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INTERNATIONAL STANDARD

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

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CONTENTS

FOREWORD ... 3
INTRODUCTION ... 5
1 Scope ... 6
2 Normative references ... 6
3 Terms and definitions ... 6
4 Standard environmental conditions ... 7
5 Test sample ... 7
5.1 General ... 7
5.2 Size of test sample ... 8
6 Testing method and test apparatus ... 8
6.1 General ... 8
6.2 Test apparatus ... 8
6.3 Test procedure ... 9
6.4 Measurement ... 10
7 Data analysis ... 11
7.1 Reporting the electrical properties ... 11
7.2 Report of the results ... 11
Annex A (normative) Stress state in bending deformation – Bending strain calculation ... 12
Annex B (informative) Damage area and electrical resistance change after sliding plate test ... 13
B.1 Damage area ... 13
B.2 Comparison of bending test methods ... 13
Bibliography ... 15

Figure 1 – Schematic diagram of mechanical test of printed film ... 8
Figure 2 – Apparatus for mechanical test of printed film ... 9
Figure A.1 – Bending strain and curvature relation in bent printed film ... 12
Figure A.2 – Schematic of outer bending and inner bending ... 12
Figure B.1 – Images of metal film after sliding test ... 13
Figure B.2 – Electrical resistance changes of sliding plate test and simple bending test ... 14

Table 1 – List of the size of the specimen ... 8
Table 2 – Combination of the effective sample length and the linear motion length ... 10
Table 3 – Resistance range of the test piece and the applied current ... 10

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRINTED ELECTRONICS –

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International Standard IEC 62899-202-5 has been prepared by IEC technical committee 119: Printed Electronics.

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

FDIS	Report on voting
119/227/FDIS	119/235/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document 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 this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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INTRODUCTION

The printing process is a highly promising technology for the fabrication of flexible devices. In particular, a printed conductive layer on an insulating substrate will be widely employed as an electrode or as an interconnect for flexible devices. It will be dealt with and commercialized as a type of composite material in which the conductive layer is formed on the substrate as a conductor.

For a conductive film, the electrical property under mechanical deformation is very important because it is highly sensitive to mechanical stress and degrades well before the mechanical fracture. Therefore, a method for evaluating the conductivity of film materials provided by suppliers, sometimes including an *in situ* measurement system, is required in the industry as these are the basic materials which will be used in printed devices. Although some bending tests already exist, it is necessary to consider the unique characteristics of the printed films that are fabricated on a polymer substrate, which is weak under high temperature. These films are operated under severe mechanical deformations, unlike the conventional Si- or glass-based conductive films.

In this document, a mechanical bending test is described to evaluate the electrical property of a printed conductive layer on a substrate under repeated mechanical deformations. This sliding plate test method can be available for practical application in the industry by enabling the long-term reliability testing of printed film.

PRINTED ELECTRONICS –

Part 202-5: Materials – Conductive ink – Mechanical bending test of a printed conductive layer on an insulating substrate

1 Scope

This International Standard specifies a mechanical bending test for evaluating the electrical properties of a printed conductive layer on an insulating substrate under repeated mechanical deformation.

2 Normative references

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

IEC 62899-202:2016, *Printed electronics – Part 202: Materials – Conductive ink*

3 Terms and definitions

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

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

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

3.1
conductive material
ingredient of a printing or coating material, which itself is electrically conductive or becomes electrically conductive by post treatment such as heating

[SOURCE: IEC-62899-202:2016, 3.1]

3.2
conductive ink
fluid in which one or more small molecules, polymers, or particles are dissolved or dispersed, and which becomes an electrically conductive layer by post treatment such as heating

[SOURCE: IEC-62899-202:2016, 3.2]

3.3
conductive layer
film-like electrically conductive body made of conductive ink, which is printed or coated on a substrate, followed as necessary by post treatment such as heating

[SOURCE: IEC-62899-202:2016, 3.3]

3.4
conductive film
substrate (sheet or roll) with conductive layer

[SOURCE: IEC-62899-202:2016, 3.4]

3.5
flexible substrate
electrically insulating substrate with flexibility on which conductive ink is printed, such as plastic film, paper, or cloth

[SOURCE: IEC 62899-502-1:2017, 3.1.3, modified – "substrate with flexibility on which conductive ink is printed" is used instead of "substrate with flexibility on which a flexible light emitting element is attached".]

3.6
bending radius
r
radius of curvature of the conductive film measured from the centreline of the bent conductive film

3.7
bending strain
ε
strain in the curved tip in the sample

Note 1 to entry: The bending strain can be calculated by the curvature relation: $\varepsilon = (h + t)/2r$, where ε, h, t, $2r$ are the nominal bending strain, substrate thickness, printed film thickness and gap between the plates, respectively (see Annex A).

3.8
linear motion length
L
length of linear reciprocating motion of the moving plate that grips conductive film

3.9
effective sample length
d
length of the sample from the edge of grip to another edge of grip excluding the sample area for metal grip

4 Standard environmental conditions

Standard atmospheric conditions for measurement shall apply as specified in IEC 62899-202:

a) temperature: (23 ± 2) °C;

b) relative humidity: (50 ± 10) %;

c) air pressure: 86 kPa to 106 kPa.

5 Test sample

5.1 General

The test sample for mechanical tests shall be prepared using a conductive ink on a flexible substrate.

5.2 Size of test sample

For uniform bending deformation and strain distribution, a sample with a rectangular shape shall be used. The sample size of a printed conductive film shall be selected from Table 1 (adopted partially from IEC 62899-202 and ISO 527-3 [3][1]). The effective sample length is the length of the sample from the edge of grip to another edge of grip excluding the sample area for metal grip. The tolerance of width and length is 0,2 mm.

Table 1 – List of the size of the specimen

	Effective sample length mm	Width mm
Type A	30 ± 0,2	10 ± 0,2
Type B	30 ± 0,2	30 ± 0,2
Type C	50 ± 0,2	10 ± 0,2
Type D	50 ± 0,2	25 ± 0,2
Type E	80 ± 0,2	50 ± 0,2

Another size sample the length of which is at least four times larger than the linear motion length may be used for the mechanical bending test.

6 Testing method and test apparatus

6.1 General

A printed conductive layer on a flexible substrate shall be placed between two plates and bent as a half circle shape between two plates as shown in Figure 1. The repeated linear motion of one plate results in cyclic bending/unbending in the sample. The electrical property of the conductive film shall be evaluated by metal grips and an electrical connection.

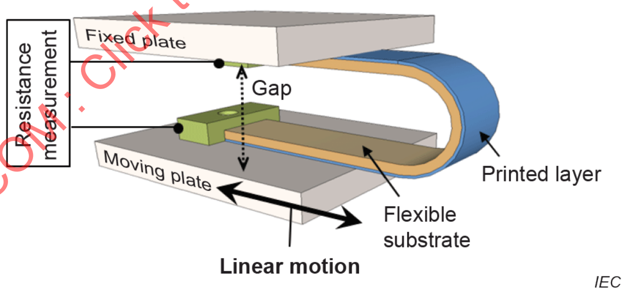


Figure 1 – Schematic diagram of mechanical test of printed film

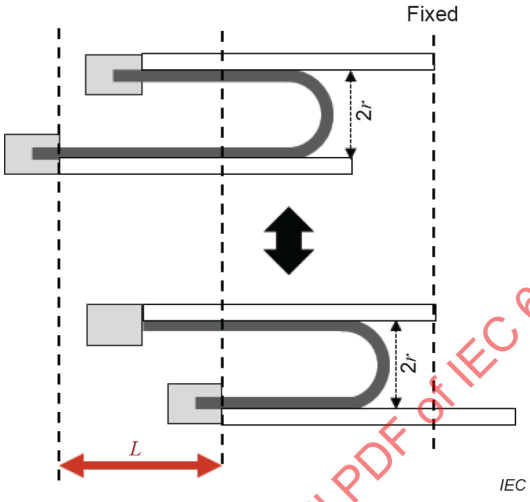
6.2 Test apparatus

As shown in Figure 1, a bending tester is used to apply a repeated sliding motion on samples. The gap between two plates may be adjustable to the target value. The linear motion length shall be variable from 0 mm to 30 mm.

1 Numbers in square brackets refer to the Bibliography.

The plates shall be clean, smooth, and rigid to avoid mechanical damage on samples. For electrical measurement, the grip shall be made from a conductive metal grip for electrical connection, but the plate shall be made from insulating materials such as the resin series, polycarbonate, mono-cast nylon, etc. The plate shall have a resistance larger than 10^6 Ω and no deformation is allowed during the bending test.

While one plate is stationary, the other plate repeats reciprocating linear motions as shown in Figure 2. Owing to the asymmetric linear motion of the moving plate, the repeated bending deformations are applied to the samples.



Key

r bending radius

L linear motion length

Figure 2 – Apparatus for mechanical test of printed film

6.3 Test procedure

The test procedure is as follows.

a) Place the sample between two plates and grip the edges of the sample. When mounting the sample, the gap between the plates shall be larger than 10 mm to avoid damage formation before testing. The longitudinal direction of the test piece shall be aligned with the linear motion direction of the test apparatus, and the deviation angle shall be less than 5° (adopted from IEC 62951-1 [4]).

b) Change the gap between the two plates, thereby decreasing the bending radius values from large to small. The test shall be conducted under the condition of the gap not interfering during the cyclic motion.

c) Fix the gap as a proper bending radius and measure the initial electrical resistance of the sample before the bending test. Start the repeated asymmetric sliding motions.

NOTE The mechanical property of printed films generally depends on the bending direction (inner or outer bending) [5]. Also, the linear motion length can affect the electrical reliability of the flexible electrode [6].

For mechanical tests of printed film, the bending radius (related to the gap) and the linear motion length shall be selected from a combination of the following values based on the operation of the product:

r (bending radius): (0,1; 0,2; 0,5; 1; 2; 3; 5; 7,5; 10; 15; 20) mm;

t (time of one bending/unbending): (0,5; 1; 2; 3; 5; 10) s;

L (linear motion length): (5, 10, 15, 20, 30) mm;

N (number of bendings): 1 000, 5 000, 10 000, 50 000, 100 000, 500 000, 1 000 000 cycles.

For stable testing and bending deformation, the liner motion length should be selected by considering the size of the sample. The combination of the effective sample length, the bending radius, and the linear motion length are listed in Table 2.

Table 2 – Combination of the effective sample length and the linear motion length

	Effective sample length mm	**Bending radius** mm	**Linear motion length** mm
Type A, B	30	0,1 to 7,5	5, 10
Type C, D	50	0,1 to 10	10, 15
Type E	80	0,1 to 15	15, 20, 30

The time waveform of the bending cycle such as the sine waveform may be applied for the cyclic sliding motion. The damage area after the cyclic mechanical test and the comparison of bending test methods are shown in Figure B.1 and Figure B.2, respectively.

6.4 Measurement

The electrical resistance change of a printed conductive film shall be measured before and after the cyclic bending test. For a more accurate evaluation, the electrical resistance can be measured periodically under the operation of bending. The electrical resistance of printed film shall be measured using a 4-wire measurement method. The conditions for electrical measurement are listed in Table 2, which is adopted from 6.2.1 of IEC 62899-202:2016.

Table 3 – Resistance range of the test piece and the applied current

Resistance range of the test piece	< 20 mΩ	< 200 mΩ	< 20 Ω	< 2 kΩ	< 20 kΩ	< 200 kΩ	< 2 MΩ
Applied current	1 A	100 mA	10 mA	1 mA	100 µA	10 µA	1 µA
Adopted from IEC 62899-202:2016, Table 1.							

If the resistance of the sample is larger than 1 kΩ, a 2-wire measurement method may also be used. The electrical resistance of conductive film can be measured *in situ* during mechanical deformations. For the exact electrical resistance measurement, the samples shall be held as tightly as possible using a metal grip. For samples such as metal nanowire, which is not strong enough to grip tightly, a metal tape or conducting paste with a lower resistance than the metal nanowire may be coated on the end parts of the samples.

7 Data analysis

7.1 Reporting the electrical properties

The electrical resistance shall be measured as a function of the bending radius (bending strain) or bending cycles at a fixed bending radius.

The initial value (R_0) and the relative ratio of resistance change ($\Delta R/R_0$) of electrical resistance shall be reported, as shown in Formula (1):

$$\Delta R / R_0 = (R - R_0) / R_0 \quad (1)$$

where

ΔR is the change in the electrical resistance;

R is the resistance after mechanical test;

R_0 is the initial resistance before mechanical test.

7.2 Report of the results

The report shall include the following items:

a) specimen identification (including film thickness, thickness of conductive layer, sample size);
b) bending radius and bending strain (calculated from the curvature relationship in Annex A);
c) bending direction: inner or outer bending;
d) linear motion length;
e) interval of bending;
f) number of bending cycles;
g) initial resistance value and change in the resistance;
h) images of damaged film (optional).

Annex A
(normative)

Stress state in bending deformation – Bending strain calculation

The bending strain in the printed layer shall be calculated from the curvature relation as shown in Figure A.1. The nominal bending strain refers to the maximum bending strain which occurs on the top surface of the printed layer.

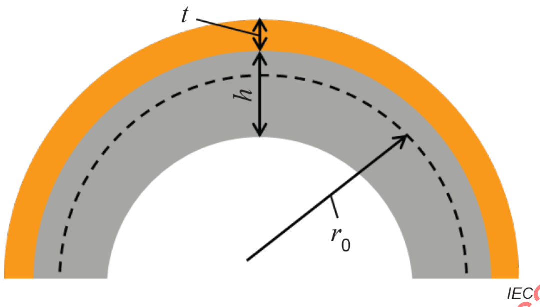


Figure A.1 – Bending strain and curvature relation in bent printed film

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{\pi r - \pi r_0}{\pi r_0} = \frac{h+t}{2r_0}$$

where

ε is the nominal bending strain;

r is the bending radius;

h is the substrate thickness;

t is the printed film thickness.

If the printed film thickness is much smaller than the substrate thickness ($t \ll h$), the bending may be simplified by $\varepsilon \approx h/2r_0$ [2].

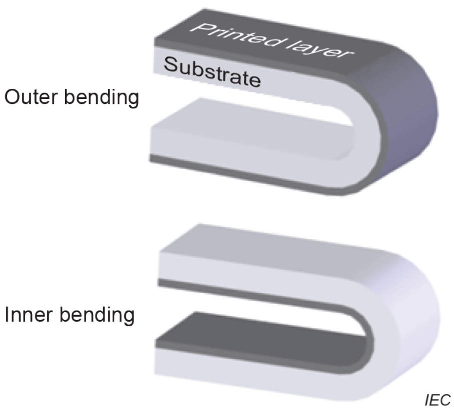


Figure A.2 – Schematic of outer bending and inner bending

The printed layer is bent either into an outer bending or an inner bending as shown in Figure A.2. When the printed layer is located on the outside of the bending shape (outer bending), a tensile stress is applied to the printed film. On the other hand, when the printed layer is located on the inside (inner bending), a compressive stress is applied to printed layer.

Annex B
(informative)

Damage area and electrical resistance change after sliding plate test

B.1 Damage area

During the cyclic mechanical test, the mechanical damage evolves in the conductive sample. It is noted that the damage is not observed at the curved tip region but at both edges of the curved area [6]. The damage area depends on the linear motion length.

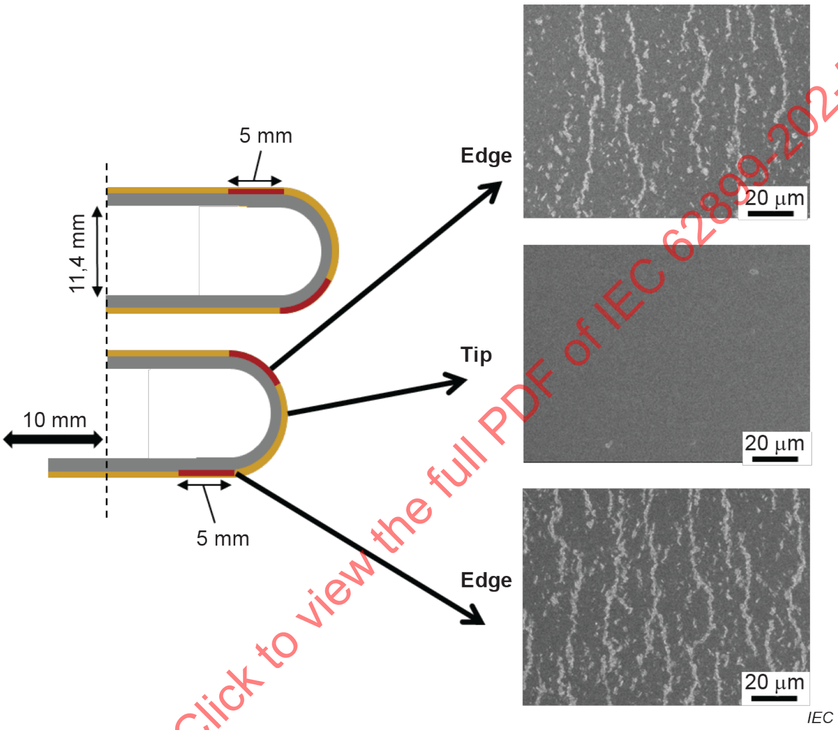
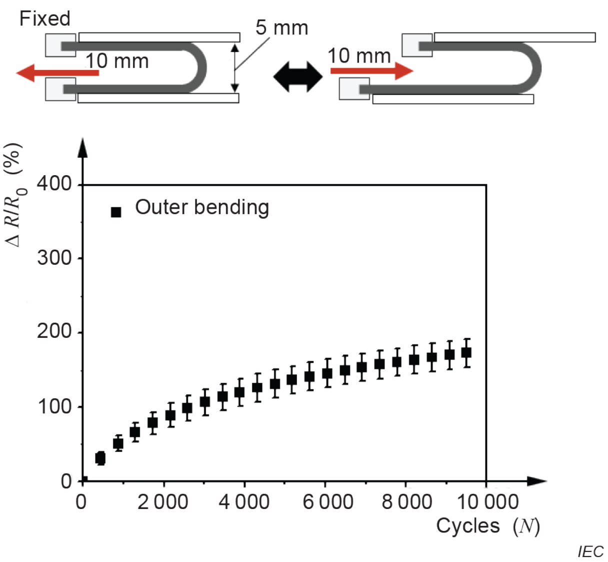


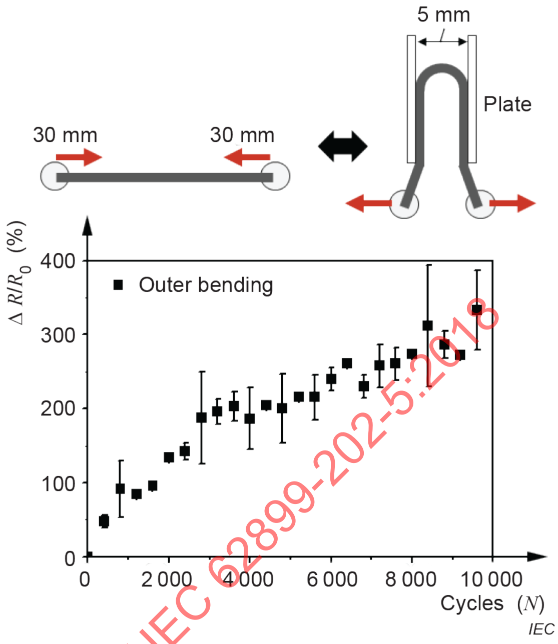
Figure B.1 – Images of metal film after sliding test

B.2 Comparison of bending test methods

To compare the different bending test methods, the reliability test was conducted using Figure B.2 a) the sliding plate test, which is proposed in this document, and Figure B.2 b) the simple bending test. The electrical resistance was increased in both tests. However, the experimental error in the sliding plate test is smaller than that in the simple bending test because the electrical measurement is more stable due to tighter grip parts.



a) Sliding plate test



b) Simple bending test

Figure B.2 – Electrical resistance changes of sliding plate test and simple bending test