IEC TS 62788-8-1

Edition 1.0 2024-06

TECHNICAL SPECIFICATION

colour inside

Measurement procedures for materials used in photovoltaic modules – Part 8-1: Electrically conductive adhesive (ECA) – Measurement of material properties

IEC TS 62788-8-1:2024-06(en)

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

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

IEC TS 62788-8-1

Edition 1.0 2024-06

TECHNICAL SPECIFICATION

colour inside

Measurement procedures for materials used in photovoltaic modules – Part 8-1: Electrically conductive adhesive (ECA) – Measurement of material properties

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-8735-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 8-1: Electrically conductive adhesive (ECA) – Measurement of material properties

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 62788-8-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/2200/DTS	82/2241/RVDTS

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

The language used for the development of this Technical Specification is English.

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 62788 series, published under the general title *Measurement procedures for materials used in photovoltaic modules*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Electrically conductive adhesive (ECA) is a material composed of conductive fillers blended with an organic adhesive polymer matrix. Already widely used as an interconnect material in electronic packaging and interconnection technologies for electronic devices, ECA is beginning to replace metallic solders as an innovative interconnection method in recent designs of photovoltaic (PV) modules. In a typical shingled PV module, solar cells are cut into strips and these solar cell strips overlap each other. ECA is applied in between the top electrode of one cell strip and the bottom electrode of the adjacent cell strip to form the electric interconnection. In some back-contact PV module designs, ECA allows the interconnection of solar cells' rear busbars to a conductive backsheet. In some PV modules where the solar cells are sensitive to high soldering temperatures, ECA is used to connect PV ribbons to the electrodes of the solar cells. The solar cell interconnections based on ECA can effectively reduce mechanical stress, shading loss and interconnect ohmic loss, and have been profiled as a promising alternative to traditional soldering process.

ECA can be used for wiring and surface assembly in PV modules. Initial performance and environmental endurance in application are highly dependent on its inherent material characteristics. For instance, adhesive properties are the primary requirement for ECA. Good adhesion between ECA and the adherends enables the structural integrity and long-term durability of the bonded joint over its service lifetime. Furthermore, the electrical performances of ECA, including volume resistance and contact resistance, are essential for the output performance and field durability of PV modules. Other characteristics such as viscosity, fineness, and conditions of use have a significant impact on the process conditions in manufacturing.

It is impractical to perform all the tests on ECA at the PV module level. Evaluation of the inherent material characteristics of ECA is highly desirable for pre-qualification of materials. This document defines test methods for key characteristics of ECA intended for use in photovoltaic modules.

The material property tests in this document cover general characteristics, mechanical characteristics, adhesion characteristics, electrical characteristics, thermal characteristics and the conditions of use.

MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 8-1: Electrically conductive adhesive (ECA) – Measurement of material properties

1 Scope

This document defines test methods and datasheet reporting requirements for key characteristics of ECA used in photovoltaic modules, involving mechanical characteristics, adhesive characteristics, electrical characteristics, thermal characteristics, etc.

The object of this document is to offer a standard test procedure to ECA manufacturers for product design, production and quality control, and to PV module manufacturers for the purpose of material screening, material inspection, process control, and failure analysis.

This document is intended to be applied to ECA used in solar PV modules.

For non-conductive adhesives or tapes used in PV modules, the applicable test methods except for electrical characteristics in this document may be used.

2 Normative references

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

IEC 60068-1, *Environmental testing – Part 1: General and guidance*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC TS 62788-2, *Measurement procedures for materials used in photovoltaic modules – Part 2: Polymeric materials – Frontsheets and backsheets*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 37:2017, *Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties*

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

ISO 1524:2020, *Paints, varnishes and printing inks – Determination of fineness of grind*

ISO 2393, *Rubber test mixes – Preparation mixing and vulcanization – Equipment and procedures*

ISO 2811-1, *Paints and varnishes – Determination of density – Part 1: Pycnometer method*

ISO 4587, *Adhesives – Determination of tensile lap-shear strength of rigid–to–rigid bonded assemblies*

ISO 4664-1:2022, *Rubber, vulcanized or thermoplastic – Determination of dynamic properties – Part 1: General guidance*

ISO 5893, *Rubber and plastics test equipment – Tensile, flexural and compression types (constant rate of traverse) – Specification*

ISO 7500-2, *Metallic materials – Verification of static uniaxial testing machines – Part 2: Tension creep testing machines – Verification of the applied force*

ISO 7886-1, *Sterile hypodermic syringes for single use – Part 1: Syringes for manual use*

ISO 8510-2, *Adhesives – Peel test for a flexible-bonded-to-rigid test specimen assembly – Part 2: 180 degree peel*

ISO 10365, *Adhesives – Designation of main failure patterns*

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

ISO 11358-2, *Plastics – Thermogravimetry (TG) of polymers – Part 2: Determination of activation energy*

ISO 11359-1, *Plastics – Thermomechanical analysis (TMA) – Part 1: General principles*

ISO 11359-2:2021, *Plastics – Thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

ISO 16525-1:2014, *Adhesives – Test methods for isotropic electrically conductive adhesives – Part 1: General test methods*

ISO 16525-2:2014, *Adhesives – Test methods for isotropic electrically conductive adhesives – Part 2: Determination of electrical characteristics for use in electronic assemblies*

ISO 17212, *Structural adhesives – Guidelines for surface preparation of metals and plastics prior to adhesive bonding*

ISO 23529:2016, *Rubber – General procedures for preparing and conditioning test pieces for physical test methods*

ASTM D1337-10, *Standard practice for storage life of adhesives by viscosity and bond strength*

ASTM D4287-00, S*tandard Test Method for High – Shear Viscosity Using a Cone/Plate Viscometer*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, together with the following 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
contact resistivity
electrical resistance that is generated on the contact surface between the isotropic electrically conductive adhesive and the adherend

Note 1 to entry: It is expressed in $\Omega \cdot mm^2$.

Note 2 to entry: Contact resistivity is the resistance times the contact area.

[SOURCE: ISO 16525-2:2014, 3.3, modified – deleted <electronic assembly> and interfacial.]

3.2
coefficient of linear thermal expansion
K^{-1}
reversible increase in length of a material per unit length per degree change in temperature

[SOURCE: ISO 11359-2:1999, 3.2]

3.3
electrically conductive adhesive
adhesive consisting of conductive fillers that provide electrical conduction and resin that serves for adhesion

Note 1 to entry: The resin can either be thermoplastic or cross-linked.

[SOURCE: ISO 16525-1:2014, 3.1, modified – deleted isotropic, added note.]

3.4
elongation at break
E_b
tensile strain in the test length at breaking point

[SOURCE: ISO 37:2017, 3.5]

3.5
four-probe method
method for measuring resistance that consists of two terminals for current application and two terminals for voltage measurement

[SOURCE: ISO 16525-2:2014, 3.4]

3.6
fineness
reading obtained on a standard gauge under specified conditions of test, indicating the depth of the groove(s) of the gauge at which discrete solid particles in the product are readily discernible

Note 1 to entry: It is expressed in µm.

[SOURCE: ISO 1524:2020, 3.1, modified – fineness of grind was changed to fineness.]

3.7
lap shear strength
force per unit surface area necessary to bring an adhesive joint to the point of failure by means of stress applied in the longitudinal mode, parallel to the plane of the bond-line

[SOURCE: EN 923:2015, 2.7.18]

3.8
loss normal modulus
loss Young's modulus
E"
component of the applied normal stress, which is 90 degree out of phase with the normal strain, divided by the strain

$$E'' = |E^*| \sin\delta$$

Note 1 to entry: It is expressed in Pa.

[SOURCE: ISO 4664-1:2022, 3.2.7]

3.9
peel strength
force per unit width necessary to bring an adhesive joint to the point of failure or to maintain a rate of failure by means of a stress applied in the peeling mode

[SOURCE: EN 923:2015, 2.7.16]

3.10
pot life
maximum period of time during which the properties of ECA in working conditions could maintain within the specified tolerances

[SOURCE: EN 923:2015, 2.4.24]

3.11
shelf life
time of storage under stated conditions during which an adhesive can be expected to retain its working properties

[SOURCE: EN 923:2015, 2.4.33]

3.12
shingled PV module
solar cell module comprising solar cell strips arranged in a shingled manner

3.13
solids content
percentage by mass of non-volatile matter in a product determined under specified test conditions

[SOURCE: EN 923:2015, 2.4.3]

3.14
elastic normal modulus
storage normal modulus
elastic Young's modulus
E'
component of the applied normal stress, which is in phase with the normal strain, divided by the strain

$$E' = \left|E^*\right| \cos\delta$$

Note 1 to entry: It is expressed in Pa.

[SOURCE: ISO 4664-1:2022, 3.2.6]

3.15
tensile strength
maximum tensile stress recorded in extending the test piece to breaking point

[SOURCE: ISO 37:2017, 3.3]

3.16
test length of a dumb-bell
initial distance between reference points within the length of the narrow portion of a dumb-bell test piece used to measure elongation

[SOURCE: ISO 37:2017, 3.10]

3.17
thixotropic index
ratio of viscosities measured at two shear rates

[SOURCE: ASTM D2556-14:2018, 3.2.2]

3.18
viscosity
property of resistance to steady flow exhibited within the body of the material

Note 1 to entry: It is expressed in mPa·s.

[SOURCE: ASTM D4092-07:2013, 3]

3.19
volume resistivity
electrical resistance of the isotropic electrically conductive adhesive for a given cross-sectional area or given length

Note 1 to entry: It is expressed in Ω·mm.

Note 2 to entry: Volume resistivity is the volume resistance times the cross-sectional area divided by the length of the sample.

[SOURCE: ISO 16525-2:2014, 3.2]

4 Test procedures

4.1 General

Tests shall be carried out under standard atmospheric conditions as described in IEC 60068-1.

ECA is usually stored at a low temperature, and it shall be returned to the experimental ambient temperature before test.

Specimens shall be pre-conditioned under 23 °C ± 2 °C and 50 % ± 10 % RH for at least 4 h, as specified/recommended in ISO 291.

4.2 General characteristics

4.2.1 Visual inspection

4.2.1.1 Purpose

To identify and document visual defects in an ECA.

4.2.1.2 Sampling

ECA is normally supplied in tubular or canned containers. To obtain uniform specimens which are adequately representative of the ECA being sampled, the following procedures shall be applied:

a) For tubular package, the ECA shall be squeezed on a substrate with flat and smooth surface.

b) For canned packaging, open and stir well before visual inspection.

4.2.1.3 Procedure

Inspect the specimens under an illumination of not less than 1 000 lux at a 15 cm to 30 cm viewing distance for the following:

a) colour inhomogeneity;

b) impurities;

c) bubbles;

d) any other phenomenon.

4.2.1.4 Reporting requirements

Report the following information:

a) Note and report the presence or absence of any phenomenon described in the procedure.

b) A photograph is recommended for documentation.

4.2.2 Density

4.2.2.1 Purpose

This test is performed to characterize the density of an ECA.

The density of an ECA can be measured according to ISO 2811-1. The test method consumes a lot of samples and is not suitable for the daily inspection. In this subclause, a test method using a small volume measuring tool, such as a syringe, is described.

4.2.2.2 Apparatus

A syringe with a nominal capacity of less than 5 ml, in accordance with ISO 7886-1.

An analytical balance, accurate to ± 1 mg.

4.2.2.3 Procedure

a) Weigh the empty syringe and record the reading as m_1.

b) Fill the syringe with a suitable amount of ECA from a tubular package. Or draw a suitable amount of ECA into the syringe from a canned package. Ensure no bubbles exist at the interface between the ECA and syringe. If there exist bubbles, push the plunger to push some ECA and all bubbles out. Record the volume reading on the syringe where the plunger is located as V.

c) Weigh the same syringe filled with ECA and record the reading as m_2.

d) Calculate the net weight m of the ECA specimen: $m = m_2 - m_1$.

e) Calculate the density ρ, in grams per cubic centimetre.

f) For each ECA sample, at least three specimens shall be prepared and tested.

4.2.2.4 Result

The density of an ECA specimen can be calculated from Formula (1).

$$\rho = \frac{m}{V} \tag{1}$$

where

ρ is the density of ECA specimen (g/cm^3);

m is the weight of ECA specimen (g);

V is the volume of ECA specimen (ml).

4.2.2.5 Reporting requirements

Report the following information:

a) test equipment information;

b) test condition;

c) specimen quantity;

d) the density of each specimen and the mean value.

4.2.3 Viscosity

4.2.3.1 Purpose

This test is used to measure the viscosity of an ECA. Viscosity affects the production process, and can also be used as an index to evaluate the stability of an ECA during storage and application.

4.2.3.2 Apparatus

The test apparatus shall conform to ASTM D4287-00.

A cone/plate type viscometer, with a viscosity test range from 1 000 mPa·s. to 1 000 000 mPa·s, and viscosity test accuracy of at least 1,0 %. A speed of 0,5 rpm to 5 rpm is recommended for viscosity test of conventional silicone based ECA with a viscosity range of 10 000 mPa·s to 100 000 mPa·s, and the rotor type should be selected according to the device type.

A constant-temperature bath, capable of maintaining a temperature from 5 °C to 80 °C with an accuracy of 0,1 °C.

NOTE cP = 1 mPa·s.

ECA is a non-Newtonian liquid whose shear stress is not linearly related to shear rate, so the data under different shear rates are not comparable. The ECA supplier and the user need to reach an agreement on what kind of equipment and parameters should be used for the test.

4.2.3.3 Procedure

a) Turn on the viscometer and constant-temperature bath, and set the bath temperature to the test temperature, which is recommended to be 25 °C.

b) Install an appropriate type of rotor and specimen cup. Adjust the rotor position to make sure the distance between the rotor and the bottom of specimen cup equal to the clearance recommended by the viscometer manufacturer.

c) Remove the specimen cup, transfer 0,5 ml to 2 ml ECA into the centre of the specimen cup, and make sure no bubbles exist.

d) Install and fasten the specimen cup.

e) Set the rotor speed (η), time length and the data logging mode. It is recommended to use the single-point data logging mode.

f) Test and record the data.

g) For each ECA sample, at least three specimens shall be prepared and tested.

Set an appropriate time length so that the output viscosity value tends to be stable and meets the requirements of the date logging mode. Choose an appropriate rotor and set a proper rotor speed so that the viscosity reading is between 10 % and 90 % of the full scale.

4.2.3.4 Reporting requirements

Report the following information:

a) test equipment information;

b) test condition: rotor type and size, speed, time length, temperature;

c) specimen quantity;

d) the viscosity of each specimen and the mean value.

4.2.4 Thixotropic index

4.2.4.1 Purpose

This subclause defines the method for measuring the thixotropic index of an ECA. The thixotropic index has a profound impact on the printability of an ECA.

4.2.4.2 Apparatus

Refer to 4.2.3.2.

4.2.4.3 Procedure

a) Test the viscosity value at rotational speed η for a specimen.

b) After the test, let the specimen stand for 10 min before another viscosity test.

c) At the same setting, test the viscosity value again at rotational speed 10 η for the same specimen.

d) For each ECA sample, at least three specimens shall be prepared and tested.

4.2.4.4 Result

The thixotropic index of an ECA specimen can be calculated from Formula (2).

$$TI = \frac{viscosity\ @\eta\, rpm}{vicosity\ @10\eta\, rpm} \tag{2}$$

where

TI is the thixotropic index.

4.2.4.5 Reporting requirements

Report the following information:

a) test equipment information;

b) test condition: rotor type and size, speed, time length, temperature;

c) specimen quantity;

d) the thixotropic index of each specimen and the mean value.

4.2.5 Fineness

4.2.5.1 Purpose

The fineness of the ECA describes the size distribution of the discrete electrically conductive particles in the resin filler. This subclause specifies a method for determining the fineness of ECA filler with a suitable gauge.

4.2.5.2 Apparatus

Test apparatus shall meet the requirements in ISO 1524:2020.

The fineness plate shall be made of hardened steel blocks with a suitable dimension, e.g. 175 mm in length, 65 mm in width and 13 mm in thickness.

The scraper shall be made of a single or double blade steel sheet with a recommended dimension of 90 mm in length, 40 mm in width and 6 mm in thickness.

4.2.5.3 Procedure

Test procedure shall meet the requirements in ISO 1524:2020.

For each ECA sample, at least three specimens shall be prepared and tested.

4.2.5.4 Reporting requirements

Record and report the following information:

a) the type of fineness plate;

b) test condition;

c) specimen quantity;

d) the fineness of each specimen and the mean value.

4.3 Mechanical characteristics

4.3.1 Tensile strength / elongation at break

4.3.1.1 Purpose

This subclause is to determine the tensile properties of an ECA.

4.3.1.2 Sampling

Prepare cured ECA films in thickness of 2 mm ± 0,1 mm without bubbles, according to ISO 2393. Then prepare test specimens according to ISO 37:2017, which recommends specimen type 2 (see Figure 1). The test length of the specimen shall be 20,0 mm ± 0,5 mm.

The dimensions of a dumb-bell specimen shall meet the requirements given by the responding die (see Figure 2 and Table 1).

For each ECA sample, at least three specimens shall be prepared and tested.

The test length shall not exceed the length of the narrow portion of the test piece.

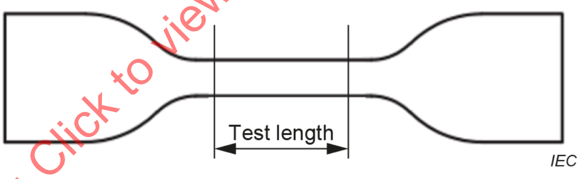


Figure 1 – Shape of dumb-bell test specimen (ISO 37:2017)

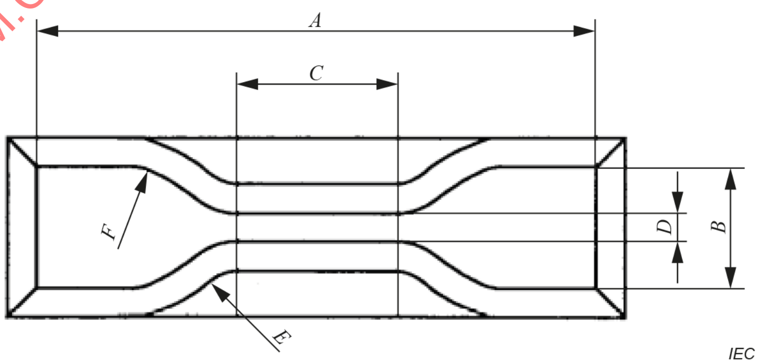


Figure 2 – Die for dumb-bell test specimen

Table 1 – Dimensions of dies for dumb-bell test specimens

Dimension mm		Type 2
A	Overall length (minimum)	75
B	Width of ends	12,5 ± 1,0
C	Length of narrow portion	25 ± 1,0
D	Width of narrow portion	4,0 ± 0,1
E	Transition radius outside	8,0 ± 0,5
F	Transition radius inside	12,5 ± 1,0

4.3.1.3 Apparatus

Test apparatus shall provide the following conditions:

a) Type 2 dumb-bell test specimens in compliance with ISO 37:2017 are recommended.

b) The thickness gauge shall meet the requirements specified in method A of ISO 23529:2016.

c) Tensile testing machine shall meet the requirements of ISO 7500-2 with accuracy of class 1.

d) The extensometer shall have an accuracy in compliance with Class D of ISO 5893.If using a non-contact extensometer, mark the dumb-bell test pieces with two reference marks to define the test length using a suitable marker.

4.3.1.4 Procedure

In the following, a test procedure using a contact extensometer is described. For non-contact extensometers, a similar procedure can be used according to ISO 37:2017.

a) Measure the width and thickness at the centre and at each end of the test length in millimetres with precision of 0,1 mm. Use the median value of the three measurements to calculate the area of the cross-section. In any one dumb-bell, none of the three thickness measurements of the narrow portion shall differ by more than 2 % from the median thickness. The width of the test specimen shall be taken as the distance between the cutting edges of the die in the narrow part.

b) Insert the test specimen into the tensile-testing machine, ensuring that the specimen is gripped symmetrically so that the tension is distributed uniformly over the cross-section. It is strongly recommended that the load cell be reset to zero before each test. If necessary, apply a prestress of 0,1 MPa so that the test piece is not bent when the initial test length is measured. Grippers shall have an inner surface that stably holds the material without piercing and causing any other mechanical damage.

c) Clamp the extensometer on the specimen with 20 mm distance (see Figure 3). There shall be no sign of distortion or damage to the test specimen.

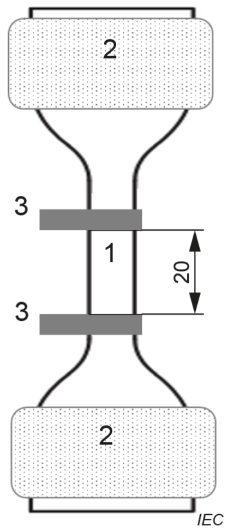
d) Start the machine and monitor the change in length and force until the test part (see 20 mm part in Figure 3) breaks.

e) The speed of the moving grip shall be 100 mm/min ± 10 mm/min.

f) The data shall be discarded and the test shall be repeated if the specimen breaks outside the test length or if there is any slippage between the extensometer grip and the test specimen that significantly affects the test results.

g) At least three specimens shall be tested.

Dimensions in millimetre



Key

1 ECA specimen

2 grip

3 extensometer

Figure 3 – Schematic diagram of tensile strength and elongation at break test

4.3.1.5 Result

The tensile strength can be calculated from Formula (3).

The elongation at break can be calculated from Formula (4).

$$\sigma = \frac{F}{W \times t} \tag{3}$$

$$\varepsilon = \frac{L_t - L_0}{L_0} \times 100\ \% \tag{4}$$

where

σ is the tensile strength (MPa);

F is the force recorded at break (N);

W is the width of the narrow part of the specimen (mm);

t is the thickness of the test piece over the test length (mm);

ε is the elongation at break (%);

L_0 is the initial test length (mm);

L_t is the test length at break (mm).

4.3.1.6 Reporting requirements

Record and report the following information:

a) test equipment information;
b) specimen information: curing condition, dimension, shape and quantity;
c) test condition;
d) tensile strength and elongation at break of each specimen and the median value.

4.3.2 Storage normal modulus and loss normal modulus

4.3.2.1 Purpose

This test is to quantify the storage normal modulus, loss normal modulus and loss factor (tanδ) of ECA. Mechanical modulus directly affects the mechanical coupling between components, including the stress and strain within the module. Results of the test offer great help in the thermal mechanical analysis of PV modules, especially at the interconnection positions, where ECA is the bonding material.

A dynamic test shall be performed to determine the normal modulus of ECA according to ISO 4664-1:2022. In the test, a dynamic force (e.g. a sinusoidal force) is applied to the specimen, and the displacement is measured. ECA is a viscoelastic material, i.e. it shows both an elastic response and a viscous drag when strained. Storage normal E' is the stiffness of the viscoelastic material and proportional to the elastically stored energy while loss normal modulus E'' is proportional to the dissipated energy during the test. Loss factor tanδ is an indication of the ratio between E'' and E'. E', E'' and tanδ can be calculated from Formulas (5), (6) and (7). These properties depend on excitation frequency and temperature. The maximum of the loss factor (tanδ), is a good indicator to identify glass transition when the material behaviour changes from energy-elastic to entropy-elastic.

4.3.2.2 Sampling

Prepare cured ECA films in thickness of 1 mm to 3 mm without bubbles first according to ISO 2393. Cut the ECA film to make test specimen with dimensions about (30 mm to 60 mm) × (3 mm to 12 mm).

The specimen length between two clamps is defined as effective length and shall be controlled within 15 mm to 20 mm.

Sandpapers could be used to smooth the specimen.

For each ECA sample, at least three specimens shall be prepared and tested.

4.3.2.3 Apparatus

A dynamic mechanical thermal analyser (DMA) according to ISO 4664-1:2022.

4.3.2.4 Procedure

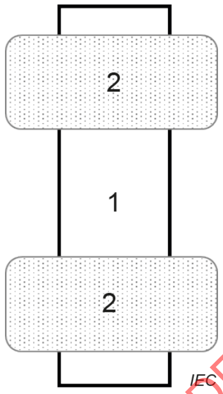
The test shall be performed according to ISO 4664-1:2022 with small-sized test apparatus and tensile mode selected.

a) Measure the width and thickness at the centre and at each end of the test length in millimetres with precision of 0,1 mm. Use the median value of the three measurements to calculate the area of the cross-section. Measure the specimen length between clamps with precision of 0,1 mm.
b) Install the specimen to DMA (see Figure 4).

c) Set test conditions as follows:
   - starting temperature: -70 °C;
   - final temperature: 150 °C;
   - heating rate: 2 °C/min;
   - frequency: 1, 5, 10, 15, 30, 50 Hz, with 1 Hz recommended.

d) A static tensile force (0,1 N recommended) shall be applied to the specimen that is sufficient to prevent buckling of the specimen under the decreasing portion of the superimposed dynamic load. The measurement shall be performed once on each replicate specimen using an applied strain of 0,1 %.

e) Test the specimen.



Key

1 ECA specimen

2 grip

Figure 4 – Schematic diagram of modulus specimen installation

4.3.2.5 Results

The storage normal modulus, loss normal modulus and loss factor can be calculated from Formulas (5), (6), (7).

$$E' = \frac{\Delta L \cdot F}{w \cdot t \cdot L_0} \times \cos\delta \qquad (5)$$

$$E'' = \frac{\Delta L \cdot F}{w \cdot t \cdot L_0} \times \sin\delta \qquad (6)$$

$$\tan\delta = \frac{E'}{E''} \qquad (7)$$

where

ΔL is the measured amplitude of the dynamic displacement (m);

F is the measured amplitude of the dynamic force (N);

w is the specimen width (m);

t is the specimen thickness (m);

L_0 is the specimen length between clamps (m);

δ is the measured phase angle between the stress and the strain (rad);

E' is the storage normal modulus (MPa);

E'' is the loss normal modulus (MPa);

tanδ is the loss factor.

4.3.2.6 Reporting requirements

Record and report the following information:

a) test equipment information;
b) specimen information: curing condition, dimension, quantity;
c) test condition;
d) The results of the test, i.e., the value of the storage normal modulus E', loss normal modulus E'' and the loss factor tanδ, the average of E', E'' and tanδ. Results shall be reported for test temperatures, including at least -40 °C, 25 °C and 85 °C.

4.4 Adhesive characteristics

4.4.1 Lap shear strength

4.4.1.1 Purpose

The purpose of this test is to characterize an ECA's adhesion property by measuring the lap shear strength of a specimen constructed by an ECA and an adherend The test can be classified into two types: on-line and off-line; On-line test is often done by measuring a specimen constructed by an ECA and solar cells, resembling the structure in a shingled PV module. Off-line test is generally used for incoming or outgoing quality control at an ECA supplier by measuring a specimen constructed by an ECA and a metal substrate.

4.4.1.2 Sampling

Refer to Annex A.

For each ECA sample, at least five specimens shall be prepared and tested.

4.4.1.3 Apparatus

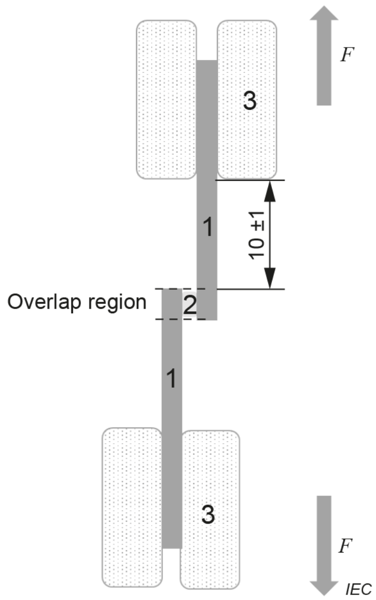
A tensile testing machine, which shall meet the requirements of ISO 7500-2 with accuracy of class 1.

4.4.1.4 Procedure

The procedure shall comply with ISO 4587 as follows:

a) Locate the specimen symmetrically in the grips (see Figure 5), with each grip at 10 mm ± 1 mm from the nearest edge of the overlap region. Rubber spacers can be used in the grips so that the force can be applied evenly across the bonding plane.
b) Operate the tensile-testing machine at a speed of 1 mm/min ± 0,2 mm/min with a data acquisition rate of 10 Hz or greater until the specimen is broken.
c) Measure the length of the adhesive on the broken specimen in millimetres with precision of 0,1 mm. Measure the width of the adhesive on the broken specimen in micrometers with precision of 1 µm.

Dimensions in millimetre



Key

1 cell or metal substrate

2 ECA

3 grip

Figure 5 – Schematic diagram of lap shear strength test

4.4.1.5 Result

Record the highest force during rupture as the breaking force for specimen.

Record the type of failure according to ISO 10365, i.e. adhesive, cohesive or adhesive and cohesive.

The lap shear strength can be calculated from Formula (8).

$$\sigma_s = \frac{F}{L \times W} \tag{8}$$

where

σ_s is the shear strength (MPa);

F is the breaking force at the point of rupture (N);

L is the length of the adhesive (mm);

W is the width of the adhesive (mm).

4.4.1.6 Reporting requirements

Record and report the following information:

a) test equipment information;

b) specimen information: curing condition, overlap dimension, quantity;

c) test condition;

d) lap shear strength of each specimen, the mean value and standard deviation.

4.4.2 Peel strength

4.4.2.1 Purpose

The ECA peel test is used to evaluate the bonding strength between PV ribbon and solar cells, ECA as bonding adhesive. The test can be classified into two types: on-line and off-line. On-line test is generally used to measure the bonding strength between a PV ribbon and a solar cell, resembling the structure in a PV module where ECA is used to bond PV ribbon to a solar cell. Off-line test is normally used for incoming or outgoing quality control at an ECA supplier by measuring the bonding strength between a PV ribbon and a metal substrate, with ECA as bonding material.

NOTE PV ribbon generally is a copper ribbon coated by a certain thickness of tin-based solder. Conductive metal ribbons such as silver can also be used.

4.4.2.2 Sampling

4.4.2.2.1 General

For each ECA sample, at least five specimens shall be prepared and tested.

4.4.2.2.2 On-line test

Prepare a bonded assembly of cell/ECA/PV ribbon as a test specimen. The procedure used for preparing the test specimen is as follows.

a) Print or dispense ECA on the front or rear busbar of a solar cell.
b) Attach a PV ribbon on ECA. Make sure the ribbon is wider than the ECA strip and covers the ECA strip across its width.
c) Use actual production equipment to cure the bonded assembly.

Specimens for test should represent the true level of the final product. Therefore, the specimens shall have the same characteristics including material, structure, and processing parameters.

4.4.2.2.3 Off-line test

In off-line test, metal plates should be used as rigid adherends instead of the solar cells.

The metal surface shall be properly treated to approach the proper conditions, according to ISO 17212 or the requirements from the ECA supplier.

The dimensions of the metal substrate shall be ≥ 200 mm in length, 25 mm ± 0,25 mm in width, 1,6 mm ± 0,1 mm in thickness.

A rectangular PV ribbon is recommended. The dimensions of the PV ribbon shall be ≥ 350 mm in length, 0,4 mm to 0,8 mm in width and 0,2 mm to 0,5 mm in thickness.

The dimensions of the bonding surface shall be 100 mm to 150 mm in length, 0,4 mm to 0,8 mm in width, and 50 µm to 100 µm in the bonding thickness.

Prepare a bonded assembly of metal substrate/ECA/PV ribbon as a test specimen. The procedure used for preparing the test specimen is as follows.

a) Print or dispense ECA on the front of metal plates.
b) Attach a flat PV ribbon with rectangular shape on ECA. Make sure the ribbon is wider than the ECA strip and covers the ECA strip across its width.
c) Use actual production equipment to cure the bonded assembly.

4.4.2.3 Apparatus

A tensile testing machine, which shall meet the requirements of ISO 7500-2, with an accuracy of class 1.

4.4.2.4 Procedure

The peeling strength between the PV ribbon and the solar cell or metal substrate shall be tested at 180° as defined in IEC TS 62788-2. The procedure shall comply with ISO 8510-2 as follows:

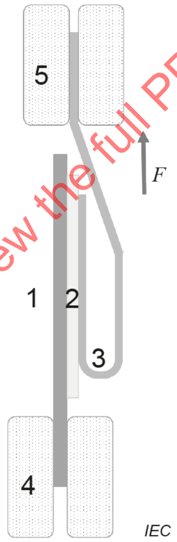
a) Bend back the unbounded end of the PV ribbon.

b) Clamp the solar cell or metal substrate in the fixed grip and the PV ribbon in the other grip. Make sure that the test specimen is accurately positioned between the grips so that the tension applied is distributed uniformly across the width of the test specimen. Rubber spacers can be used in the grips so that the force can be applied evenly across the bonding plane.

c) Operate the tensile-testing machine at a speed of 1 mm/min ± 0,2 mm/min with a data acquisition rate of 10 Hz or greater until the specimen is broken.

d) Measure the width of the adhesive on the broken specimen in micrometers with precision of 1 µm.

Figure 6 is the schematic diagram of peeling strength test.



Key

1 cell or metal substrate

2 ECA

3 flexible PV ribbon

4 fixed grip

5 moving grip (self aligning)

Figure 6 – Schematic diagram of peel strength test (180° peel)

4.4.2.5 Result

Record the highest force during peeling as the peel force of specimen.

Record the type of failure in accordance with ISO 10365, i.e. adhesive, cohesive or adhesive and cohesive.

The peel strength can be calculated from Formula (9).

$$б_{180°} = \frac{F}{w} \tag{9}$$

where

$б_{180°}$ is 180° peel strength (N/mm);

F is the peel force (F);

W is width of the ECA in the bonding area (mm).

4.4.2.6 Reporting requirements

Record and report the following information:

a) test equipment information;
b) specimen information: curing condition, width of the ECA in the bonding area, quantity;
c) test condition;
d) peel strength of each specimen, the mean value and standard deviation.

4.5 Electrical characteristics

4.5.1 Volume resistivity

4.5.1.1 Purpose

Volume resistivity is a key electrical property of ECA. When applied in PV modules, the volume resistivity affects not only the electrical properties of PV modules, but also the reliability of modules.

4.5.1.2 Sampling

Refer to Annex B for sampling.

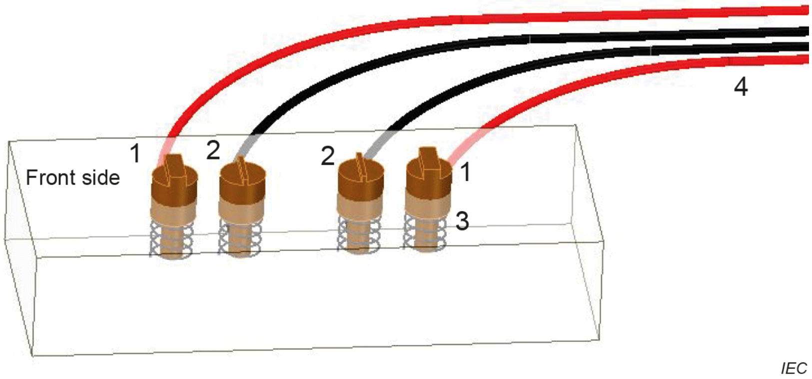
For each ECA sample, at least five specimens shall be prepared and tested.

4.5.1.3 Apparatus

Use a digital ohmmeter with measuring range 0,1 mΩ to 1 MΩ and accuracy of at least 0,1 % according to ISO 16525-2:2014.

Use a four-probe test tooling as below (see Figure 7):

– It shall have two current probes and two voltage probes.
– Four probes shall be fixed into a polypropylene block with spring.
– The distance between two current probes is recommended to be 5,1 cm ± 0,2 mm.
– The distance between the voltage probe and current probe is recommended to be 1,3 cm ± 0,2 mm.
– The width of current probes is recommended to be 2 mm to 10 mm and the width of voltage probes is recommended to be less than 0,5 mm, according to ISO 16525-2:2014.



Key

1 current probes

2 voltage probes

3 spring

4 cable

Figure 7 – Schematic diagram of volume resistivity test tooling

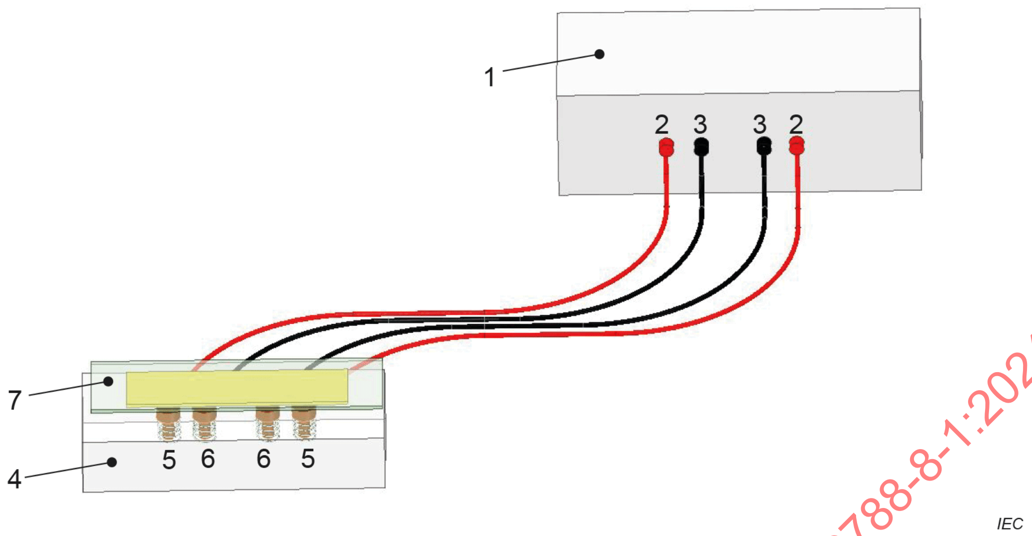
4.5.1.4 Procedure

Follow the test procedure as below:

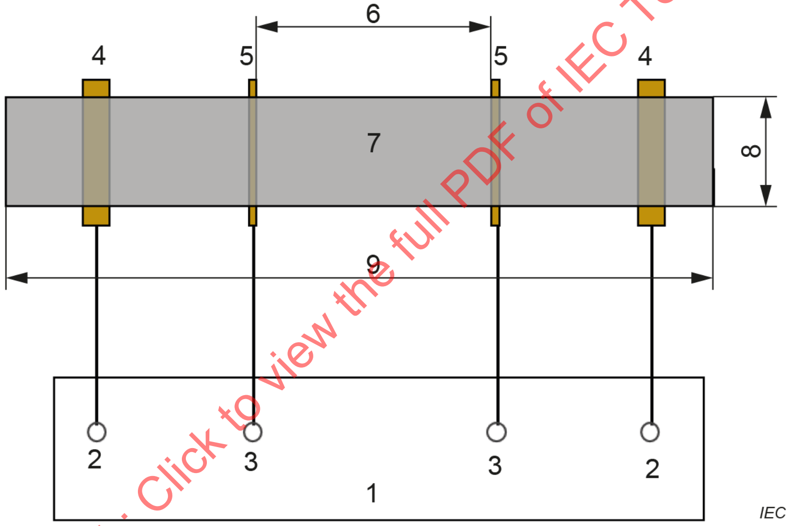
a) Connect the cables of the four-probe tooling to the corresponding ports of the digital ohmmeter. Press the specimen against the front side of the four-probe tooling to ensure good contact between the metal probes and the specimen (see Figure 8).

b) Turn on the digital ohmmeter and do the test. Make sure there is a suitable pressure between the specimen and the tooling to stabilize the resistance test. The minimum contact force of 2,5 N shall be used for each probe. A rigid substrate (plate of plastic) may be used to press the sample to the fixture to ensure good electrical contact. Record the stable resistance value.

c) Measure the width of the ECA strip in millimetres with precision of 0,1 mm. Measure the thickness of the ECA strip in micrometers with precision of 1 µm.



a) **Schematic diagram of test setup**



b) **Schematic diagram of test circuit**

Key

1	digital ohmmeter	6	distance between voltage probes (L)
2	current source terminals	7	ECA specimen
3	voltage measurement terminals	8	width of ECA strip (W)
4	current probes	9	length of ECA strip
5	voltage probes	10	four-probe tooling

Figure 8 – Schematic diagram of volume resistivity test

4.5.1.5 Result

The volume resistivity can be calculated from Formula (10).

$$\rho = R \times \frac{W \times t}{L} \qquad (10)$$

where

ρ is the volume resistivity (Ω·mm);

R is the volume resistance (Ω);

W is the width of the ECA strip (mm);

t is the thickness of the ECA strip (mm);

L is the distance between voltage probes (mm).

4.5.1.6 Reporting requirements

Record and report the following information:

a) test equipment information;

b) specimen information: curing condition, ECA strip dimension, quantity;

test condition;

c) volume resistivity of each specimen, Max, Min, mean and standard deviation;

d) an estimate of the standard uncertainty of R, W, t, L and the combined standard uncertainty of ρ according to 4.2.4 and 5.1.2 of ISO/IEC GUIDE 98-3:2008, respectively.

4.5.2 Contact resistivity

4.5.2.1 Purpose

Contact resistivity is an important parameter to evaluate the quality of the contact between the ECA and the conductive substrate, affecting the electrical performance and reliability of PV modules. Contact can occur in two situations. When ECA is applied to a shingled module, contact occurs between the ECA and the silver electrodes of solar cells. When ECA is used to bond PV ribbons to solar cells, contact occurs between the ECA and PV ribbons. This section describes methods to test both.

4.5.2.2 Sampling

4.5.2.2.1 General

For each ECA sample, at least five specimens shall be prepared and tested.

4.5.2.2.2 Contact resistivity between ECA and silver electrode

Refer to Annex C for sampling.

Recommended ECA strip dimension: 4 cm to 8 cm in length, 4 mm to 6 mm in width, 50 µm to 200 µm in thickness.

4.5.2.2.3 Contact resistivity between ECA and PV ribbon

Refer to Annex D for sampling.

Recommended ECA strip dimension: 4 cm to 8 cm in length, 2 mm to 4 mm in width, 50 µm to 200 µm in thickness.

4.5.2.3 Apparatus

Use a digital ohmmeter with measuring range 0,1 mΩ to 1 MΩ and accuracy of at least 0,1 % according to ISO 16525-2:2014. Use two voltage probes and two current probes to do the measurement, with probes meeting the requirements as follows:

– The tip material shall be beryllium copper plated with gold.

– The diameter of the tip shall be 0,5 mm to 1 mm.

– The probes should have a proper spring to ensure good contact between its tip and the specimen and not damage the specimen.

4.5.2.4 Procedure

4.5.2.4.1 Contact resistivity between ECA and silver electrode

a) Place the sample on a rigid and insulating substrate such as a hard countertop, glass substrate or acrylic substrate, which will prevent the sample from cracking.

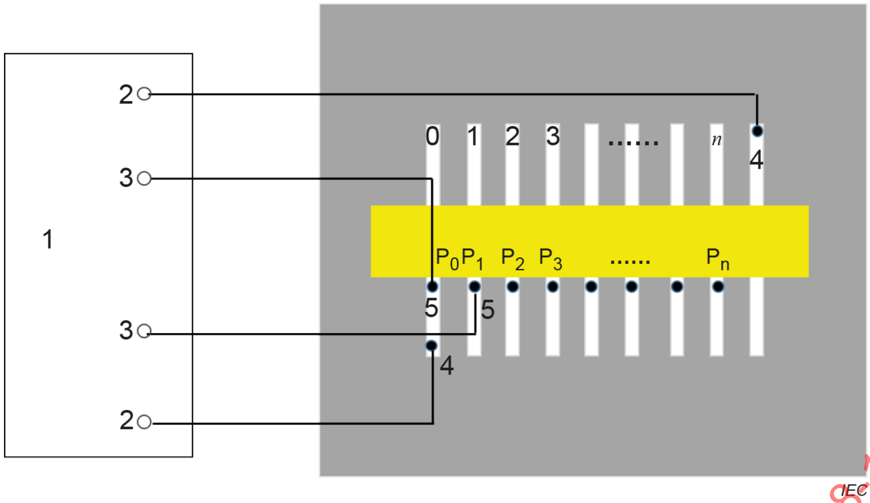
b) Place the current probe I_1 and I_2 at the first silver electrode 0 and the last electrode. Place the voltage probe V_1 at the position P_0 on the first silver electrode (see Figure 9).

c) Place the voltage probe V_2 at position P_1 on the electrode 1, inject current from current probe I_1 and I_2, measure the voltage between voltage probe V_1 and V_2 and record the resistance between probes V_1 and V_2 as R_1. Make sure the resistance value is stable. If the value is not stable, scratch the probe tip against the electrode to test again. If the resistance value is still not stable, replace the probe tip and test again. The distance between electrode 0 and electrode 1 is recorded as L_1, which is equal to L (a fixed length value between neighbouring electrodes). Change the position of probe V_2 to $P_2 \ldots P_n$ in sequence, measure and record the resistance data between probes V_1 and V_2 as $R_2 \ldots R_n$. The distance between electrode 0 and electrode n is recorded as L_n, which is equal to n*L.

d) Plot the L R scatter plot with the data of $L_1 \ldots L_n$ and $R_1 \ldots R_n$. Fit the scatter plot with y = ax + b. Eliminate the outliers using Z score method (see Annex E). After outlier data elimination, if the number of remaining valid data points is less than 2/3 of the original data points or less than 5, the data shall be discarded and the test shall be repeated. Otherwise, fit the remaining valid data with y = ax + b again. If the fitting is poor (R^2 is less than 98 %) or if b is negative, the data shall be discarded and the test shall be repeated. Y-intercept b represents the contact resistance R_C between the ECA strip and the first silver electrode 0 (see Figure 11).

e) Measure the width of the ECA strip in millimetres with precision of 0,1 mm. Measure the width of silver electrode 0 in micrometers by a micrometer caliper with precision of 1 μm. Measure the thickness of the ECA strip in micrometers with precision of 1 μm.

f) Calculate the contact resistivity ρ_C from Formula (12).



Key

1 digital ohmmeter

2 current source terminals

3 voltage measurement terminals

4 current probes I_1, I_2

5 voltage probes V_1, V_2

Figure 9 – Schematic diagram of contact resistivity test between ECA and silver electrode

4.5.2.4.2 Contact resistivity between ECA and PV ribbon

a) Place the sample on a rigid and insulating substrate such as a hard countertop, glass substrate or acrylic substrate, which will prevent the sample from cracking.

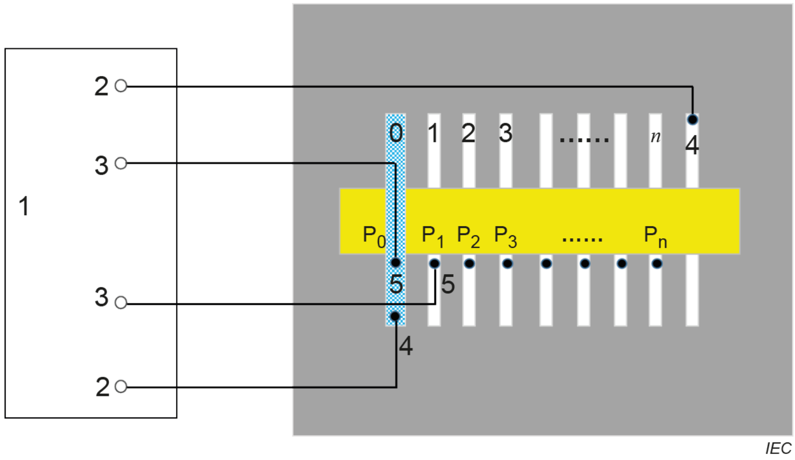
b) Place the probes I_1 and I_2 at the PV ribbon and the last electrode. Place the probe V_1 at the position P_0 on the PV ribbon (see Figure 10).

c) Place the probe V_2 at the position P_1 on the electrode 1, inject the current from probe I_1 and I_2, measure the voltage between probe V_1 and V_2, record the resistance between probes V_1 and V_2 as R_1. Make sure the resistance value is table. If the value is not stable, scratch the probe tip against the PV ribbon or electrode to test again. If the resistance value is still not stable, replace the probe tip and test again. The distance between PV ribbon and electrode 1 is recorded as L_1, which is equal to L (a fixed length value between neighbouring electrodes/PV ribbon). Change the position of probe V_2 to $P_2 \ldots P_n$ in sequence, measure and record the resistance data between probes V_1 and V_2 as $R_2 \ldots R_n$. The distance between PV ribbon and electrode n is recorded as L_n, which is equal to n×L.

d) Plot the L R scatter plot with the data of $L_1 \ldots L_n$ and $R_1 \ldots R_n$. Fit the scatter plot with y = ax + b. Eliminate the outliers using Z score method (see Annex E). After outlier data elimination, if the number of remaining valid data points is less than 2/3 of the original data points or less than 5, the data shall be discarded and the test shall be repeated. Otherwise, fit the remaining valid data with y = ax + b again. If the fitting is poor (R^2 is less than 98 %) or if b is negative, the data shall be discarded and the test shall be repeated. Y-intercept b represents the contact resistance R_C between the ECA strip and the PV ribbon (see Figure 11).

e) Measure the width of the ECA strip in millimetres with precision of 0,1 mm. Measure the width of PV ribbon in micrometers by a micrometer caliper with precision of 1 µm. Measure the thickness of the ECA strip in micrometers with precision of 1 µm.

f) Calculate the contact resistivity ρ_C from Formula (12).



Key

1 digital ohmmeter

2 current source terminals

3 voltage measurement terminals

4 current probes I_1, I_2

5 voltage probes V_1, V_2

Figure 10 – Schematic diagram of contact resistivity test between ECA and PV ribbon

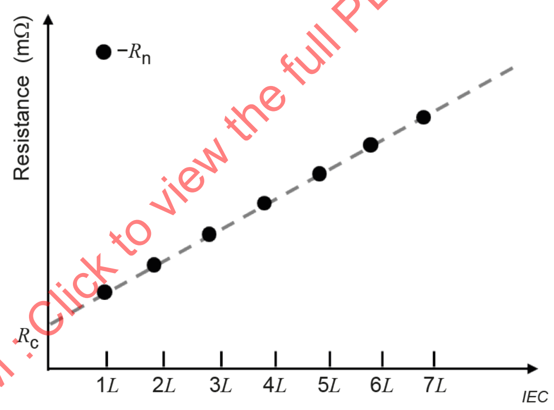


Figure 11 – *LR* scatter plot and linear fit curve

4.5.2.5 Result

The total resistance between probe V_1 and V_2 can be calculated from Formula (11).

The contact resistivity can be calculated from Formula (12).

$$R = R_C + R_{VS} + R_{VE} = R_C + R_{VS} + \frac{\rho_E \times L}{W \times t} \approx R_C + \frac{\rho_E \times L}{W \times t} \ (R_{VS} << R_C) \qquad (11)$$

$$\rho_c = R_C \times W \times W_S \qquad (12)$$

where

R is the total resistance (Ω);

R_C is the contact resistance between ECA and the silver electrode or PV ribbon where probe V_1 is positioned (Ω);

R_{VS} is the volume resistance of the silver electrode or PV ribbon where probe V_1 is positioned (mΩ);

R_{VE} is the volume resistance of ECA (Ω) between probe V_1 and V_2;

ρ_E is the volume resistivity of ECA (Ω·mm);

ρ_C is the contact resistivity of ECA (Ω·mm^2);

L is the distance between neighbouring silver electrodes (mm);

W is the width of ECA strip (mm);

W_S is the width of silver electrode 0 or PV ribbon (mm);

T is thickness of ECA strip (mm).

4.5.2.6 Reporting requirements

Record and report the following information:

a) test equipment information;
b) specimen information: curing condition, ECA strip dimension, quantity;
c) test condition;
d) contact resistivity of each specimen, maximum, minimum, mean and standard deviation;
e) an estimate of the standard uncertainty of R_C and the combined standard uncertainty of ρ_C calculated according to 4.2.4 and 5.1.2 of ISO/IEC GUIDE 98-3:2008, respectively.

4.6 Thermal characteristics

4.6.1 Coefficient of thermal expansion (CTE)

4.6.1.1 Purpose

The purpose of this test is to quantify the coefficient of linear thermal expansion (CTE) for the ECA. The thermal expansion behaviour is necessary to simulate internal strains due to temperature changes for PV module application.

4.6.1.2 Sampling

Prepare cured ECA strip with the dimension of at least 10 mm in length, 5 mm to 6 mm in width and 1 mm to 3 mm in thickness. Specimens shall be cured according to the ECA supplier's specification, using a process as similar as possible to the method used in the ECA user's manufacturing process.

For each ECA sample, at least three specimens shall be prepared and tested.

4.6.1.3 Apparatus

A thermomechanical analyser (TMA) in compliance with ISO 11359-1 shall be used. The TMA may has the capacity to maintain a constant flow of purge gas for the specimen in the range from 0 to 100 ml·min^{-1} throughout the experiment. Typically, an atmosphere of dry air or an inert gas (e.g. nitrogen gas with a purity of 99,99 % or higher) should be used to avoid oxidative degradation during testing.

4.6.1.4 Procedure

The test procedure shall be performed according to ISO 11359-2:2021.

a) Measure the initial specimen length in the direction of the expansion test in millimetres with precision of 0,1 mm.
b) Place the specimen in specimen holder.
c) Apply an appropriate load force to the sensing probe to ensure that it is in contact with the specimen. Depending on the compressibility of the specimen and the temperature range to be investigated, a force of between 1 mN and 200 mN is adequate.
d) The recommended heating procedure for the specimen is as follows:
   - initial temperature: -70 °C;
   - final temperature: 150 °C;
   - heating rate: 5 °C/min;
   - flow rate of purge gas: 50 ml/min recommended;
e) Test the specimen.

4.6.1.5 Results

The differential coefficient of linear thermal expansion at temperature T shall be obtained from the TMA curve using Formula (13);

The mean coefficient of linear thermal expansion between two temperatures T_1 and T_2 shall be obtained from the TMA curve using Formula (14);

$$\alpha = \frac{1}{L_0} \cdot \frac{dL}{dT} = \frac{1}{L_0} \cdot \frac{dL/dt}{dT/dt} \tag{13}$$

$$\bar{\alpha} = \frac{1}{L_0} \cdot \frac{\Delta L}{\Delta T} = \frac{1}{L_0} \cdot \frac{(L_2 - L_1)}{(T_2 - T_1)} \tag{14}$$

where

L_0 is the length of the specimen at room temperature (mm);

ΔL is the difference in length (mm);

ΔT is the temperature difference (K);

α is the differential coefficient of linear thermal expansion (K^{-1});

$\bar{\alpha}$ is the mean coefficient of linear thermal expansion (K^{-1}).

4.6.1.6 Reporting requirements

Report the following information:

a) specimen information: curing condition, dimension, and quantity;
b) environment temperature and humidity;
c) testing parameters;

d) the results of the test, i.e., the value of the differential coefficient of linear thermal expansion α for each specimen, the mean of α and the standard deviation; the value of the mean coefficient of linear thermal expansion $\bar{\alpha}$ for each specimen, the mean of $\bar{\alpha}$ and the standard deviation. Results for α shall be reported for different test temperatures, including at least -40 °C, 25 °C and 85 °C. Results for $\bar{\alpha}$ shall be reported for different temperature range, including at least between -40 °C to 25 °C and 25 °C to 85 °C. In case of a specimen exhibiting a glass transition within the temperature range of measurement, the glass transition temperature and the test curves shall also be obtained and reported.

4.6.2 Solids content

4.6.2.1 Purpose

This subclause is to determine the amount of residual matter of an ECA by analysing the mass change using thermogravimetric method.

4.6.2.2 Apparatus

Use a thermogravimetric anaylzer (TGA) according to ISO 11358-1 and ISO 11358-2, from room temperature to 800 °C to ensure the organic components in the ECA are completely burned. The TGA shall have the capacity to maintain a constant flow of purge gas for the furnace in the range from 20 to 100 ml·min^{-1} throughout the experiment. A dry inert gas (e.g. nitrogen gas with a purity of 99,99 % or higher) should be used as purge gas to avoid hydrolytic degradation during testing.

4.6.2.3 Procedure

a) Tare an empty and clean specimen container.

b) Add a certain amount (5 mg to 10 mg is recommended) of ECA into the tared container.

c) Put the container into the thermogravimetric analyzer and heat the specimen to 800 °C at a constant heating rate of 20 °C/min. For standard TGA furnace, the flow rate of furnace purge gas is recommended to be 60 ml/min and the flow rate of balance purge gas is recommended to be 40 ml/min.

d) At least three specimens shall be tested.

4.6.2.4 Result

The ratio of the residual weight obtained after the test to the initial specimen weight is the solid content.

The solid content can be calculated from Formula (15).

$$m = \frac{m_s}{m_f} \times 100\ \% \tag{15}$$

where

m is the solid content (%);

m_f is the mass at the start (mg);

m_s is the mass at the end (mg).

4.6.2.5 Reporting requirements

Record and report the following information:

a) environment temperature and humidity;
b) testing parameters;
c) the TG curve. The solid content results shall be reported for the average of the replicate measurements.

4.7 Conditions of use

4.7.1 General

For the safe use of ECA, this subclause provides a method to evaluate the shelf life and pot life of an ECA over its life time (see Figure 12).

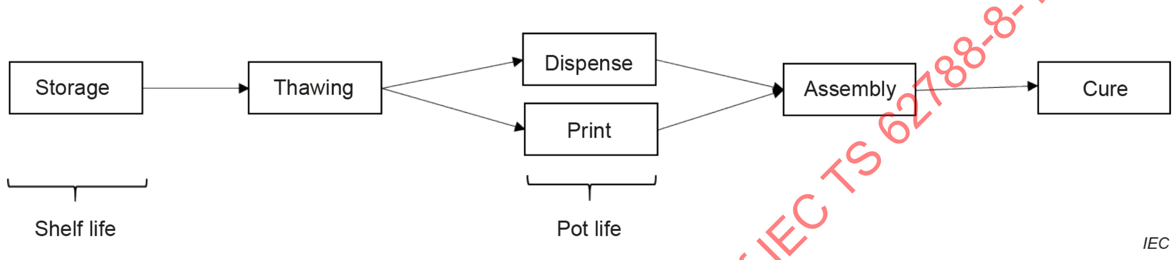


Figure 12 – Schematic diagram of ECA life time at various stages

4.7.2 Shelf life

4.7.2.1 Purpose

This subclause is to determine the shelf life of an ECA by testing the change of viscosity, adhesive and electrical characteristics before and after storage.

The storage conditions shall be agreed upon between the ECA supplier and the user.

Test the shelf life of an ECA according to ASTM D1337-10.

If multiple test methods for each characteristic are available, select the appropriate method which are most relevant to the applications. For instance, for ECA usage in shingled modules, lap shear strength test is a better choice compared to peeling test for adhesive characteristic.

The ECA samples need to be stored under specified storage conditions recommended by the ECA supplier

4.7.2.2 Apparatus

See 4.2.3.2 for viscosity test.

See 4.4.2.3 for adhesive characteristics test.

See 4.5.1.3 and 4.5.2.3 for electrical characteristics test.

4.7.2.3 Procedure

Measure the viscosity, adhesive characteristics and electrical characteristics of the ECA as freshly received, and after being subjected to storage at various intervals of time (normally in unit of days).

See 4.2.3.3 for the viscosity test on both the freshly received and stored ECA samples.

See 4.4.1.4 or 4.4.2.4 for the adhesive characteristics test on both the freshly received and stored ECA samples.

See 4.5.1.4 and 4.5.2.4 for electrical characteristics test on both the freshly received and stored ECA samples.

4.7.2.4 Result

The tolerable ranges for viscosity, adhesive characteristics and electrical characteristics of an ECA shall be agreed upon between the ECA supplier and user.

The shelf life is defined as the maximum storage time (normally days) during which all the viscosity, adhesive characteristics and electrical characteristics of stored ECA still remain within the tolerable range.

4.7.2.5 Reporting requirements

Record and report the following information:

a) storage conditions: temperature, humidity;
b) test values of viscosity, adhesive characteristics and electrical characteristics of the ECA under different storage time;
c) appearance changes of the ECA under different storage times: precipitation, discoloration, delamination, etc.
d) the determined shelf life.

4.7.3 Pot life

4.7.3.1 Purpose

By measuring the changes in viscosity, adhesive characteristics and electrical characteristics of an ECA before and after use to determine the pot life of the ECA under specified working conditions, which shall be agreed upon between the ECA supplier and the user.

4.7.3.2 Sampling

The ECA samples need to be placed under prescribed working conditions.

4.7.3.3 Apparatus

See 4.2.3.2 for viscosity test.

See 4.4.2.3 for adhesive characteristics test.

See 4.5.1.3 and 4.5.2.3 for electrical characteristics test.

4.7.3.4 Procedure

Measure the viscosity, adhesive characteristics and electrical characteristics of the ECA, as freshly received and after being subjected to prescribed working conditions at various intervals of time (normally in unit of hour).

See 4.2.3.3 for viscosity test.

See 4.4.1.4 or 4.4.2.4 for adhesive characteristics test.

See 4.5.1.4 and 4.5.2.4 for electrical characteristics test.

4.7.3.5 Result

The tolerable ranges for viscosity, adhesive characteristics and electrical characteristics of the ECA shall be agreed upon between the ECA supplier and user.

The pot life is defined as the maximum working time (normally hours) during which all the viscosity, adhesive characteristics and electrical characteristics of the ECA still remain within the tolerable range.

4.7.3.6 Reporting requirements

Record and report the following information:

a) pot conditions: temperature, humidity;

b) test values of viscosity, adhesive characteristics and electrical characteristics of the ECA under different pot time;

c) appearance changes of the ECA under different pot times: precipitation, discoloration, delamination, etc.

d) the determined pot life.

5 Uniform characterization form (UCF)

5.1 Purpose

The uniform characterization form for an ECA provides an extensive overview of the general, mechanical, electrical and thermal characteristics that are related to manufacturing and use of the ECA.

5.2 Details of the UCF

The UCF shall be given as an overview table of results according to Table 1. In the completed document, the table shall include the details of the test conditions which defined by the reporting requirements per test item. The items shall be referenced by the UCF number in the first column of the table. Temperature dependent material properties need to be reported as required in the standard.

Table 2 defines the requirements of ECA status (uncured or cured) for different test items.

Table 2 – Uniform characterization form (UCF) for an ECA

UCF number	Test name	Reference	Uncured specimens	Cured specimens
1	Visual inspection	4.2.1	√	—
2	Density [g/cm^3]	4.2.2	√	—
3	Viscosity [mPa·s]	4.2.3	√	—
4	Thixotropic index	4.2.4	√	—
5	Fineness [µm]	4.2.5	√	—
6	Tensile strength [MPa] Elongation at break [%]	4.3.1	—	√
7	Storage normal modulus and loss normal modulus[MPa]	4.3.2	—	√
8	Lap shear strength [MPa]	4.4.1	—	√

UCF number	Test name	Reference	Uncured specimens	Cured specimens
9	Peel strength [N/mm]	4.4.2	—	√
10	Volume resistivity [Ω·mm]	4.5.1	—	√
11	Contact resistivity [Ω·mm^2]	4.5.2	—	√
12	Coefficient of thermal expansion [K^{-1}]	4.6.1	—	√
13	Solids content [%]	4.6.2	√	—
14	Shelf life [d]	4.7.2	√	—
15	Pot life [h]	4.7.3	√	—

5.3 Reporting requirements

The UCF shall be prepared by the ECA manufacturer, based on the results of a test agency having competence of testing and calibration. The UCF shall at least contain the required results of material characterization tests, and may also contain results of optional characterization tests. Furthermore, an UCF shall include at least the following information:

a) title;
b) name and address of the test laboratory and location where the tests were carried out;
c) unique identification of the report and each of its pages;
d) name and address of client, where appropriate;
e) description and identification of the item tested;
f) characterization and condition of the test item;
g) date of receipt of test item and date (s) of test, where appropriate;
h) identification of test method used;
i) reference to sampling procedure, where relevant;
j) any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific test;
k) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate;
l) statement of the estimated uncertainty of the test results (where relevant);
m) a signature and title, or equivalent identification of the person (s) accepting responsibility for the content of the report, and the date of issue;
n) where relevant, a statement to the effect that the results relate only to the items tested;
o) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

6 Data sheet

6.1 Purpose

Data sheet is a simplification of UCF. It provides an overview of critical technical characteristics material data from the uniform characterization, which will directly affect the use of the ECA and the performance of PV module.

6.2 Details of the data sheet

The datasheet shall be given as tabular overview of results according to Table 3. The table defines the critical technical characteristics of the ECA and defines the requirements of ECA status (cured/uncured) for different test items.

Table 3 – Minimum required characteristics for the datasheet

UCF number	Test name	Reference	Uncured specimens	Cured specimens
3	Viscosity [mPa·s]	4.2.3	√	—
5	Fineness [µm]	4.2.5	√	—
8	Lap shear strength [MPa]	4.4.1	—	√
9	Peel strength [N/mm]	4.4.2	—	√
10	Volume resistivity [Ω·mm]	4.5.1	—	√
11	Contact resistivity [$\Omega \cdot mm^2$]	4.5.2	—	√
14	Shelf life [d]	4.7.2	√	—

6.3 Reporting requirements

The data sheet shall be prepared by the ECA manufacturer, based on the results of a test agency having competence of testing and calibration. The datasheet shall at least contain the required results of material characterization tests, and may also contain results of optional characterization tests. Furthermore, the datasheet shall include at least the following information:

a) title;
b) name and address of the test laboratory and location where the tests were carried out;
c) unique identification of the report and each of its pages;
d) name and address of client, where appropriate;
e) description and identification of the item tested;
f) characterization and condition of the test item;
g) date of receipt of test item and date (s) of test, where appropriate;
h) identification of test method used;
i) reference to sampling procedure, where relevant;
j) any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific test;
k) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate;
l) statement of the estimated uncertainty of the test results (where relevant);
m) a signature and title, or equivalent identification of the person (s) accepting responsibility for the content of the report, and the date of issue;
n) where relevant, a statement to the effect that the results relate only to the items tested;
o) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

7 Product identification sheet (label)

The following information is required on the product identification sheet:

a) product name or part number;
b) name, address and contact information of the manufacturer or importer;
c) shelf life and recommended storage conditions;
d) transportation conditions and their maximum duration, if deviating from storage conditions.

Annex A
(normative)

Sampling for lap shear strength test

A.1 Sampling for on-line test

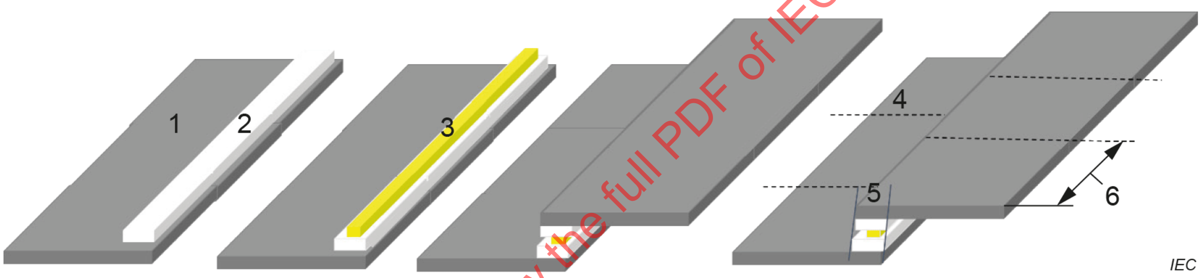
a) Dispense or print certain amount of ECA on the busbar of the first cell. The ECA strip width shall be 300 µm ± 50 µm.

b) Cover the dispensed or printed ECA with the busbar of a second solar cell. The overlap width shall be 1 mm ± 0,1 mm (see Figure A.1).

c) Use actual production equipment to cure the bonded assembly.

d) Cut the bonded assembly to the required dimension for test. The test specimen width shall be 20 mm ± 2 mm.

Specimen for test shall represent the true level of the final product. Therefore, the specimen shall have the same characteristics including material, structure, and processing parameters with the final product from manufacturing process. It is recommended to cut directly from the shingled cell string (see Figure A.2 and Figure A.3).



Key

1 solar cell

2 silver electrode

3 ECA strip

4 cutting line

5 the overlap width

6 test specimen width

Figure A.1 – Schematic sampling diagram of lap shear strength test (on-line)

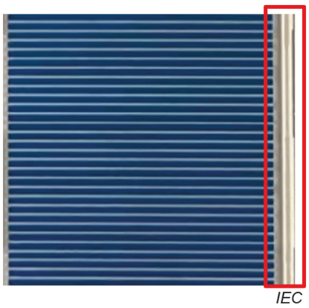


Figure A.2 – Picture of ECA on the top of the electrode of a solar cell

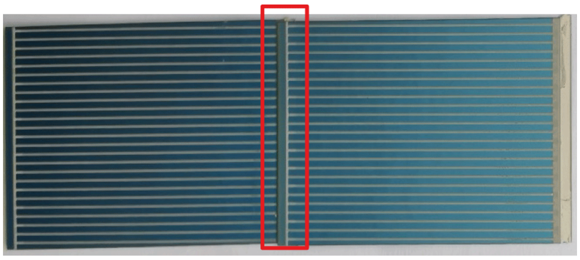


Figure A.3 – Picture of a final specimen slice cut from the bonded assembly

A.2 Sampling for off-line test

a) Use a metal substrate and pre-treat its surface according to ISO 17212.

b) The metal substrate shall be 100 mm ± 0,25 mm in length, 25 mm ± 0,25 mm in width and 1,6 mm ± 0,1 mm in thickness according to ISO 4587.

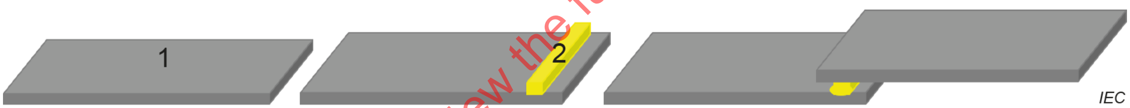
c) Dispense or print a certain amount of ECA on the first metal substrate with a distance of 5 mm to 10 mm from the edge. The ECA strip shall be 1 mm to 2 mm in width and 50 µm to 100 µm in thickness.

d) Cover the dispensed or printed ECA with a second metal substrate (see Figure A.4).

e) The overlap width of two metal substrates shall be 6 mm ± 0,2 mm.

f) Cure the structure to get the final specimen.

NOTE Specimens for on-line test are made by equipment while for off-line test are made by hand. Therefore, the overlap dimension of off-line specimens is set to be larger than that of on-line specimens to ensure the accuracy.



Key

1 metal substrate

2 ECA strip

Figure A.4 – Schematic sampling diagram of lap shear strength test (off-line)

Annex B
(normative)

Sampling for volume resistivity test

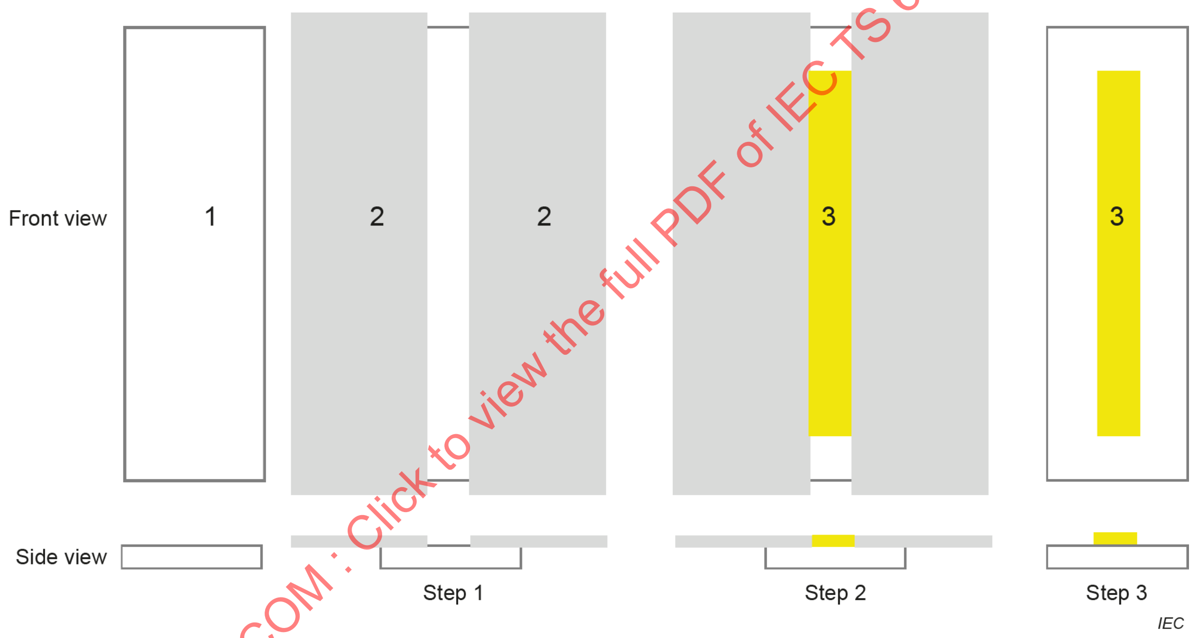
Make specimen on a glass slide substrate with 5 cm to 8 cm in length, 3 mm to 6 mm in width and 50 µm to 200 µm in thickness. Use a tape with thickness between 50 µm to 200 µm and uniformity of ± 10 % (including surface roughness) to control the thickness of the specimens.

a) Stick two strips of tape to the glass surface to make a groove with desired width and depth (see Figure B.1). 3M 244 masking tape is recommended.

b) Fill ECA in the formed groove and level the ECA with a scraper. See 4.2.5.2 for scraper specifications.

c) Peel off the tapes slowly and properly to ensure the ECA strip left has a flat and smooth surface and no air bubbles.

d) Cure the ECA strip under specified conditions recommended by the ECA supplier. See also Figure B.2.



Key

Step 1: stick tapes to form groove;

Step 2: fill ECA in the groove and level it;

Step 3: peel the tape and cure the ECA;

Step 4: trim the ends (<5 mm from the edges) to ensure thickness uniformity along the length by removing the ends.

1 Glass slide

2 Tape

3 ECA strip

Figure B.1 – Schematic sampling diagram of volume resistivity test