# IEC 62899-202-10

Edition 1.0 2023-08

# INTERNATIONAL STANDARD

colour inside



## Printed electronics –
## Part 202-10: Materials – Resistance measurement method for thermoformable conducting layer

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**Part 202-10: Materials – Resistance measurement method for thermoformable conducting layer**

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

| Draft | Report on voting |
|---|---|
| 119/436/FDIS | 119/448/RVD |

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

The language used for the development of this International Standard is English.

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

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

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- withdrawn,
- replaced by a revised edition, or
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# INTRODUCTION

In-mould-electronics (IME) manufacturing can include thermoforming during which two-dimensional electric films with conducting layers are thermoformed into three-dimensional shapes. During thermoforming, the substrate and printed layers will experience plastic strain leading to elongation (see Figure 1). The conductive layer's resistance increases as a function of plastic strain. Designers of electric circuitry should know how much the resistance changes. Using a standardized measurement method ensures comparability of the results.


NOTE 1 The top image shows a 2D substrate and ink stack after printing and cure.

NOTE 2 The bottom image shows a substrate and ink stack after thermoforming into a 3D shape. The ink layers have been elongated.

**Figure 1 – Substrate with ink stack in 2D (top) and 3D (bottom) shape**

# PRINTED ELECTRONICS –

## Part 202-10: Materials – Resistance measurement method for thermoformable conducting layer

## 1 Scope

This part of IEC 62899 defines terminology and measurement methods for the resistance change of conductive ink layer(s) as a function of thermoplastic elongation. The method measures resistance changes in-situ or post-elongation.

This document is applicable to thermoformable substrates with conductive ink layers. The thermoformable substrates can have printed graphic ink as well and cover insulation layers.

## 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, *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 terminology databases for use in standardization at the following addresses:

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

**3.1**
**in-mould-electronics**
**IME**
3D circuit manufactured by integrating and embedding printed electronics and electronic components within shaped structures

Note 1 to entry: Manufacturing steps include, but are not limited to, printing, surface mounting, thermoforming and injection moulding.

**3.2**
**thermoforming**
process of shaping heated thermoplastic sheets or other articles, generally on a mould, followed by cooling

Note 1 to entry: In this document, the test structures are elongated in the measurement equipment; they are not thermoformed on a mould.

[SOURCE: ISO 472:2013, 2.1172, modified – Note 1 has been added.]

**3.3**
**thermoformable substrate**
substrate made of a material that deforms irreversibly when subjected to heating and force

**3.4**
**conductive ink**
fluid in which one or more conductive materials are dissolved or dispersed, and which is used to form an electrically conductive structure

[SOURCE: IEC 62899-202-7:2021, 3.1, modified – "printable fluid intended for printing in which one or more molecules, polymers, or particles" is changed to "fluid in which one or more conductive materials" and "which becomes an electrically conductive layer by post treatment such as heating" is changed to "and which is used to form an electrically conductive structure".]

**3.5**
**graphic ink**
composite material containing colorants, functional components, vehicle and additives

Note 1 to entry: In most cases, it is applied as a fluid to a substrate by a printing process and setting or drying by either physical (evaporation) and/or chemical (polymerizations e.g., oxidation, radiation induced, or other) processes in order to form an image for decorative, informative or technical purposes.

Note 2 to entry: Functional components are materials in the graphic ink that add or enhance its characteristics.

Note 3 to entry: Graphic ink forms visual layers after post treatment such as heating.

[SOURCE: ISO 2834-2:2015, 3.5, modified – the term "printing ink" is changed to "graphic ink", Note 2 and Note 3 are added.]

**3.6**
**insulation layer**
film-like structure formed by printing or coating of insulator ink on a substrate, which can become electrically insulating after post treatment

[SOURCE: IEC 62899-204:2019, 3.3, modified – "insulating layer" is changed to "insulation layer" and "electrically insulating body made of insulator ink, which is printed or coated on a substrate, followed as necessary by the application of a post treatment such as heating" is changed to "structure formed by printing or coating of insulator ink on a substrate, which can become electrically insulating after post treatment"]

**3.7**
**ink stack**
combination of ink layers printed on a substrate

Note 1 to entry: Ink layers can include graphic ink layers and conductive layers, or conductive layers only. A stack can also include an insulation layer.

**3.8**
**elongation**
increase of length of a test piece

[SOURCE: ISO 1924-3:2005, 3.3]

**3.9**
**elongation at break**
percent elongation of a test piece at rupture

[SOURCE: ISO 1382:2020, 3.171, modified – in the term, "ultimate elongation" has been removed.]

**3.10**
**plastic strain**
plastic strain component of a controlled strain

Note 1 to entry: The strained specimen does not return to its original size and shape after the deforming force has been removed.

[SOURCE: ISO 23718:2007:2007, 1.6.28, modified – in the term, the symbol has been removed and Note 1 is added.]

**3.11**
**glass transition temperature**
temperature where a polymer substrate changes from a rigid glassy material to a soft (not melted) material, and is usually measured in terms of the stiffness, or modulus

[SOURCE: ISO 11119-2:2020, 3.22, modified – in the term, the symbol has been removed.]

**3.12**
**melting temperature**
temperature at which transition between fully or partially crystalline solid becomes a liquid of variable viscosity, which is indicated by an endothermic peak in the DSC curve

[SOURCE: ISO 15309:2013, 3.4, modified – in the term, the symbol has been removed, Note 1 and Note 2 have been omitted.]



## 4 In-situ resistance measurement method

### 4.1 Measured value

The measured value is the conducting layer resistance change (%) as a function of time (s) or elongation (mm) at specified elongation speed (mm/s) and temperature (°C).

Results include also conducting layer resistance change (%) between pre- and post-elongation at specified elongation (mm) and elongation speed (mm/s). Resistance measurements are made at room temperature (°C).

### 4.2 Test specimen

#### 4.2.1 Ink stack

Select the substrate material that can be elongated at elevated temperatures, i.e., it shall be thermoformable. The substrate shall include conductive ink layers that have been printed and cured in accordance with ink material specifications. The test specimen can also include graphic and insulation layers that have been printed and cured in accordance with ink material specifications. All of these layers shall be thermoformable as well.

The following four types of stacks are permitted:

a) substrate and conductive layer;
b) substrate, graphic layer and conductive layer;
c) substrate, conductive layer and insulation layer;
d) substrate, graphic layer, conductive layer and insulation layer.

The substrate, conductive ink layer, graphic ink layer and insulation layer form an ink stack (see Table 1).

**Table 1 – Test specimen ink stack**

| | Material | Specifications |
|---|---|---|
| Substrate | Thermoformable material | Nominal thickness shall be 0,175 mm or more. The tolerance of the nominal thickness shall be ±10 % for maximum and minimum values. |
| Graphic layer | Thermoformable graphic inks | This layer is optional. If used, select graphic ink materials, layer thicknesses and number of layers. |
| Conductive layer | Thermoformable conductive inks | Select conductive ink materials, layer thicknesses and number of layers. |
| Insulation layer | Thermoformable insulation layer | This layer is optional. If used, select insulation materials, layer thicknesses and number of layers. |

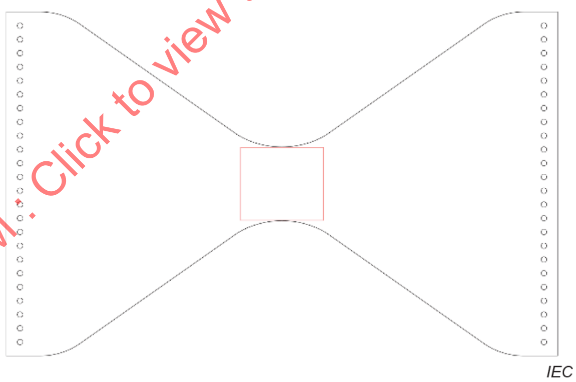
NOTE 1 Films thinner than 0,175 mm can have internal stresses that cause flaws to the thermoformed shapes.

NOTE 2 Test specimen with thicker substrate, for example, > 0,50 mm, will have longer heating times, and temperature distribution can be less homogeneous.

### 4.2.2 Size and shape

The size of the elongated area shall be smaller than the size of the heater element in the measurement apparatus. However, the size of the test specimen can be larger so that it can be fastened into the test specimen holder of the measurement equipment.

The test specimen shape shall be suitable for uniaxial elongation (see Figure 2). The substrate shall be narrower in the elongation area than outside it. This is to concentrate conductive line elongation to the intended area. The substrate also has an hour-glass shape, and its middle is slightly curved. This is to improve uniform elongation of conductive ink lines. See more from Annex B.




NOTE The red rectangle comprises the elongation area.

**Figure 2 – Example of test specimen shape**

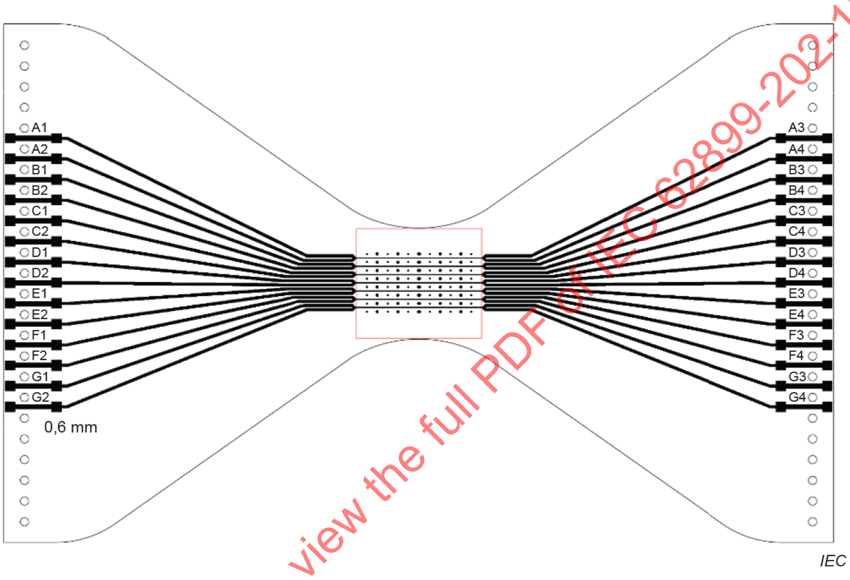
### 4.2.3 Conductive layer layout

All conductive lines shall have the same width in the elongated area. This is to minimize the elongation differences between the conductive lines. Suitable line widths are, for example, 0,3 mm, 0,45 mm, 0,6 mm, 1,0 mm, and 1,5 mm. The line width of 0,3 mm can be suitable only for appropriately stretching conductive inks or for small elongation (e.g., < 20 %). The conductive line width in the test specimen shall be recorded in the test report.

The conductive layer layout shall also include reference dots on both sides of conductive lines in the elongation area. They are used to measure the actual elongation of the conductive lines. The distance between the dots shall be below 10 mm, it can be for example 5 mm. If the test specimen ink stack includes an insulation layer, it shall not hide the reference dots. For example, the insulating layer is transparent or it has openings for the reference dots.

Outside the elongation area, the conductive lines shall be at least two times wider than the conductive lines in the elongated area. This is to concentrate conductive line elongation to the intended area. The conductive line length is defined by sample size. Conductive lines shall make electrical contact with the test specimen holder. In addition, there shall be a clearance between the edge of the substrate and the conductive lines, for example 12 mm. This is to minimize the elongation differences between the conductor lines. Figure 3 shows an example of the layout.

Select the conducting layer thickness from a range that the conductive ink manufacturer has specified. If the conductive ink manufacturer has not specified layer thicknesses, it can be agreed between the user and supplier. Conducting layer thickness values shall be measured from at least three different samples. In each sample, at least both edge lines and the middle line shall be measured. The recommendation is not to measure samples that have been printed sequentially.




NOTE 1 The black lines show the conductive layer.

NOTE 2 The red rectangle comprises the elongated area.

NOTE 3 The conductive layer lines will not necessarily contact the test specimen holder if they are used only for pre- and post-resistance measurements.

**Figure 3 – Example of conductive layer layout**



### 4.3 Measurement apparatus

#### 4.3.1 General

The measurement apparatus consists of elongation equipment and resistance measurement equipment.

#### 4.3.2 Elongation equipment

The elongation equipment shall include:

a) test specimen chamber with holder;
b) heater element with temperature sensors;
c) elongation element.

An example of the elongation equipment is shown Figure 4. The measurement apparatus also includes a cover because measurements shall be made at constant temperature (the cover is not shown in Figure 4).

The test specimen chamber with holder shall isolate the temperature from the ambient temperature so that requirements for the heater element are fulfilled. Figure 5 shows an example of the test specimen holder.

The heater element shall be able to heat the test specimen to the elongation temperature in less than 30 min and hold the temperature at target temperature ± 3 °C.

The elongation element shall be able to define length at constant speed.

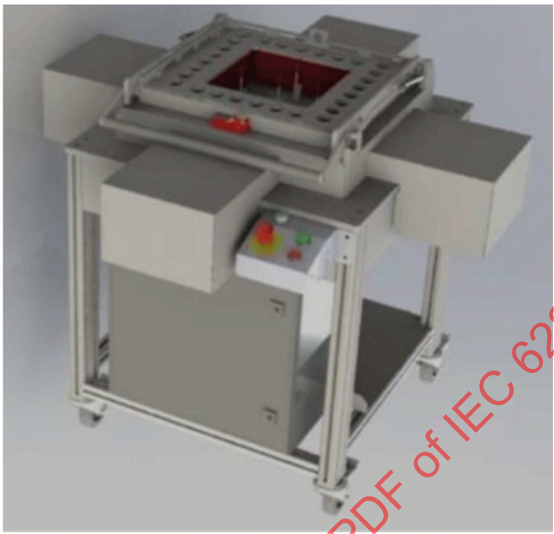


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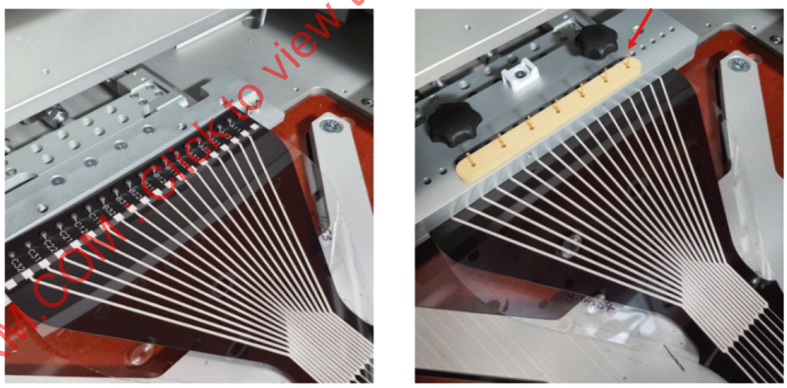
**Figure 4 – Example of elongation equipment**



IEC

NOTE 1 The photo on the left shows how the specimen sample aligns with the bottom part of the holder.

NOTE 2 The photo on the right shows the specimen sample when the top part of the holder is in place. The red arrow points to a pin that the resistance measurement equipment connects to.

**Figure 5 – Example of test specimen holder**

### 4.3.3 Resistance measurement equipment

Resistance measurement equipment shall comply with the test equipment specified in IEC 62899-202. The resistance measurement equipment connects to the test specimen holder. Figure 5 shows an example of the connection. The measurement interval shall be at least 20 divisions of the final elongation length. The measuring equipment shall create a file where resistance values are saved as a function of elongation or as a function of time.

### 4.4 Measurement parameters

#### 4.4.1 Elongation

The measurement range shall be from 0 strain to the specified elongation. The target elongation shall be selected from the following values: 10 %, 15 %, 20 %, 25 %, 30 %, 40 %, 50 %, 75 %, and 100 %. The target elongation shall be recorded in the test report.

#### 4.4.2 Elongation speed

The elongation speed shall be selected from the following values: 2 mm/s, 3 mm/s, 4 mm/s, 6 mm/s, 8 mm/s, and 12 mm/s. At these values, inks elongate in a similar way as in thermoforming. Elongation speed shall be recorded in the test report.

#### 4.4.3 Elongation temperature

The elongation temperatures are substrate material-specific. Select the elongation temperature ($T_E$) from a range that is between the substrate material glass transition temperature and the melting (or thermal decomposition) temperature. The selected elongation temperature shall be suitable also for the printed ink layers and the insulation layer. They shall not decompose at $T_E$. Elongation temperature shall be recorded in the test report. If protective gas medium is used in the elongation equipment chamber, that shall also be recorded.

### 4.5 Measurement procedure

The electrical resistance shall be measured at room temperature before and after elongation. The electrical resistance changes shall also be measured while the test specimen is elongated at a specified temperature.

The measurement procedure is as follows:

a) Measure electrical resistance from the conductive lines at room temperature.

b) Fasten the test specimen to the holder in the horizontal or vertical direction. A small amount of force is applied to the test specimen, so that it does not hang loose during heating.

c) Set the measurement parameters for elongation temperature, elongation speed and target elongation distance. The parameters are defined in 4.4.

d) Wait until the test specimen has reached the elongation temperature (set temperature ± 3 °C).

e) Start in-situ resistance measurement. Then start elongation. Continue elongation and resistance measurement until elongation reaches its set value or until all conductive lines become non-conductive.

f) Stop the resistance measurement.

g) Remove the test specimen from the holder. Avoid touching the heating element during test specimen removal. Alternatively, it is possible to wait until the heating element and the test specimen have cooled to a temperature below 45 °C. Then remove the test specimen from the holder.

h) Measure electrical resistance from the conductive lines at room temperature.

The measured samples shall include at least 30 conductive lines with the same values of line width, elongation temperature, elongation speed and target elongation distance. At least 5 of those shall be in-situ resistance measurements.

### 4.6 Measuring conductive line elongation

The conductive lines do not always have uniform elongation. Thus, their actual elongation shall be measured using the reference dots that are part of the conductive layer layout. Elongation measurement shall be done after the test specimen have cooled down to room temperature.

Measure the distance between adjacent dots on both sides of the conductive lines using an optical microscope or other suitable image acquisition system. Its magnification shall be 10 times or more. Figure 6 shows an example of conductive line elongation measurement between dots. Then add the distances to calculate the line elongation $\Delta L_M$. Use $\Delta L_M$ when calculating the conductive line resistance change $\Delta R$ as function of elongation $\Delta L$.

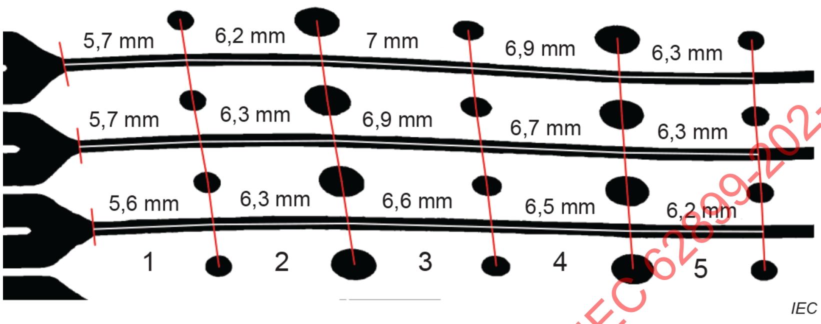



**Figure 6 – Example of measuring conductive line elongation**

The conductive lines can elongate also outside the intended area. Check those areas of conductive lines visually. Other methods, such as X-ray analysis, can also be used. If it is found that elongation can affect conductive line resistance, a note should be made about it.

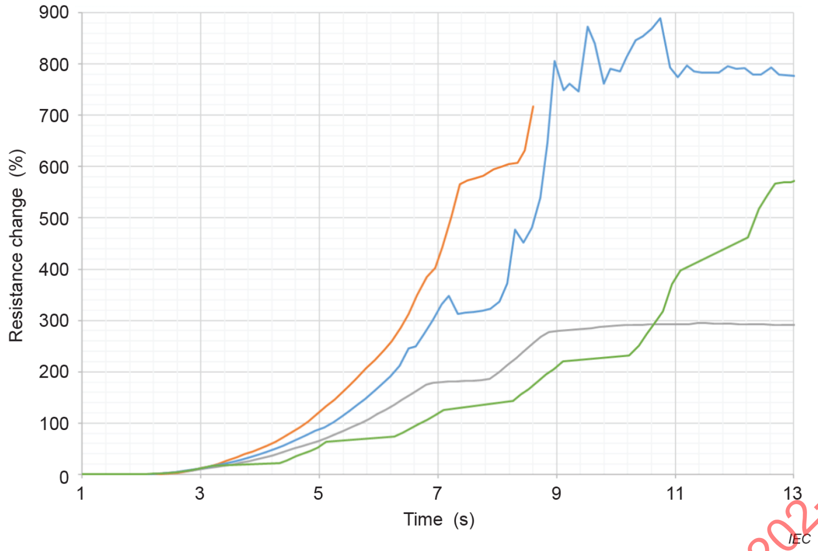
### 4.7 Data analysis

#### 4.7.1 General

All of the analysed samples shall have the same values of line width, elongation temperature, elongation speed and target elongation distance. If any of those parameters change, make a separate analysis.

#### 4.7.2 Calculating results

The measured value is the conductive layer resistance $R$ (Ω) as a function of elongation $\Delta L$ (mm) or function of time $T$ (s). Plot the resistance change $\Delta R$ (%) into a graph as a function of elongation $\Delta L$ (mm) or of time $T$ (s). Figure 7 shows an example.




NOTE The lines show measurements from different samples.

**Figure 7 – Example of conductive line resistance increase (%) as a function of elongation time (s)**



Results include also the conducting layer resistance change (%) between pre- and post-elongation at specified elongation (mm) and elongation speed (mm/s). Resistance measurements are made at room temperature. Calculate the resistance change $\Delta R$ with Formula (1):

$$\Delta R = \frac{R(\Delta L) - R(0)}{R(0)} \tag{1}$$

where

$R(0)$ is the resistance value before elongation at room temperature, expressed in ohms (Ω);

$R(\Delta L)$ is the resistance value after $\Delta L$ elongation at room temperature, expressed in ohms (Ω).

Group the resistance change values for each conductive line according to their measured elongation $\Delta L_M$. An example of grouping is 2,5 % elongation range. Calculate the resistance change values for each group. Table A.2 shows an example. Also make a boxplot of the grouped resistance changes. Figure A.2 and Figure A.3 show examples.

### 4.7.3 Excluding outliers in data analysis

To improve result accuracy, outliers from data analysis should be excluded. Potential outliers show as data points outside ± 3 standard deviation. They can also be identified from boxplots as an asterisk mark, see Figure A.2. Exclude the potential outlier data points from the data analysis if:

- line defects correspond to a potential outlier, see 4.6;
- measurement or data entry errors correspond to a potential outlier.

If a reason cannot be identified for the potential outliers, include them in data analysis.

### 4.8 Measurement report

The measurement report shall include the following items:

a) test specimen information including:
   - description of ink stack (see Table 1);
   - conductive layer layout, showing the conductive lines in the intended elongation area;
   - average thickness and thickness range of conductive lines in the elongated area, as well as number of thickness measurements. Include also at least one profilometry measurement that shows the conductive line cross-sectional area;

b) elongation parameters:
   1) elongation temperature;
   2) use of protective gas medium, when applicable;
   3) elongation speed and target elongation distance;

c) results:
   1) measured line elongation range; also include elongation at electric break, when applicable;
   2) plot of resistance changes during elongation as a function of elongation or time;
   3) analysis of potential outliers, when applicable. This includes number of conductive lines that were excluded from data analysis as outliers and reasons for excluding them;
   4) analysis of resistance changes (before and after elongation) at room temperature;

d) date of the measurements.

The measurement report should also include test specimen material characteristics that are considered important for result comparison and reuse.

## 5 Pre-and post-elongation resistance measurement method

### 5.1 Measured value

The measured value is the conducting layer resistance change (%) between pre- and post-elongation at specified elongation (mm) and elongation speed (mm/s). Resistance measurements are made at room temperature (°C).

### 5.2 Test specimen

The test specimen has a uniaxial elongation shape. The ink stack is the same as in 4.2.1. The size of the elongated area is the same as in 4.2.2. The conductive layer layout is similar to 4.2.3, except that the conductive lines do not have to contact the test specimen holder.

### 5.3 Measurement apparatus

#### 5.3.1 Elongation equipment

The elongation equipment shall include:

a) test specimen chamber with holder for mechanical fastening;

b) heater element with temperature sensors;

c) elongation element.

The test specimen chamber with holder shall isolate the temperature from ambient temperature so that requirements for the heater element are fulfilled.

The heater element shall be able to heat the test specimen to the elongation temperature in less than 30 min and hold the temperature at target temperature ± 3 °C.

#### 5.3.2 Resistance measurement equipment

Resistance measurement equipment shall comply with the test equipment specified in IEC 62899-202.

### 5.4 Measurement parameters

Measurement parameters are the same as in 4.4.

### 5.5 Measurement procedure

The electrical resistance shall be measured at room temperature before and after elongation.

The measurement procedure is as follows:

a) Measure the electrical resistance from the conductive lines at room temperature.
b) Fasten the test specimen to the holder in the horizontal or vertical direction. A small amount of force is applied to the test specimen, so that it does not hang loose during heating.
c) Set the measurement parameters for elongation temperature, elongation speed and elongation distance. The parameters are defined in 4.4.
d) Wait until the test specimen has reached the elongation temperature (set temperature ± 3 °C).
e) Start elongation and maintain it to the set distance.
f) Remove the test specimen from the holder. Avoid touching the heating element during test specimen removal. Alternatively, it is possible to wait until the heating element and the test specimen have cooled to a temperature below 45 °C. Then remove the test specimen from the holder.
g) Measure the electrical resistance from the conductive lines at room temperature.

The measured samples shall include at least 30 conductive lines with same values of line width, elongation temperature, elongation speed and target elongation distance.

### 5.6 Measuring conductive line elongation

Conductive line elongation measurement is same as in 4.6.

### 5.7 Data analysis

#### 5.7.1 General

All of the analysed samples shall have the same values of line width, elongation temperature, elongation speed and target elongation distance. If any of those parameters change, make a separate analysis.

#### 5.7.2 Calculating results

The reported value is the resistance change $\Delta R$ between pre- and post-elongation values. Calculate the resistance change $\Delta R$ with Formula (1).

Group the resistance changes for each conductive line according to their measured elongation $\Delta L_{\mathrm{M}}$. An example of grouping is 2,5 % elongation range. Calculate the average resistance change values for each group and make a boxplot of the grouped resistance changes, as instructed in 4.7.2.

### 5.7.3 Excluding outliers in data analysis

Excluding outliers in data analysis is the same as in 4.7.3.

## 5.8 Measurement report

The measurement report shall include the following items:

a) test specimen information including:
   - description of ink stack (see Table 1);
   - conductive layer layout, showing the conductive lines in the intended elongation area;
   - average thickness and thickness range of conductive lines in the elongated area, as well as number of thickness measurements. Include also at least one profilometry measurement that shows the conductive line cross-sectional area;

b) elongation parameters:
   1) elongation temperature;
   2) use of protective gas medium, when applicable;
   3) elongation speed and maximum elongation distance;
   4) elongation at electric break, when applicable;

c) results:
   1) measured line elongation range and elongation at electric break, when applicable;
   2) analysis of potential outliers, when applicable. This includes number of conductive lines that were excluded from data analysis as outliers and reasons for excluding them;
   3) analysis of resistance changes (before and after elongation) at room temperature;

d) date of the measurements.

The measurement report can also include test specimen material characteristics that are considered important for result comparison and reuse. Annex A shows an example of a measurement report.

# Annex A
(informative)

# Example report for pre- and post-elongation resistance measurement

## A.1 Test specimen information

Description of ink stack:

- substrate: polycarbonate film, thickness 0,375 mm;
- graphic layer: black colour ink;
- conductive layer: silver filled conductive ink.

Conductive layer layout is shown in Figure A.1. Red rectangle shows the intended elongation area. The conductive line width in the intended elongation area is 0,6 mm.



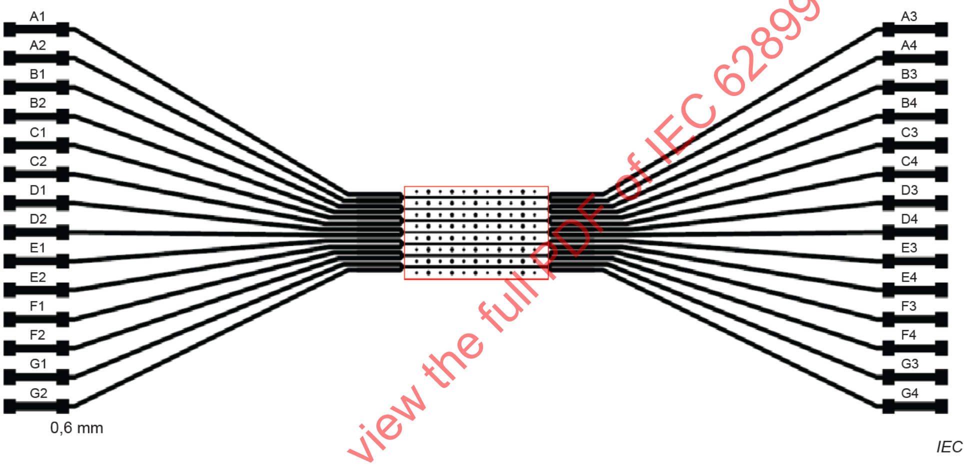



**Figure A.1 – Conductive layer layout**

Average thickness of conductive layer lines in the elongation area is 10,8 µm, the measured values ranging between 7,7 µm and 13,1 µm. Nine conductive lines have been measured.

The average cross-sectional line area is 5 163 µm$^2$. The measured values range between 3 171 µm$^2$ and 6 089 µm$^2$.

## A.2 Elongation parameters

The sample temperature during elongation was between 150 °C and 155 °C.

The target elongation distance was 18 mm (30 %). Elongation speed was 3 mm/s.

## A.3 Results

### A.3.1 Measured line elongation range and elongation at electric break

The measured conductive line elongation varied between 15,0 % and 30,0 %. Twelve conductive lines had electric break during elongation. They are listed in Table A.1.

**Table A.1 – Conductive lines that had electric break during elongation**

| Elongation range (%) | Number of measured lines | Number of lines that had electric break | Elongation at electric break (%) |
|---|---|---|---|
| 15,0 … < 17,5 | 12 | 0 | - |
| 17,5 … < 20,0 | 7 | 1 | 18,5 |
| 20,0 … < 22,5 | 4 | 1 | 22,3 |
| 22,5 … < 25,0 | 5 | 4 | 22,5; 22,8; 23,3; 23,8 |
| 25,0 … < 27,5 | 4 | 4 | 25,0; 25,0; 25,5; 26,7 |
| 27,5 … < 30,0 | 1 | 1 | 28,0 |
| ≥ 30 | 1 | 1 | 30,0 |

### A.3.2 Analysis of potential outliers

Figure A.2 shows boxplots of line resistance changes for different elongation ranges. The boxplots indicate two potential data outliers.

- No reason was detected for the conductive line corresponding to the outlier in the elongation range 15,0 … < 17,5 %.
- The conductive line corresponding to the outlier in the elongation range 17,5 … < 20,0 % had a defect outside the intended elongation area. Thus, this measurement was removed when calculating average resistance changes.

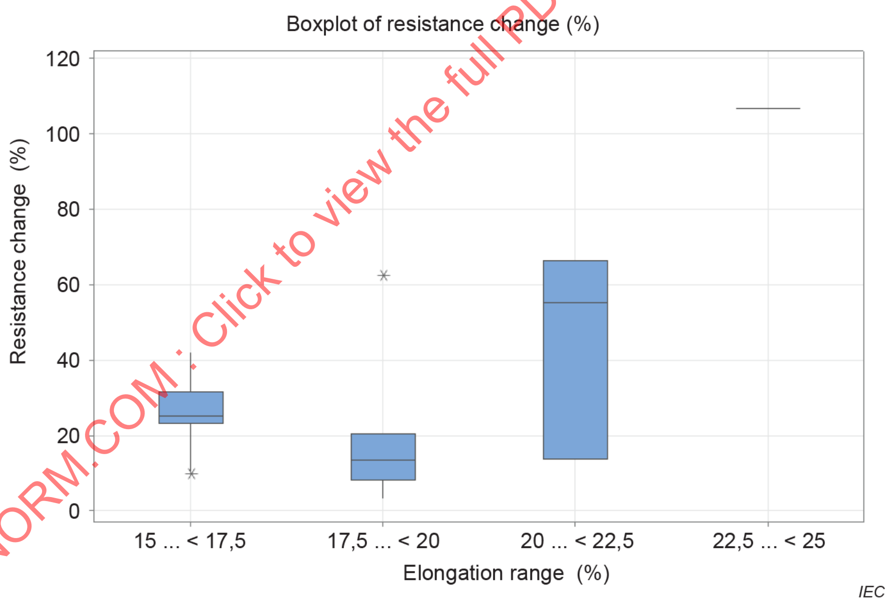


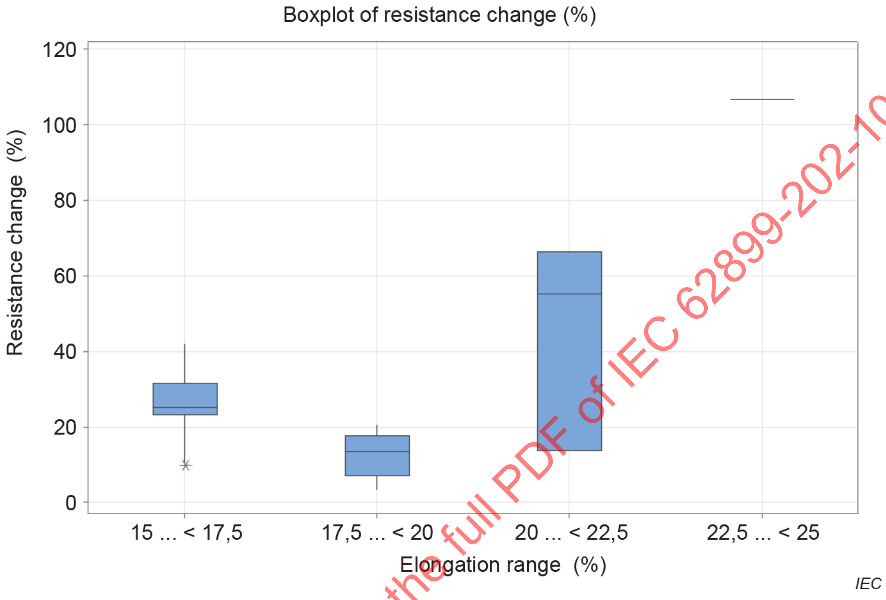

**Figure A.2 – Boxplot of resistance change before outlier analysis**

### A.3.3 Average resistance changes

Table A.2 shows the average resistance changes according to elongation ranges for the conductive lines that did not have electric break. Figure A.3 shows the same data as boxplots.

**Table A.2 – Resistance changes according to line elongation ranges**

| Elongation range (%) | Average resistance change (%) | Standard deviation of resistance change (%) | Number of conductive lines |
|---|---|---|---|
| 15,0 … < 17,5 | 25,8 | 9,5 | 12 |
| 17,5 … < 20,0 | 12,5 | 6,1 | 6 |
| 20,0 … < 22,5 | 45,0 | 28 | 3 |
| 22,5 … < 25,0 | 107 | - | 1 |




NOTE One outlier has been removed

**Figure A.3 – Boxplot of conductive line resistance changes**

## A.4 Date of the measurements

Measurements were made in September 2022.

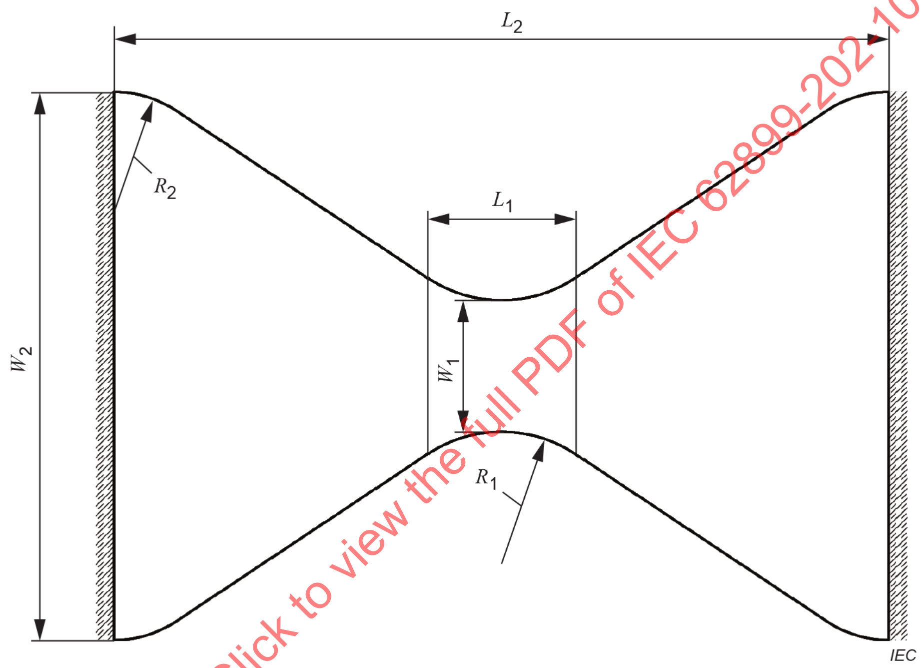
# Annex B
(informative)

# Guidelines for test specimen shape and conductive layer layout

## B.1 Test specimen shape and dimensions

Sample shape should enhance deformation of conductive lines in the intended elongation area and minimize the deformation outside of this area. The test specimen shape should be different from the commonly acknowledged "dumb-bell" shapes. This is because a narrow parallel-sided region in the centre of the test specimen can increase the deformation outside of the intended elongation area. Figure B.1 shows an example of test specimen shape and dimensions.






| Symbol | Dimension (mm) |
|---|---|
| $W_1$ | 55 |
| $W_2$ | 250 |
| $L_1$ | 60 |
| $L_2$ | 350 |
| $R_1$ | 60 |

**Key**

$W_1$ minimum width of the elongation area;

$W_2$ sample width;

$L_1$ length of the elongation area;

$L_2$ sample length (clamp to clamp);

$R_1$ curvature radius of the elongation area.

The regions on the sample sides filled with the hatch pattern represent the regions that are clamped to the holders.

**Figure B.1 – Example of the test specimen shape**