test speed (mm/min);
c) specimen size (mm);
d) test environment (temperature and humidity);
e) tensile strength (MPa).

6.2.3 Tensile modulus

6.2.3.1 Test method

ISO 527-1 and the following shall be applied to tensile modulus.

6.2.3.2 Recommended test speeds

A test method is selected from ISO 527-2012, Table 1, as agreed between user and supplier and described in the product specifications.

6.2.3.3 Test specimens

For the size and preparation of test specimens, appropriate standards shall be selected from ISO 527-2, ISO 527-4, ISO 527-5 according to the material of the substrate, and shall be described in the product specifications.

6.2.3.4 Report of the results

The report shall include the following items:

a) testing machine;

b) test speed (mm/min);

c) specimen size (mm);

d) test environment (temperature and humidity);

e) tensile modulus (MPa).

6.2.4 Minimum bending radius

6.2.4.1 Principle

When the substrate is bent beyond the minimum bending radius, permanent structural changes (creases or cracks) occur on the substrate at a certain radius.

Subclause 6.2.4 defines the method for obtaining the minimum bending radius below which no permanent structural changes occur on the substrate. One test method uses a flex resistance tester and the other a fracture resistance tester. An appropriate test method shall be selected according to the material of the substrate, and shall be described in the product specifications.

6.2.4.2 Measurement equipment

6.2.4.2.1 General

The measurement equipment shall be a flex resistance tester (also known as a U-shaped flex tester) or a fracture resistance tester (also known as a two-sided fracture tester).

6.2.4.2.2 Flex resistance tester

A flex resistance tester has the structure shown in Figure 3 near the part where the specimen is attached, and shall satisfy the following requirements:

– The two flat plates are parallel. The distance d between the flat plates can be adjusted and measured.

– Each flat plate has a mechanism to hold the side of the specimen so that no part of the specimen protrudes when it is bent in a U shape.

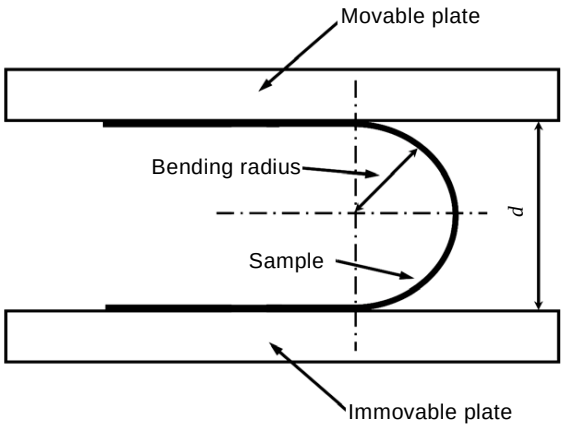

Figure 3 – Structure of the flex resistance tester near the part where the specimen is attached

6.2.4.2.3 MIT instrument

The MIT instrument which is described in the ISO 5626 is used. This instrument has the structure shown in Figure 4.

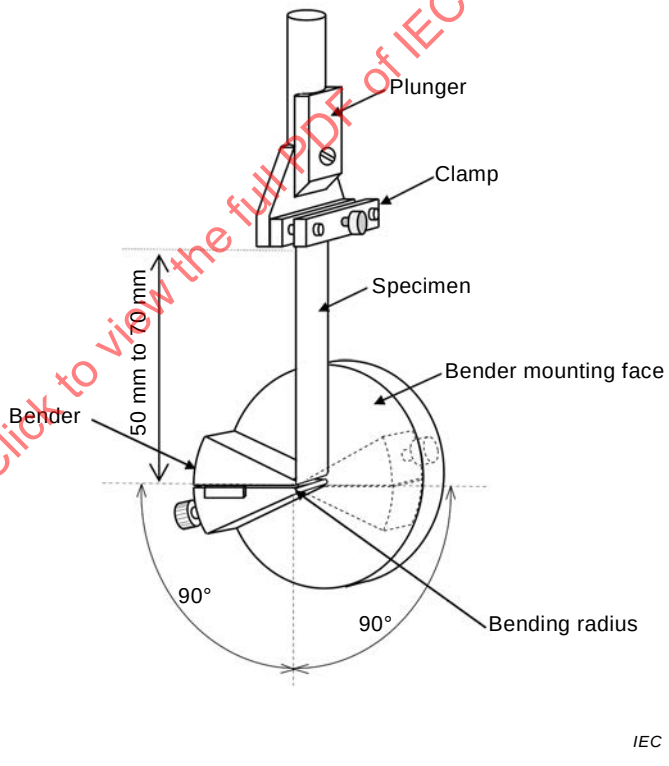

Figure 4 – Structure of the MIT instrument

The MIT instrument has a movable part which holds the specimen and bends it by 180º (90º on both sides of the vertical direction), a bending part for applying constant curvature to the specimen, and a mechanism for applying constant tension to the specimen. This instrument shall satisfy the following requirements.

– It can apply the tension specified in the product specifications to the specimen, and measure and display the tension.

– It can conduct tests at radiuses of curvature greater than that specified in the product specifications.

– It has a power unit that applies rotational motion at the speed specified in the product specifications to the bending device.

6.2.4.3 Test specimens

The specimen shall be in its original form, and of the size specified in the product specifications.

6.2.4.4 Measurement procedure

6.2.4.4.1 Flex resistance test

As shown in Figure 3, the specimen is bent in a U shape and fixed to both parallel plates. The distance d between the parallel plates shall be sufficiently larger than twice the minimum bending radius of the specimen. Then d shall be set to four times the minimum bending radius and kept for the time specified in the product specifications. When the test is completed, increase d, detach the specimen, and perform the inspection after testing.

The test shall be repeated with d reduced each time until permanent structural change is detected according to 6.2.4.4.2.

6.2.4.4.2 MIT instrument

The tension applied to the specimen, bending speed, and hold time shall be according to the product specifications.

Fix the plunger with locking screws and apply to the plunger the force equal to the tension applied to the specimen. Accurately attach the specimen to the clamp connected to the plunger and the bender so that it is kept flat and does not touch the mounting face of the bender. The specimen shall be attached to the clamp and the bender without rotating the bender or causing deflection to the specimen. Loosen the locking screws on the plunger to apply tension to the specimen. If the reading of the indicator changes, adjust the tension to the specified level.

Rotate the bender 90º from the vertical direction at the specified bending speed and keep it for the specified time. Then rotate the bender back to the original position and rotate it 90º in the opposite direction. When the test is completed, detach the specimen, and perform the inspection after testing.

Repeat the test by gradually reducing the radius of the curvature at the bender from approximately twice the minimum bending radius of the specimen specified in the product specifications to the level specified in the product specifications.

The test shall be repeated by reducing the bending radius from twice the minimum bending radius to the one specified in the product specification, until permanent structural change is detected according to 6.2.4.4.2.

6.2.4.4.3 Inspection after test

To evaluate whether permanent structural changes occurred or not (creases or cracks), the specimen shall be inspected with normal or corrected vision (6/6 or better), with a microscope, or with a surface inspection machine.

6.2.4.5 Expression of the results

The minimum bending radius at which no permanent structural change occurs to the specimen is the minimum bending radius.

6.2.4.6 Report of the results

The report shall include the following items:

a) test method (flex resistance tester or MIT instrument);
b) type and thickness of the specimens;
c) number of specimens;
d) conditioning (temperature, humidity, and kept time);
e) test environment (temperature and humidity);
f) minimum bending radius.

6.2.5 Tear strength and tear propagation resistance

6.2.5.1 Test method

Tear strength shall be measured and calculated using the trouser tear method specified in ISO 6383-1 or the Elmendorf tear method specified in ISO 6383-2. Either method can be used to measure tear strength. An appropriate test method depends on the stiffness and deformation (extent) of the material to be tested. The test method shall be as specified in IEC 60674-3-1, or the test method as agreed between user and supplier.

As the tear properties change according to the thickness, tear speed, and measuring atmosphere, if a data comparison is required, these conditions shall be accurately controlled.

6.2.5.2 Test specimens

When comparing tear strength between different materials, adjust the specimen so that the difference in thickness is no more than 10 %. In addition, since the dependency on tear speed might greatly differ between materials, care shall be taken when comparing the results.

6.2.5.3 Expression of the results

The tear property obtained is the tear propagation resistance in newton per millimetre (N/mm), which is calculated by dividing the force required to tear the specimen (tear strength) in newton (N) by the thickness of the specimen.

6.2.5.4 Report of the results

The report shall include the following items:

a) thickness of the specimen;
b) tear speed;
c) measuring atmosphere;
d) tear propagation resistance (tear strength may be accompanied).

6.2.6 Edge strength

Under consideration.

6.2.7 Hardness

6.2.7.1 Test method

Hardness shall be measured as pencil hardness according to ISO 15184. If required, Shore hardness (see ISO 868) or ball indentation hardness (see ISO 2039-1 and ISO 2039-2) can be used.

6.2.7.2 Report of the results

The report shall include the following items:

a) test method;
b) thickness of the specimen;
c) temperature and humidity during the test;
d) brand of the pencil used (for pencil hardness), durometer type (for Shore hardness), or Rockwell hardness scale (for ball indentation hardness);
e) test result;
f) difference from the specified test method (if applicable).

6.3 Chemical properties

6.3.1 Resistance to chemicals

6.3.1.1 Test method

ISO 175 and the following shall apply to the resistance to chemicals.

6.3.1.2 Selection of test conditions

The properties of the specimen soaked in the liquid such as mass, size, and colour are selected from ISO 175 as agreed between user and supplier, and described in the product specification.

The liquid used for the test shall be an acid solution, an alkaline solution, or an organic solvent, which should preferably be selected from Table A.1 (reagents) and Table A.2 (various liquid products) in ISO 175:2010. However, depending on the target material and the process used, other liquids may be used as agreed between user and supplier.

6.3.1.3 Test specimens

The size and preparation of test specimens shall follow ISO 175 and be described in the product specification.

6.3.1.4 Report of the results

The report shall include the following items:

a) test method;
b) test conditions;
c) test specimen;
d) test environment (temperature and humidity);
e) resistance to chemicals.

6.3.2 Halide contents

6.3.2.1 Test method

Mass fraction (10^{-6}) shall be obtained using the method in IEC 61189-2:2006, 8.12 (test 2C12).

6.3.2.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass fraction (10^{-6}).

6.3.3 Volatile content

6.3.3.1 Test method

The test method shall be the mass reduction in a high-temperature oven as specified in IEC 61189-2:2006, 8.4 (test 2C04).

For materials which are not specified in IEC 61189-2:2006, 8.4 (test 2C04), the oven shall follow the instruction of the material manufacture.

6.3.3.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass fraction (10^{-6}).

6.3.4 Gas transmission

6.3.4.1 Water vapour transmission

6.3.4.1.1 Test method

Water vapour transmission shall be measured using the humidity detection sensor method specified in ISO 15106-1, infrared sensor method specified in ISO 15106-2, gas chromatographic method specified in ISO 15106-4, or electrolytic sensor method specified in ISO 15106-3. However, as agreed upon between user and supplier, another method may be used. The test method selected shall be described in the product specification.

6.3.4.1.2 Report of the results

The report shall include the following items:

a) test method;

b) test conditions;

c) test specimen;

d) test environment (temperature and humidity);

e) mass of water vapour which passes through an area of 1 m^2 in 24 h (g/m^2 d).

6.3.4.2 Oxygen gas transmission

6.3.4.2.1 Test method

Oxygen gas transmission shall be measured using the differential pressure method (pressure sensor method) specified in ISO 15105-1 or isopiestic method (electrolytic sensor method or gas chromatographic method) specified in ISO 15105-2. However, as agreed upon between user and supplier, another method may be used. The test method selected shall be described in the product specification.

The gas transmission and gas transmission coefficient (gas permeability) can be obtained as test results. The properties used for the evaluation shall be described in the product specification as agreed between user and supplier.

6.3.4.2.2 Test specimens

Since both sides of the specimen may have different properties, a method for distinguishing each side shall be determined and the side which is exposed to the test gas shall be recorded.

6.3.4.2.3 Report of the results

The report shall include the following items:

a) test method;
b) test conditions;
c) test specimen (method for distinguishing sides and the side exposed to the test gas);
d) test environment (temperature and humidity);
e) gas transmission and gas transmission coefficient (gas permeability).

6.3.5 Moisture absorption

6.3.5.1 Test method

The test is conducted using the D method (exposing the specimen to a relative humidity of 50 % and measuring the amount of water absorption) specified in ISO 62.

The change in the amount of water in the substrate before and after moisture absorption is obtained according to the method for determining water content specified in ISO 15512.

6.3.5.2 Report of the results

The report shall include the following items:

a) test method;
b) test environment (temperature and humidity);
c) test conditions (exposure time);
d) test specimen (area size and thickness);
e) water absorption coefficient (mass fraction in percentage: %).

6.4 Electrical properties

6.4.1 Measurement at ambient temperature

6.4.1.1 Volume resistance and surface resistance

6.4.1.1.1 Outline

Volume resistance is expressed in Ohm centimetre (Ω cm). Surface resistance is expressed in Ohm (Ω).

6.4.1.1.2 Test method

Volume resistance and surface resistance shall be measured as specified in IEC 60093.

6.4.1.1.3 Measurement equipment

Measurement equipment shall be as specified in IEC 60093. The dimensions of the measuring electrode described in IEC 60093:1980, Clause 6, are: d_1 = 50 mm, d_2 = 60 mm,

and d_3 = 80 mm (see Figure 5). However, the other electrode dimensions of d_1 = 50 mm, d_2 = 70 mm, d_3 = 80 mm, may be used.

6.4.1.1.4 Applied voltage

Applied voltage shall be selected from the voltage listed in IEC 60093:1980, Clause 4.

6.4.1.1.5 Test specimens

The shape, dimensions and preparation of the test specimen shall be as specified in IEC 60093:1980, Clause 6.

6.4.1.1.6 Calculation of the results

Volume resistivity shall be calculated in accordance with IEC 60093:1980, 11.1, from the measurement results. Surface resistivity is calculated in accordance with IEC 60093:1980, 11.2, from the measurement results.

6.4.1.1.7 Report of the results

The report shall include:

a) volume resistance and/or surface resistance;

b) shape and dimensions of the specimen: length × width or diameter (mm), and thickness (μm);

c) treatment and conditioning for the specimen (application of cleaning and method, conditioning atmosphere, etc.);

d) test atmosphere (temperature and relative humidity);

e) electrode dimensions (d_1, d_2 and d_3) and material;

f) applied voltage (V).

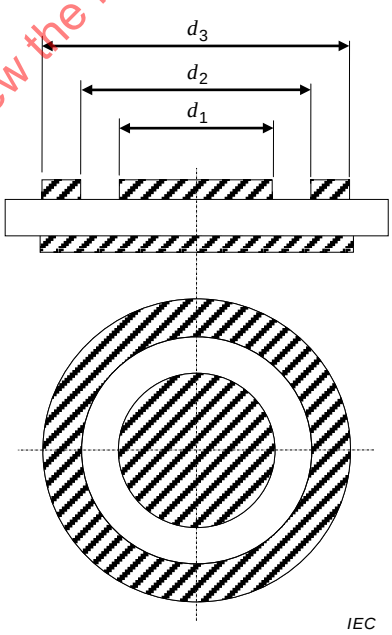

Figure 5 – Example of a measuring electrode

6.4.1.2 Electrical strength

6.4.1.2.1 Outline

Breakdown voltage is measured in the direction perpendicular to the surface of the substrate. Electric strength is the quotient of the breakdown voltage by the distance between the electrodes under specified test conditions.

6.4.1.2.2 Test method

Breakdown voltage shall be measured by the test method as specified in IEC 60243-1 with the following details:

a) the specimen shall be as specified in 5.2;

b) the specimen shall be conditioned as specified in 5.3;

c) the temperature and humidity of the test shall be as specified in 5.3;

d) the surrounding medium should be air. If the specimens have high breakdown values, they may be tested in insulating liquid as agreed between user and supplier;

e) the electrodes are unequal electrodes;

f) the frequency of the applied voltage is selected between 48 Hz and 62 Hz;

g) the test voltage is increased according to IEC 60243-1:2013, 10.1 (short time test), with a rising rate of 500 V/s.

6.4.1.2.3 Report of the results

The report shall include:

a) measured electric strength in kV/mm (minimum, maximum and median), preferably in conjunction with breakdown mode and location;

b) dimensions of the specimen (length × width or diameter (mm), and thickness (μm));

c) treatment and conditioning for the specimen (application of cleaning and method, conditioning atmosphere, etc.);

d) test atmosphere (surrounding medium: air or insulation liquid, temperature and relative humidity);

e) electrode dimensions (d_1, d_2 and d_3) and material;

f) mode of increasing voltage.

6.4.1.3 Relative permittivity

Under consideration.

6.4.1.4 Dissipation factor

Under consideration.

6.4.2 Measurement at high temperature

6.4.2.1 Surface resistance

Under consideration.

6.4.2.2 Volume resistance

Under consideration.

6.5 Thermal properties

6.5.1 Glass transition temperature

6.5.1.1 Test method

Glass transition temperature shall be measured using the DSC method specified in IEC 61189-2:2006, 9.10 (test 2M10), or the TMA method specified in IEC 61189-2:2006, 9.11 (test 2M11).

6.5.1.2 Report of the results

The report shall include:

a) measurement method;

b) rate of temperature rise;

c) glass transition temperature.

6.5.2 Coefficient of linear thermal expansion

6.5.2.1 Test method

The coefficient of linear thermal expansion shall be measured using the method as specified in ISO 11359-2 or an equivalent method.

6.5.2.2 Measurement conditions

Measurement conditions such as the measuring of the temperature range, heating rate, surrounding atmosphere, gas flow rate, are dependent on the specimen characteristics, and shall be specified in the product specification.

6.5.2.3 Conditioning atmosphere

According to ISO 11359-2:1999, 6.2, the conditioning atmosphere shall be as specified in ISO 291. However, if a modification of the condition is required to the characteristics of the material, the conditioning atmosphere may be determined by agreement between user and supplier.

6.5.2.4 Report of the results

The report shall include the following items:

a) coefficient of linear thermal expansion;

b) conditioning atmosphere;

c) measuring temperature range;

d) heating rate;

e) surrounding atmosphere;

f) gas flow rate, etc.

6.5.3 Dimensional stability

6.5.3.1 Dimensional stability (heating)

6.5.3.1.1 Test method

Dimensional stability (heating) shall be measured using the method specified in IEC 61189-2:2006, 12.1 (test 2X02) or the method agreed between user and supplier.