IEC TS 62788-2

Edition 2.0 2024-07

TECHNICAL SPECIFICATION

colour inside

Measurement procedures for materials used in photovoltaic modules –
Part 2: Polymeric materials – Frontsheets and backsheets

IEC TS 62788-2:2024-07(en)

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MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

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FOREWORD

IEC TS 62788-2 has been prepared by IEC Technical Committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

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

a) With revision of IEC 61730-1 the requirements for the polymeric front- and backsheet have been moved from IEC 61730-1 into IEC 62788-2-1. This is reflected accordingly.

b) The tensile testing method has been refined based on findings of round robin tests, including updated drawings.

c) A thermal pre-exposure method has been introduced to be equivalent to the thermal effects of a "lamination" cycle. This pre-exposure defines the "fresh" state of the front- or backsheet in final application for evaluation of changes in ageing tests. For practical reasons, an oven exposure has been defined as an equivalent test.

d) The multiple functions of the lamination protrusion test (previously DTI test) have been clarified, to identify and measure RUI layer thickness as well as to identify layers for which the comparative tracking index (CTI) needs to be determined. Also the content of IEC 62788-2-1 has been updated, by which the lamination protrusion test and MST 04 are additionally set in perspective to each other via engineering judgement.

e) The DC breakdown voltage test method has been updated and the option to perform a withstand voltage test has been added (to reduce the required measurement voltage). The correction of DC breakdown voltage (V_{BD}) measurements, needed in the presence of non-RUI layers and after the lamination protrusion test, has been defined more precisely.

f) Details for thickness measurement have been added (engineered surface roughness due to embossing).

g) The adhesion test methods have been reviewed and updated. The single cantilevered beam test has been added. Figures have been updated to align with IEC 62788-1-1.

h) The thermal failsafe test has been added as a test method based on discussion in the parallel project for IEC 62788-2-1. The test method offers a single temperature-point evaluation to include elongation at break to the thermal endurance evaluation.

i) A sequential UV/TC test ("solder bump test") has been added.

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

Draft	Report on voting
82/2109/DTS	82/2169/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,
- replaced by a revised edition, or
- amended.

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MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 2: Polymeric materials – Frontsheets and backsheets

1 Scope

This part of IEC 62788 defines test methods and datasheet reporting requirements for safety and performance-related properties (mechanical, electrical, thermal, optical, chemical) of non-rigid polymeric materials intended for use in terrestrial photovoltaic modules as polymeric front- and backsheets.

The test methods in this document define how to characterize front- and backsheet materials and their components in a manner representative of how they will be used in the module, which eventually includes combination with other matched components such as encapsulants or adhesives. It is impractical to conduct all characterization and endurance tests for the front- or backsheet component on the module level. Instead, testing is performed directly on these components or on dedicated test coupons prepared under comparable processing conditions (i.e. lamination) as for PV modules.

Results of testing described in this document are called by IEC 62788-2-1 for safety qualification of polymeric front- and backsheets on component level and support the safety and performance-related tests defined on the PV module level as defined in the series IEC 61730 (for safety) and IEC 61215 (for performance). This document also defines test methods for assessing inherent material characteristics of polymeric front- and backsheets or their components, which can be required in datasheet reporting or can be useful in the context of product development or design of PV modules.

Backsheets provide the electrical insulation at the backside of a photovoltaic (PV) module under the environmental stress factors and use conditions encountered during the intended lifetime of the module. Frontsheets have the same function at the sun-facing side of the module. Both can be made from glass or polymeric material.

Polymeric front- and backsheets are typically compositions of layered materials, such as films, adhesives or coatings, in which at least one material layer delivers the relied-upon insulation (RUI) for electrical safety. Other layers can provide extended protection of the RUI against the environmental factors or adhesive functionality. As an integral part of the PV module, the front- or backsheet provides their durable electrical insulating function in the presence of the other components of the PV module, such as solar cells, electrical circuits and connectors, encapsulant, sealing material, and junction boxes. These elements can introduce additional stresses on the front- or backsheet (e.g. by chemical interactions or introducing thermal load or mechanical stress) or alter environmental stresses (e.g. filtering of ultraviolet radiation reaching the sun-facing side of the backsheet).

Material characterization in this document is performed on unaged samples (after a thermal pre-exposure) or after accelerated ageing including thermo-oxidative ageing (thermal endurance and failsafe tests), hydrolytic ageing (damp heat), photolytic ageing (UV weathering), abrasion, and sequential UV ageing plus thermal cycling.

Rigid polymeric sheet materials (also providing mechanical support) can require further consideration, which is outside the scope of this document.

2 Normative references

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

IEC 60050-581, *International Electrotechnical Vocabulary – Part 581: Electromechanical components for electronic equipment*

IEC 60050-826, *International Electrotechnical Vocabulary – Part 826: Electrical installations*

IEC 60112, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

IEC 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

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

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

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

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

IEC 60243-2, *Electric strength of insulating materials – Test methods – Part 2: Additional requirements for tests using direct voltage*

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60664-1, *Insulation co-ordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61215-2, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

IEC 61730-1, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

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

IEC 62788-1-4, *Measurement procedures for materials used in photovoltaic modules – Part 1-4: Encapsulants – Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off wavelength*

IEC 62788-1-5, *Measurement procedures for materials used in photovoltaic modules – Part 1-5: Encapsulants – Measurement of change in linear dimensions of sheet encapsulation material resulting from applied thermal conditions*

IEC 62788-2-1, *Measurement procedures for materials used in photovoltaic modules – Part 2-1 Polymeric materials – frontsheet and backsheet – Safety requirements*

IEC 62788-6-2, *Measurement procedures for materials used in photovoltaic modules – Part 6-2: General tests – Moisture permeation testing of polymeric materials*

IEC TS 62788-6-3, *Measurement procedures for materials used in photovoltaic modules – Part 6-3: Adhesion Testing of Interfaces within PV Modules*

IEC TS 62788-7-2, *Measurement procedures for materials used in photovoltaic modules – Part 7-2: Environmental exposures – Accelerated weathering tests of polymeric materials*

IEC 62790, *Junction boxes for photovoltaic modules – Safety requirements and tests*

IEC 62805-2, *Method for measuring photovoltaic (PV) glass – Part 2: Measurement of transmittance and reflectance*

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

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

ISO 527-3, *Plastics – Determination of tensile properties – Part 3: Test conditions for films and sheets*

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

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

ISO 1520, *Paints and varnishes – Cupping test*

ISO 2409, *Paints and varnishes – Cross-cut test*

ISO 2813, *Paints and varnishes – Determination of gloss value at 20 degrees, 60 degrees and 85 degrees*

ISO 4593, *Plastics – Film and sheeting – Determination of thickness by mechanical scanning*

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

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

ISO 11664-1, *Colorimetry – Part 1: CIE standard colorimetric observers*

ISO 11664-2, *Colorimetry – Part 2: CIE standard illuminants*

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

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

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

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

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

ISO 17223, *Plastics – Determination of yellowness index and change in yellowness index*

ISO 22007-4, *Plastics – Determination of thermal conductivity and thermal diffusivity – Part 4: Laser flash method*

ASTM D374, *Standard Test Methods for Thickness of Solid Electrical Insulation*

ASTM D7869, *Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings*

UL 746B, *Standard for Polymeric Materials – Long Term Property Evaluations*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-581, IEC 60050-826, IEC 60664-1, IEC 61140, IEC 61730-1, and IEC TS 61836, together with the following, apply.

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

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

3.1
abrasion resistance
ability of a material to withstand mechanical action such as rubbing, scraping, or erosion, which tends to progressively remove material from its surface

Note 1 to entry: See IEC 62788-7-3 for abrasion testing methods.

3.2
adhesive failure
de-bonding occurring between the adhesive and the adherent, to be differentiated from cohesive failure within the adhesive material

Note 1 to entry: See also Annex B.

3.3
air-side
side of the front- or backsheet oriented towards the outside of the PV module, i.e., away from the cells

3.4
backsheet
BS
(combination of) outer layer(s) of the PV module, located as substrate on the back of the PV module (designed for prolonged use only with indirect or limited direct sunlight < 300 W/m^2) and providing protection of the inner components of the PV module from external stresses and weather elements, as well as providing electrical insulation

3.5
breakdown voltage
V_{BD}
DC voltage at which electric breakdown occurs under prescribed test conditions, or in use

Note 1 to entry: Breakdown voltage testing in the context of PV modules and component materials applies direct current (DC).

[SOURCE: IEC 60050-212:2010, 212-11-34, modified – added symbol, added "DC" in the definition, and added Note 1 to entry.]

3.6
cohesive failure
crack propagating within the adhesive during adhesion test, e.g., peel test

3.7
comparative tracking index
CTI
numerical index value related to the maximum voltage that a material can withstand without formation of a permanent and electrically conductive carbon (tracking) path and without a persistent flame occurring, when evaluated under specified test conditions defined in IEC 60112

Note 1 to entry: The mentioned maximum test voltage is not in conjunction with any system or operational voltage, but it is used for evaluation of material groups.

[SOURCE: IEC 60050-212:2010, 212-11-59, modified – The definition has been rephrased by also clarifying that CTI is an index value to evaluate material groups according to IEC 60112. Note 1 to entry has also been added.]

3.8
directions of films, specimens and cracks

3.8.1
machine direction
MD
direction along which the material layer was extruded or produced, extending out of a die or other manufacturing equipment in a production line

3.8.2
transverse direction
TD
direction perpendicular to which the material layer was extruded or produced

3.9
distance through insulation
t_{DTI}
thickness of relied-upon insulation (RUI) after the lamination protrusion test, with the minimum allowable value defined by the maximum working voltage

3.10
elongation at break
ε_B
strain at which the specimen under test breaks

3.11
frontsheet
FS
(combination of) outer layer(s) of the PV module designed for prolonged exposure to direct sunlight (> 300 W/m^2) and providing protection of the inner components of the module from external stresses and weather elements, as well as providing electrical insulation

3.12
inner side
side of the front- or backsheet that is oriented to the solar cells, typically laminated to the encapsulant

3.13
material group
category of insulation materials according to IEC 60664-1 as defined by the results of the CTI test

3.14
polymeric material
materials that are either natural or synthetic and are primarily composed of chained molecules of monomers, combinations of monomers, and combined polymers and may contain cross-linking agents, fillers, colorants, and other materials

3.15
release material
rm
film material that is inserted in a layer stack before lamination to render inactive the adhesion between interfaces

Note 1 to entry: Examples of suitable release materials are fluoropolymer sheets (e.g. PTFE, FEP, ETFE) as well as silicon treated sheets.

3.16
relied-upon insulation
RUI
solid insulation system providing protection against electric shock in the final application, with the material's requirements for thermal endurance and resistance against environmental stress factors

Note 1 to entry: Thin-films used as polymeric front- or backsheet can consist of RUI plus additional layers that have other functions, e.g., they protect the polymeric materials from UV radiation.

3.17
relative thermal endurance index
RTE
numerical value of the Celsius temperature expressed in degrees Celsius at which the estimated time to endpoint of an insulating material is the same as the estimated time to endpoint of a control material at a temperature equal to its assessed thermal endurance

[SOURCE: IEC 60050-212:2010, 212-12-14, modified – Abbreviated term added and notes to entry omitted.]

3.18
relative temperature index
RTI
temperature index of an insulating material or system obtained from the time which corresponds to the known temperature index of a reference material or system when both are subjected to the same ageing and diagnostic procedures in a comparative test

[SOURCE: IEC 60050-212:2010, 212-12-12]

3.19
sun-facing side
side of the front- or backsheet that is oriented in direction of the sun-facing front side of the PV module

3.20
temperature index
TI
numerical value of the Celsius temperature expressed in degrees Celsius characterizing the thermal capability of an insulating material or an insulation system

[SOURCE: IEC 60050-212:2010, 212-12-11, modified – Notes removed.]

3.21
tensile strength at break
σ_B
maximum engineering stress measured when a specimen is elongated in tension to the point of breaking

3.22
transparent release material
TRM
release material with an AM1.5 photon weighted total transmission value of ≥ 85 % in the range 280 nm to 2 500 nm as well as in the range 300 nm to 400 nm

Note 1 to entry: Example of a suitable UV transparent release material is ETFE (ethylene tetra-fluoroethylene) and perfluorinated ethylene propylene copolymer (FEP) film, both as pure formulations without UV absorbers and 50 µm to 125 µm in thickness.

3.23
water vapour transmission rate
WVTR
rate of water vapour transport through the material per unit area induced by a unit vapour pressure difference under specified temperature and humidity conditions

4 Test procedures

4.1 General

4.1.1 Purpose

Test procedures in this document are designed to evaluate properties of front- or backsheets, or individual (sub)layers relied upon for insulation. Adhesion tests are provided to probe the adhesion strength between various front- or backsheet layers. Procedures for environmental stress exposures are included, with a schedule for post-stress evaluation testing.

Purposes for which the data are intended to be used include:

- Evaluation of requirements for front- or backsheets as described in IEC 62788-2-1;
- Supplier driven comparison of front- or backsheet properties;
- Quality control testing of incoming backsheets used in PV module production;
- Guide to front- or backsheet product development.

The user is guided to be mindful of the purpose of testing, as not all tests will be useful for all purposes. Recommendations for a data sheet are provided in the uniform characterization form (UCF) provided in Clause 5.

This document stipulates ageing tests on engineering samples containing front- or backsheet materials for the purpose of component endurance characterization. These tests are conducted on representative coupon samples, and may provide results different from modules aged in similar accelerated test conditions due to, e.g., different sample sizes, which can impact the mechanical stresses, or interactions with other components in the PV module. Correlation of results from accelerated tests with failures observed in the field has not been fully established due to limited data sets.

Ensure that film material is representative and does not exhibit damage due to proximity to the roll's surface, e.g., due to local mechanical impact during transport, or due to pressure marks or deformations from film splices.

Cut samples should be marked to indicate the manufacturing direction (MD) and the sun-facing sides of the film, such that subsequently smaller samples and test panels can be prepared with well-defined orientation.

4.1.2 Sample pre-treatment

During PV module manufacturing, the polymeric front- or backsheet undergoes a lamination cycle, which may introduce physical relaxation and/or re-crystallization of the polymer material. This may change the mechanical properties and impact the results of ageing tests, where retention of aged versus initial material properties is evaluated. For this reason, a pre-treatment of candidate materials is appropriate before some of the tests.

Three options for pre-treatment are considered:

1) No pre-treatment;
2) Thermal pre-treatment. If no conditions are specified in the data sheet, the thermal pre-exposure shall be set to 10 min at 150 °C; otherwise, the most severe lamination conditions as defined by the product datasheet are used.
3) A combination of heat (as above) and atmospheric pressure. Temperature and duration are as described in option 2); the pressure level is ideally set by the recommended lamination pressure, but in the absence of a laminator, heating with a weighted sample may be considered.

Recommendations for pre-treatment depend on the tested property and are provided in each procedure. Properties which are tested for qualification according IEC 62788-2-1 typically require a thermal pre-treatment. An overview is provided in Table A.2.

After thermal pre-exposure, the material is conditioned at 23 °C ± 2 °C and 50 % ± 5 % relative humidity RH, as in ISO 291 according to the requirements of the test procedure that follows.

4.1.3 Type of sample constructions

Test methods can be performed on different type of sample constructions (see also Table A.1):

1) Individual (sub)layers of front- or backsheet (A0);
2) Complete front- or backsheet (A1);
3) Coupons (B-L);
4) Mini-modules (M).

The various test methods in this document describe the required type of sample construction. More details on sample constructions for coupons and mini-modules can be found in Annex A. The remainder of this Clause 4 highlights aspects relevant for individual (sub)layers and complete front- or backsheets.

To provide a basis for understanding which materials should be tested given the variety of front- and backsheet designs, Table 1 provides an overview of typical front- and backsheet "building blocks".

Table 1 – Overview of typical front- and backsheet building blocks

	Front- or backsheet construction					
layer	**single layer**		**multilayer**[a]			
type	**monolithic**	**combined**[b]	**coated**		**laminated**	
building blocks	homogenous material composition of the base polymer and the additive package across extruded layer	Non-homogenous material composition across the layer, e.g., gradients of the same or different base polymer(s) and/or additive packages that are combined into one single layer, typically produced by co-extrusion	single layer (as coating base)	coated layer by extrusion coating (from polymer melt) or coating from water-based or solvent-based formulations coating typically provides UV protection in application and/or adhesive function to the encapsulant	single layers (combined by lamination)	adhesive layer(s) to form a durable multilayer sheet in a lamination process adhesives typically provide mechanical function (physical integrity of multilayer film) in application
process	one-step-integrated production process.		production process with more than one step, e.g., sequential combination of single layers by lamination and/or application of a coating layer onto a single layer.			

[a] Includes coated layers, laminated layers and combinations of coated and laminated layers.

[b] Combined layers cannot easily be separated.

Requirements for (testing of) front- and backsheet constructions including (combined) single-layer and multi-layer constructions are described in IEC 62788-2-1. Specific layers within a front- or backsheet which are intended for use as relied-upon insulation (RUI) have individual requirements. A subset of the included test methods are targeted at individual layers, these include thermal endurance and breakdown voltage (for basic or reinforced insulation).

For monolithic single-layer materials, there is no distinction between the individual layer and the complete front- or backsheet.

For combined single-layer materials, for example co-extruded films of different polymer base materials, it is acknowledged that the properties of the final product may depend on the combination of process parameters and material formulation, that cannot easily be separated or simulated on a laboratory scale in a representative way. In most cases, test methods can be performed on the complete front- or backsheet. In specific cases, for example in the case of a non-linear Arrhenius plot for thermal endurance, samples of individual (sub)layers are required and engineering judgement is needed in view of compatibility and interaction (e.g., cross-migration) of combined materials, and how process conditions effect residual stresses and crystallinity.

For (laminated) multilayer materials, the individual layer materials are sampled before final film integration. For coated multilayer materials, deactivation of the coating process (e.g., slot/cascade or similar depending on viscosity of coating formulation and/or extrusion coating) at the start or end of a batch is an option to produce material for test without coating.

Before planning of the test program, the construction of the front- or backsheet is defined by the manufacturer, including layer structure, layer thickness values, and layer materials. Cross-sectioning and microscopic characterization are suitable for layer stack characterization (see methods described for evaluation of the lamination protrusion test). This information is of particular relevance for the thermal endurance test and to define the relied-upon insulation.

4.2 Mechanical characteristics

4.2.1 General

The tests shall be conducted under the Class 2 standard atmospheric conditions of ISO 291, unless otherwise specified.

4.2.2 Thickness

4.2.2.1 Purpose

This test is performed in order to characterize the thickness of the front- or backsheet. The thickness value is also used to calculate the breakdown strength.

The method provides an upper limit of thickness in the presence of material surface structuring, e.g. "engineering roughness" introduced by embossing.

4.2.2.2 Apparatus

Use a thickness measuring device capable of measuring to the following accuracies (or better):

- $d \leq 100$ µm with accuracy ± 1 µm;
- 100 µm < $d \leq 250$ µm with accuracy ± 2 µm;
- $d > 250$ µm with accuracy ± 3 µm.

The measuring surfaces of the device shall comprise plane faces and the surfaces shall be polished.

The diameter of each face shall be between 2,5 mm and 10 mm and they shall be parallel to within 5 µm. The force applied to the measuring face shall be 0,5 N to 1,0 N.

4.2.2.3 Procedure

Pre-treatment by heat with pressure (option 3 in 4.1.2) is recommended for samples expected to show compression during lamination. Any subsequent tests which use thickness as input shall use the same pre-treatment option.

Condition the specimens for at least 1 h at 23 °C ± 2 °C and 50 % ± 5 % RH, as in ISO 291.

Follow the procedure in ASTM D374 that gives an established method to quantify the thickness of insulator materials.

Ensure that the specimens and the faces of the measuring device are free from contamination (e.g., dust) by cleaning/blowing the surfaces with pressured air or nitrogen.

Check the zero point of the measuring device before starting the measurements and recheck after each series of measurements.

When determining the thickness, lower the measuring surface gently to avoid deforming the material.

Determine the thickness of the specimens at points equally spaced along the length of the specimen for the minimum of 10 points. Measurement shall not be taken within 50 mm of the edges of the roll.

4.2.2.4 Reporting requirements

Report the mean of the individual thickness measurements, to the nearest 1 µm or 0,001 mm and the standard deviation (± 1 σ) of the measurement.

4.2.3 Area weight

4.2.3.1 Purpose

This test is performed to characterize the front- or backsheet by its area weight.

4.2.3.2 Sampling

Sample three test specimens each having square dimensions of 100 mm × 100 mm from the left, center, and right of the roll, excluding the 50 mm closest to the edge.

4.2.3.3 Apparatus

Use a balance with an accuracy of 10^{-4} g.

4.2.3.4 Procedure

No pre-treatment is needed.

Conduct the test according to ISO 536.

Condition the specimens for at least 1 h at 23 °C ± 2 °C and 50 % ± 5 % RH, as in ISO 291.

4.2.3.5 Reporting requirements

Report the mean weight of the film in g/m² and the standard deviation (± 1 σ).

4.2.4 Tensile properties

4.2.4.1 Purpose

Cracking of the backsheet in field use has been observed, related to ageing induced embrittlement. Tensile strength and elongation at break values are related to cracking and are therefore used as pass/fail criteria in safety qualification in IEC 62788-2-1.

Tensile strength and elongation at break testing can be applied after ageing tests to check for the mechanical durability of the material.

Different results are typical for different orientations of the same material. It is recommended that both the machine direction (MD) and transverse machine direction (TD) are evaluated.

For front- or backsheets intended for use in cold climates with extended periods of sub-zero temperatures, measurements performed at low temperatures may be useful.

4.2.4.2 Sampling

Specimens shall be cut as 10 mm ± 1 mm strips. Alternative strip widths are 12,5 mm ± 1 mm or 15 mm ± 1 mm. The length (L) of the strips shall be at least 70 mm long to address the practical limitation of specimen size in specimen holders of weathering test chambers (see 4.10), but preferably L is 100 mm. The initial sample length between the grips (L_0) is set to 50 mm ± 0,5 mm. For materials with elongation at break greater than 200 %, (L_0) can be reduced to 25 mm (see Figure 1).

Dumbbell shaped specimens may also be used. If a dumbbell shaped sample it used, it shall conform to ISO 527-3 and the tensile properties shall be determined using only the area between the gauge marks using an optical method.

Comparison of results before and after a given ageing test (see 4.10) shall be based on the same initial grip distance and specimen dimensions.

For each measurement, prepare at least five specimens per orientation (MD and TD). Cut or punch the specimens so that the edges are smooth and free from notches.

Tensile break, characterized by tensile strength and elongation at break, is frequently a defect-driven process, and the cutting method can produce defects, which may impact the results. Examples of such artefacts include jagged edges (at a micro-level) for materials with brittle failure characteristics (including, e.g., PET) or plastically deformed edges for softer materials with limited yield force (including, e.g., polyolefinic materials), respectively. Therefore, a highly repeatable cutting process is necessary.

– For materials with brittle failure characteristics, cuts made with, e.g., a fresh razor blade were found to give higher values than samples cut with a paper cutter. It is recommended that test labs periodically confirm that their method is equivalent to a standardized cutting method such as with a fresh razor blade.
– For materials with limited yield force, different (slower) cutting methods, e.g. punching, may be preferred to avoid stressing and relaxation of cut edges. Test labs shall maintain honing quality of appropriate knives or punching dies accordingly.

4.2.4.3 Conditioning

Condition the specimens prior to the test at 23 °C ± 2 °C and 50 % ± 5 % RH as in ISO 291 for at least 24 h before the test.

4.2.4.4 Apparatus

A mechanical load frame as in ISO 527-1 shall be used, capable of providing the following conditions:

- The load cell and displacement range shall be selected such that the maximum load on the specimen falls between 15 % and 85 % of the upper limit of the loading range.
- The machine shall be equipped with suitable grips capable of clamping the specimens firmly and without slipping throughout the test. Grippers shall have an inner surface that stably holds the material without piercing. Examples of suitable gripper surfaces include curved metal grippers, (reinforced) polymeric layers and fine sandpaper. Use of serrated metal grippers is not allowed. Cleaning the grips with solvent may help to eliminate the occurrence of sample slip during testing.

- Use of an optical extensometer is strongly recommended. If an optical extensometer is not used, the manual procedure for compensation of strain in grips (4.2.4.5) shall be applied. Use of mechanical extensometers (introducing mechanical contact with film under test) is not allowed. For materials with elongation at break larger than 200 %, laser-type extensometers are especially recommended, since the field-of-view of video extensometers is often limited to 200 %.

The applied tension is measured and recorded accurate to ± 1 % of any reading when calibrated.

4.2.4.5 Procedure

Front- or backsheet samples shall be pre-treated with heat (option 2 or 3 of 4.1.2). No pre-treatment is required for individual (sub)layers of a multilayer construction. Coupon samples (e.g. for UV weathering) are prepared through lamination (heat with pressure, option 3).

Conduct the test in the same atmosphere used for conditioning the test specimen. Optionally, for front- or backsheets intended for use in cold climates with extended periods of sub-zero temperatures, perform additional measurements at −40 °C.

Measure the width to the nearest 0,10 mm and the thickness to the nearest 0,02 mm based on the average of five measurements evenly distributed across the central region of each specimen, i.e. no measurements are taken in parts that will be clamped by the grips.

Calculate the arithmetic means for the width and thickness of each specimen, which will be used for calculation purposes.

Place the test specimen in the grips, taking care to align the longitudinal axis of the specimen with the motion axis of the load frame. Mark the position of material (with a soft pen or other method) following the requirements of the optical extensometer if applicable. Alternatively, mark the material at the front edges of the gripper to assess strain-in-grippers. To control for slippage, note the position of both ends of the strip in the grippers, e.g., by marking the material at the back edge of the gripper. For guidance on markings see Figure 1.

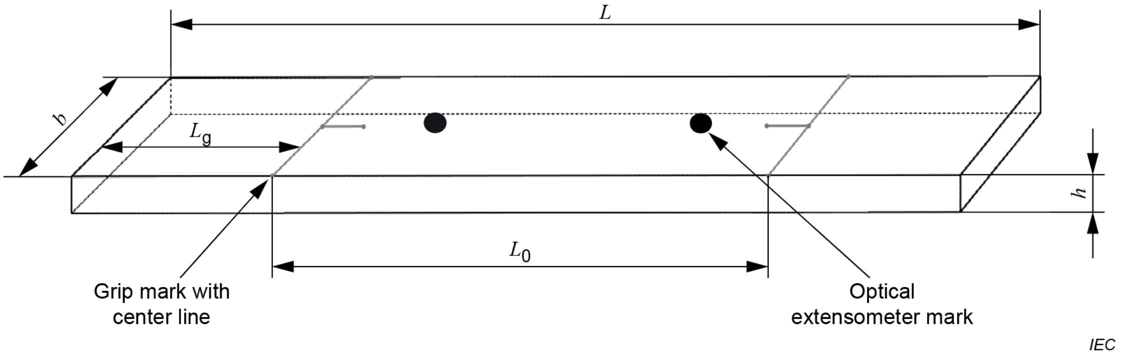
NOTE Dots of black, uncured silicone can be suitable as reliable marking for recognition in the extensometer, especially for materials with a high elongation at break.

Set an initial grip distance of 50 mm. Optionally, 25 mm grip distance may be used if the elongation at break is ≥200 %. Testing speed is 50 mm/min. Application of a small pre-strain is highly recommended to avoid a toe-region in the stress-strain curve. If applied, the pre-strain shall be smaller than 2 % of the tensile strain at break. Record the force and the corresponding gauge distance during the test.

NOTE When an optical extensometer is used, the actual gauge distance of the marks is typically smaller than the gripper distance.

If slippage has occurred, or another obvious fault has resulted in premature failure, the result of that test instance shall not be included in the analysis. Similarly, measurements that differ by more than two standard deviations shall be eliminated. In these cases, tests shall be repeated on new specimens until a total of five (5) good measurements are obtained.

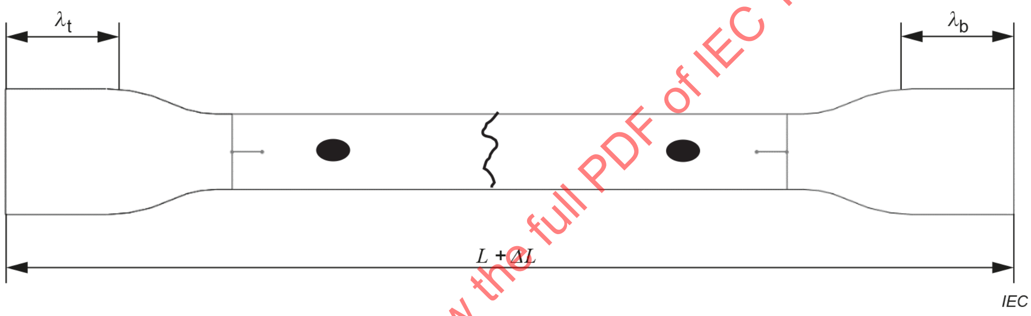
Pneumatic grips are recommended to reduce the buckling of specimens on loading and to reduce the toe in the load/displacement data profile.



Key

b	width	10 mm ± 1 mm (widths of 12,5 mm and 15 mm may also be used)
h	thickness	
L_0	initial grip distance	50 mm ± 0,5 mm (25 mm ± 0,5 mm optional for high ε_B)
L	Initial total sample length	> 70 mm, 100 mm preferred
L_g	Initial sample length not located between the grips	

a) Unstrained specimen



Key

$\lambda_{t/b}$	unstrained length at ends of sample (index t = top, b = bottom)
L	Initial total sample length
ΔL	change in grip distance at break

b) Strained specimen

Figure 1 – Specimen dimensions and markings in tensile test (unstrained and strained)

When testing monolithic layers, engineering tensile strength at break, σ_B is determined at the point where the test specimen ruptures. When testing composite layer stacks (e.g., combined single layers or multilayers), the first (sub)layer to rupture defines the break. If the load frame does not stop the test at that point, a discontinuity or excursion in the load-displacement curve shall determine the point of elongation at break.

Engineering tensile stress σ_B is calculated based on the original cross-sectional area of the specimen ($b \times h$) and the applied force at break or first partial rupture F_B as:

$$\sigma_B = \frac{F_B}{b \times h} \qquad (4\text{-}1)$$

and shall be expressed in (mega) Pascal (MPa). When a non-contact method, e.g., an optical extensometer, is used to measure elongation at break ε_{BO}, the change in distance of two marks

(ΔL_v) on the sample when it broke (either fully or partially, see above), divided by the initial separation distance of these video extensometer marks L_v:

$$\varepsilon_\mathrm{BO} = \frac{\Delta L_\mathrm{v}}{L_\mathrm{v}} \qquad (4\text{-}2)$$

Alternatively, when no optical extensometer method is used, an elongation ε_BG is calculated, that is corrected for strain-in-grip. This evaluation as defined by formula (4-3) where λ_t and λ_b represent the length of un-deformed material at the top and bottom ends of the sample and ΔL is the load frame displacement (see Figure 1):

$$\varepsilon_\mathrm{BG} = \frac{\Delta L}{L - \lambda_\mathrm{t} - \lambda_\mathrm{b}} \qquad (4\text{-}3)$$

4.2.4.6 Reporting requirements

Report average specimen length L, average specimen width b, and average thickness h, as well as their standard deviation (±1 σ).

Report the method of strain (elongation) measurement, either by using an optical, non-contact method, such as a video extensometer, or by applying the strain-in-grip correction.

Report initial grip separation and test speed.

Report the median values and standard deviation (±1 σ), for MD and TD specimens, of

- tensile strength at break σ_B;
- elongation at break ε_B (ε_BO or ε_BG) as a percentage.

In the context of ageing tests (see 4.10) calculate the ratios of measured values after test versus initial values, i.e. the retained tensile strength $r\sigma_\mathrm{B} = \sigma_\mathrm{B,after} / \sigma_\mathrm{B,initial}$ and the retained elongation at break $r\varepsilon_\mathrm{B} = \varepsilon_\mathrm{B,after} / \varepsilon_\mathrm{B,initial}$.

4.3 Adhesion testing

4.3.1 Purpose

Adhesion between materials used in construction of a multilayer front- or backsheet is required to ensure their integrity and endurance during service life. Lasting adhesion of the front- or backsheet to other components of the PV module, such as adhesion to the encapsulant, edge seal or junction box adhesive, is also needed.

4.3.2 General

Results from adhesion tests can depend strongly on test parameters (rate, temperature), test geometry, and sample preparation procedure. Additionally, material properties can affect the results, and quantitative comparison of absolute adhesion strength between different materials or sheet constructions may be limited. This also applies to materials before and after ageing. The different adhesion methods described here may give not only different relative values between different materials, but even the rank ordering of the adhesion strength may be different when using different methods or different sample constructions. Therefore, only for large differences in adhesion strength should one assume that even rank ordering is correct.

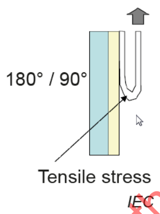
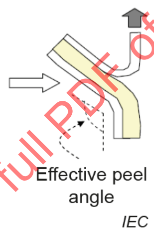
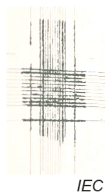
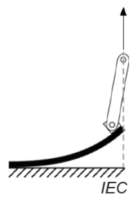
An overview of adhesion testing is provided in Annex B.

The test-method selection should be consistent with the purpose of the test, e.g., product consistency, or product selection for use in a targeted application.

Numerous adhesion test procedures are used across industries, with a range of sample structures/geometries, type of stress to separate layers, and parameters used with specific methods, such as test speed. Ease of practice is also an issue to consider.

Four methods have been identified as relevant for front- and backsheets as shown in Table 2, with recommendations for specific use cases.

Table 2 – Overview of adhesion tests

Interface under test	**Adhesion test**			
	Peel test with backing 4.3.4.1 	T-peel test 4.3.4.2 	Cross-hatch tape test 4.3.4.3 	Single cantilevered beam test 4.3.4.4 
1) Interlayer adhesion (4.3.3.1)	recommended	not applicable	recommended for coatings	alternate
2) Adhesion of a front- or backsheet to an encapsulant or edge sealant (4.3.3.2)	recommended	optional	not applicable	alternate
3) Adhesion of backsheet to a junction box adhesive (4.3.3.3)	not applicable	recommended	not applicable	alternate

4.3.3 Specific use cases

4.3.3.1 Adhesion between layers of front- or backsheet

The following methods are useful for a supplied front- or backsheet product.

A peel test is the historical approach recommended for evaluating adhesion between layers of a front- or backsheet. The single cantilevered beam (SCB) method is an alternate. For layers which have a low integral strength (e.g., thin coatings), the cross-hatch method is used.

The peel test is a simple and quick method which will provide a quantitative value if the integral strength of the layers is sufficient to withstand the test. Both 90° or 180° orientation can be used, where the 180° method is widely available and easy to carry out, and the 90° method requires a more advanced test setup, but is more practical for materials with a high elongation at break. The values for 90° and 180° will be different and can give different rankings in comparative testing. A limitation of these tests is that the measured peel strength is not directly correlated to the adhesion energy; energy put into a material with high elongation will result in stretching, rather than debonding of the interface. Comparison between products, or of the same material before and after ageing, can give incorrect comparison between products, or between initial and aged samples, and this method is considered most useful for quality control, or for comparison of different thin layers (e.g., adhesive or surface coating/treatment).

An alternate is the SCB test, which measures adhesion energy without convolution with the material properties of the layers. This is a recently developed method for use with backsheets.

The cross-hatch tape test is a simple, semi-quantitative test, to be used for comparing materials with low cohesive strength.

Tests can be performed on the complete front- or backsheet. An alternative approach, if the individual layer materials are available, is to take a subset of individual layers of a front- or backsheet, coat or laminate them under laboratory conditions, and perform any of the above tests (see also Table A.1). This allows for targeting of adhesion of two specific layers, and for easy insertion of a tab to allow for pre-start of the debonding. It could be that results are not representative of production material.

4.3.3.2 Adhesion between sheet and encapsulant (or edge sealant)

Adhesion of a front- or backsheet to an encapsulant will vary with different products. However, as different products of the same chemistry are likely to give similar results, it is recommended that one example for each type of encapsulant evaluated (e.g. EVA or polyolefin) is included in data sheet reporting.

The methods shown in Table 2 row 2) can be used to evaluate adhesion of front- or backsheet to encapsulant. The 180° peel test is recommended. The construction includes a laminated glass/encapsulant/(front- or back)sheet coupon. This procedure is a simple means to get a quantitative value but has some limitations: stretching or breaking of the pull tab can happen before debonding which results in an "adhesion greater than" value rather than a single number. Additionally, the measured peel strength is not directly correlated to the adhesion energy; energy put into a material with high elongation will result in stretching, rather than debonding of the interface. However, this might not be a concern for quality control (QC) purposes.

An alternative is the SCB test which measures adhesion energy, with minimal complication from material properties of the layers and is thus better suited for comparison of different materials.

4.3.3.3 Adhesion between backsheet and junction box adhesive

Adhesion of a backsheet to a junction box adhesive will vary with different products. However, as different products of the same chemistry are likely to give similar results, it is recommended for data sheet reporting that one example for each type of adhesive evaluated (e.g., silicone) is included, referring to the type of adhesive in the reporting.

To measure the adhesion strength of the adhesive used for mounting of the junction box to the outer (airside) layer of a backsheet, the following tests can be used.

The methods shown in Table 2 row 3) can be used to evaluate adhesion of backsheet to junction box adhesive. The T-peel test is recommended. This procedure is a simple means to get a quantitative value, but has the same concerns as adhesion to encapsulants as explained in 4.3.3.2.

4.3.4 Methods

4.3.4.1 180° and 90° peel adhesion test

4.3.4.1.1 Specimens

This test applies to three types of specimens:

a) Test specimens can be constructed from sheets of at least two adjoining layers of the components used in the front- or backsheet. These may be prepared and bonded together with the same adhesive as used in serial production of the front- or backsheet. The samples may be created using the same vacuum lamination process used in the PV module fabrication.

b) Samples for the weakest-link test of the front- or backsheet are prepared from finished sheet material. Introduce a separation in the sheet by suitable means (e.g., knife, fingernails) such that the free ends can be used as handles inserted into the grips of the load frame machine.

c) Samples for the test of adhesion of front- or backsheets to other materials are produced by laminating a frontsheet with an encapsulant to a rigid substrate or a backsheet with an encapsulant to a rigid superstrate (glass) in a representative production lamination process.

Cut the bonded test sheets into 10 mm wide test specimens, discarding the edge cuts, by a means that is not deleterious to the bond. Alternatively 15 mm wide test specimens may be used but then this deviation shall be included in the report.

The 100 mm long unbonded ends bend apart, perpendicular to the bond line, for clamping in the grips of the test machine. For a 90° peel adhesion test, the grip region can be shorter.

4.3.4.1.2 Procedure for 180°

Samples are prepared by lamination using default lamination conditions as specified in 4.1.2.

In addition:

a) For flexible/flexible samples, reinforce the side of the thicker film with a flat metal plate (see Figure 2, left) by clamping the film together with the flat metal plate in the lower test grip of the tension machine (initial gauge length is 50 mm). Optionally, the film may be adhered to the plate. Clamp the bent, unbonded end of the test specimen in the upper test grip. Apply the load at a constant displacement speed of 50 mm/min or 100 mm/min. The film which is fixed to the metal plate is not allowed to move in any direction during the peel test.

b) For flexible/rigid samples (laminated coupons with, e.g., a glass or aluminium base), the flat metal plate is omitted.

NOTE Based on round robin tests, a test speed of 50 mm/min has shown to improve reproducibility of test results compared to a higher test speed of 100 mm/min (which is standard in the film industry). Tests performed at 50 mm/min versus at 100 mm/min can show different results.

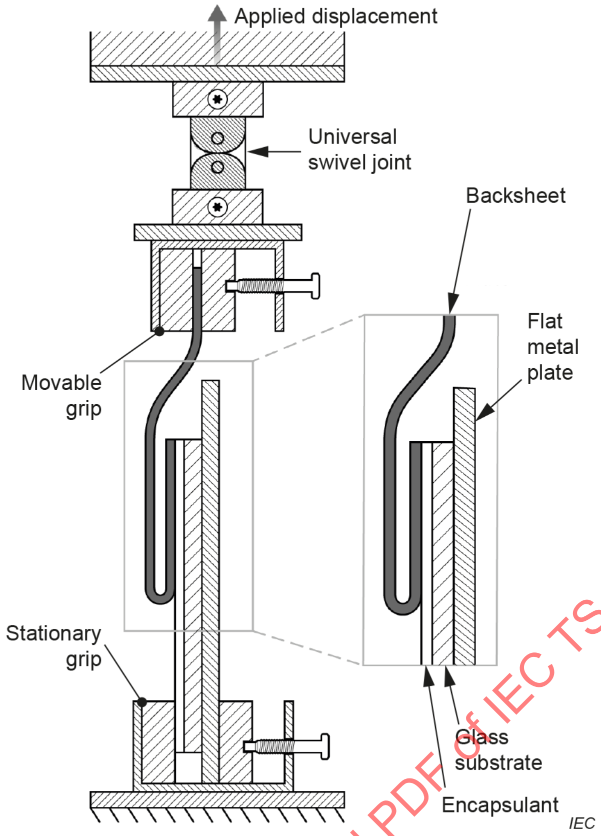


Figure 2 – Fixation of the sample for 180° peel (for use with flexible/flexible samples)

4.3.4.1.3 Procedure for 90°

Samples are prepared by lamination using default lamination conditions as specified in 4.1.2.

For the 90° peel test the length of unbonded film may be shorter than for the 180° test. Pull at a rate of 50 mm/min or 100 mm/min while maintaining an angle of 90° ± 10°. The sample can be clamped onto a moveable stage which is used to maintain the angle. Alternatively, a long arm connecting the pulled end to the force transducer can be used to maintain the proper angle.

NOTE Based on round robin tests, a test speed of 50 mm/min has shown to improve reproducibility of test results compared to a higher test speed of 100 mm/min (which is standard in the film industry). Tests performed at 50 mm/min versus at 100 mm/min can show different results.

4.3.4.1.4 Measurement evaluation

Determine from the autographic curve the average load, in Newtons per millimetre of the specimen width required to separate the adherents.

To avoid an artificial toe-region in the graph, apply a small pre-load that is not larger than 1 % of the constant load while peeling (see below). It may be necessary to evaluate the level of the pre-load in a test-run on an extra specimen of the material under test.

If the mode of failure has not changed, then a plateau-like load versus displacement curve is recorded (see Figure 3, left). In that case, average the recorded data for all specimens over the entire peel length except the incipient tear, with 100 mm marking the upper limit of the displacement range and 20 mm the lower, both measured from the onset of load. In the event of changes in failure mode, verify by inspection of the samples where the adhesion failure has occurred and which data range is actually associated with the interface under test. Then, the average specimen peel strength shall be determined using the portion of the data associated with the failure of the interface of interest (see Figure 3, right).

The average value and standard deviation (± 1 σ) for the adhesion between the peeled layers shall be calculated.

Both directions, MD and TD, of the sheet material, shall be tested and reported for peel tests.

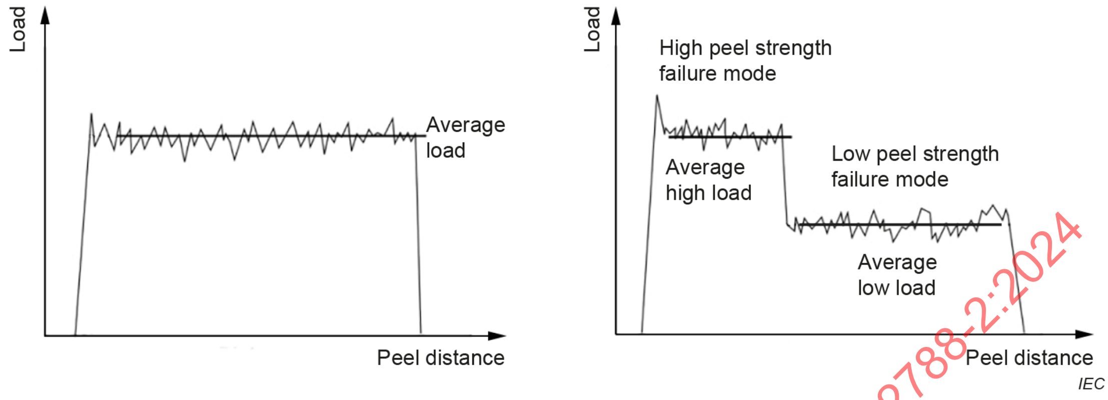


Figure 3 – Single and multiple failure modes in a peel test

4.3.4.2 T-peel adhesion test

4.3.4.2.1 Sample preparation

The laminated test specimen (see Figure 4) shall be prepared from two flexible sheets of the same kind of front- or backsheet and the matching material for test as adherent. Examples include:

a) Two sheets of finished backsheet (or finished frontsheet), with their inner sides oriented inside and sandwiching an encapsulant, are laminated in accordance with the encapsulant manufacturer's recommendations, including a release film for the incipient tear or foreseeing the length of encapsulant as about two-thirds of the length of the polymeric sheets;

b) Two sheets of finished backsheet with their airside oriented inside and sandwiching a junction-box adhesive (e.g. silicone or adhesive tape) that is applied and cured in accordance with the adhesive manufacturer's recommendations, including a release film for the incipient tear or foreseeing the length of adhesive as about two-thirds of the length of backsheets.

Apply adhesive tapes in 10 mm wide strips or apply an adhesive bead (e.g. for silicone adhesives) to the sheet. In the case of an adhesive bead, a mould may be used to create an adhesive strip 10 mm wide and 2 mm high. Flatten the strip to a height of 1 mm by using distance plates in combination with the second sheet and cure it in accordance with the adhesive manufacturer's recommendations.

Cut the bonded sheet sandwiches into test strips with a width of preferably 15 mm, but at least 10 mm. Discard the cut edges by a means that is not deleterious to the bond. The 50-mm-long unbonded ends shall be bent apart, perpendicular to the adherent/release film line, for clamping in the grips of the test machine.

The choice of encapsulant or junction-box adhesive may be made by the test requestor or the front- or backsheet manufacturer.

Dimensions in millimeters

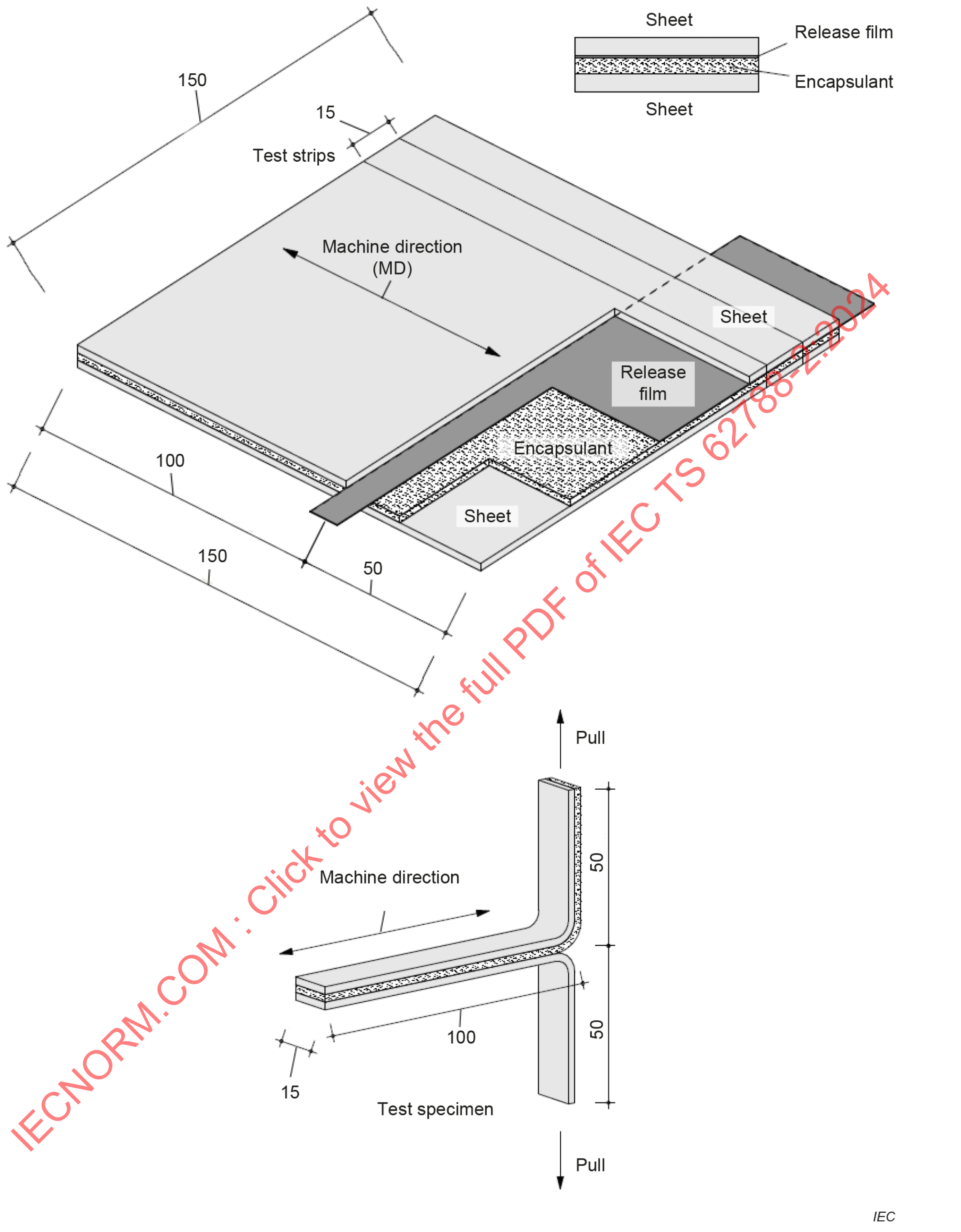


Figure 4 – Sheet sandwich (top) for preparation of T-peel test specimens (bottom)

4.3.4.2.2 Procedure

Samples are prepared by lamination using default lamination conditions as specified in 4.1.2.

The peel-arms are peeled apart at a pull rate of 50 mm/min or 100 mm/min.

NOTE Based on round robin tests, a test speed of 50 mm/min has shown to improve reproducibility of test results compared to a higher test speed of 100 mm/min (which is standard in the film industry). Tests performed at 50 mm/min versus 100 mm/min can show different results.

4.3.4.2.3 Measurement evaluation

Evaluate the results in a manner analogous to that for the 180° peel tests as explained in 4.3.4.1.4.

4.3.4.3 Cross-hatch tape test

4.3.4.3.1 Apparatus

Use the multi-blade cutting tool with 1 mm spacing and the tape method for testing of removal of loose coating according to ISO 2409. In addition to provisions given in ISO 2409 the tape is defined as follows:

– A polyester adhesive tape of 0,055 mm thickness and 25 mm width;
– The tape provides a peel strength of at least (10 ± 1) N/25 mm when applied to the surface of the material under test. The adhesive peel strength of the tape is measured in 180° peel geometry;
– If no tape with the minimum adhesion strength is available, the T-peel method (4.3.4.2) can be considered as secondary replacement for the tape test for testing of inner layers: the T-peel sample is constructed with 2 sheets of front- or backsheet and an encapsulant. For cross-hatch testing of the outer (= airside) layer of a front- or backsheet, the T-pluck method in Annex B can be applied using a junction-box adhesive.

4.3.4.3.2 Procedure

Follow the procedure from ISO 2409. Condition the specimens prior to the test at (23 ± 2) °C and (50 ± 5) % RH for at least 24 h. Score a clean section of the surface to form a cross-hatch pattern, applying steady force sufficient to penetrate the coating but not the substrate.

Remove any loose flakes from the film using a brush or clean cloth. Apply a ca. 10 cm piece of the tape as defined in 4.3.4.3.1 to the scored section of the surface. Smooth the tape to ensure good surface contact using a squeegee.

Let the tape rest 1 min to 2 min to stabilize the adhesion of the tape to the material, then remove the tape by grasping the free end and pulling it off steadily in 0,5 s to 1,0 s at an angle which is as close as possible to 60°.

NOTE Type of tape, pressure of tape application, curing time, angle and speed of tape release can influence the result. Also, ageing of the material under test by, e.g., damp heat test or UV weathering, may affect the peel strength (e.g., due to presence of chalking or other changes of the materials surface).

4.3.4.3.3 Final measurements

An observer with normal vision or corrected-to-normal vision compares the removal of coating area with the illustrations given in ISO 2409, see also Figure 5.

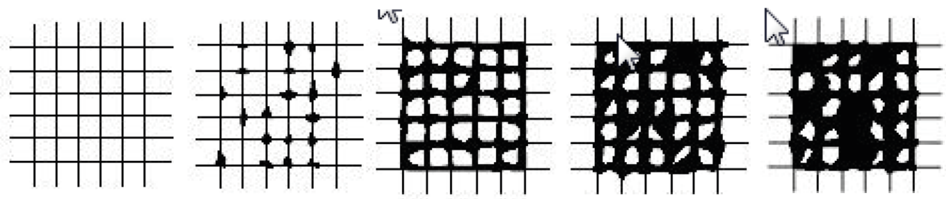


Figure 5 – Illustration of area removal by tape in cross-hatch test, with classification from 0 to 5 (from left to right)

4.3.4.4 Single cantilevered beam test

Follow the procedure described in IEC TS 62788-6-3 for the specific use case.

4.3.5 Reporting requirements

4.3.5.1 Reporting requirements for adhesion tests

Report the following:

- Specific use case

For the cross-hatch test (see 4.3.4.3), report:

- Class of area loss after cross-hatch test by comparison to the visual ruler in ISO 2409;
- Report the initial adhesive strength of the tape for the material under test: ageing of the material under test (e.g., by DH testing or weathering) may result in different adhesive strength of the tape and initial value has to be reported.

For all other tests, report:

a) Mean of the stress in N/cm as described for each test, and the standard deviation (± 1 σ);
b) Test method:
   - 180° or 90° peel test (4.3.4.1)
   - 90° T-peel test (4.3.4.2)
   - Cross-hatch tape test (4.3.4.3)
   - SCB test (4.3.4.4 or IEC TS 62788-6-3)
c) Direction (MD or TD) of the specimen;
d) Failure mode and type of failure (cohesive/adhesive);

NOTE In the event of cohesive failure, peak load (N/cm^2) does not represent the bond strength between (components of) front- or backsheet and adhesive, but represents a lower limit of the bond strength of all other adhesive interfaces in the sample under test.

e) Interface that has been tested and materials used:
   - Components of backsheet (name/type)
   - Backsheet to encapsulant (name/type)
   - Backsheet to junction box adhesive (name/type);
f) Details of sample construction and preparation:
   - Lamination conditions (encapsulant)
   - Curing conditions (junction-box adhesive)
   - Release layer material (if used)
   - Auxiliary adhesives and handles (e.g., glass or aluminium)
   - Sample width;
g) Sample pre-conditioning, including thermal exposure;
h) Temperature of test (required is 23 °C/50 % RH, optional 70 °C).

Trace the context of the adhesion test: unaged (fresh) or after ageing.

4.4 Thermal characteristics

4.4.1 Thermal endurance

4.4.1.1 Purpose

To ensure that the polymeric materials can withstand the thermal stresses which may occur during service lifetime of the PV module.

NOTE Thermal endurance is obtained from measured changes in mechanical and electrical properties that are assessed in accelerated thermal ageing tests and make use of the Arrhenius scheme for extrapolation.

4.4.1.2 Procedure

Front- or backsheet samples are recommended to be pre-treated with heat (option 2 or 3 of 4.1.2). No pre-treatment is required for individual (sub)layers of a multilayer construction.

The thermal endurance ratings shall be acquired according to IEC 60216-1 (TI) or IEC 60216-5 (RTE). RTI values according to UL 746B are accepted as an alternative to RTE. Values are equally acceptable for the purpose of this document, but may be slightly different in practice. Default evaluation time for TI is 20 000 h (see IEC 60216-1). Correlation times for RTE (RTI) depend on the comparison material and may range between 20 000 h and 100 000 h. Therefore, RTE and RTI index values are typically smaller than TI values.

Thermal endurance testing is performed per layer of material considered as RUI in the front- or backsheet to meet the requirements of the underlying Arrhenius type of evaluation. Therefore, the TI or RTE (RTI) values of a multi-layered film constructed from different material layers, shall be determined for each RUI layer, e.g., a film, coating, or adhesive.

Mechanical TI or RTE (RTI) values are recommended to be evaluated for 50 % retention of elongation at break (using the tensile test method in 4.2.4 or equivalent). Electrical TI or RTE (RTI) values are recommended to be evaluated for 50 % retention of dielectric strength (using the DC breakdown voltage method in 4.5.1 or equivalent). For reasons of practicality and use of generic legacy data, thermal-endurance ratings based on tensile strength testing may be used in combination with the thermal failsafe test (4.4.2) and AC breakdown is accepted as alternative for assessment of retention of dielectric strength in context of thermal endurance testing.

A thermal endurance value based on a mechanical-impact rating is not required.

NOTE In historical tests of TI or RTE (RTI), the AC breakdown voltage test can have been applied, whereas the DC mode is preferred for an envisaged use case in PV modules. Depending on material, the AC breakdown values are typically 3 to 5 times smaller than DC breakdown values. Impact on the TI or RTE (RTI) rating may be limited because analysis is based on relative retention.

4.4.1.3 Thermal endurance of coating layers

Thermal endurance test methods for coating layers are not yet standardized in the industry, options for consideration are provided.

Values for TI or RTE (RTI) of coating layers shall be evaluated under consideration of particular requirements of IEC 60216-2, namely retention of dielectric strength and retention of flexibility.

Coating material is applied to a suitable substrate using conditions for coating thickness and curing representative for the application in the front- or backsheet. Depending on the evaluation method, coatings may either be released from the substrate to be tested as free-standing film or coatings may reside on the substrate during the test. Examples are standardized metallic test panels, e.g., as defined in ISO 1514.

For determination of the dielectric strength after thermal exposure the DC breakdown voltage method (4.5.1) is used, with the metal test panel as electrode. In the case of a dielectric substrate, the additional dielectric strength due to the coating needs to be evaluated separate from the value of the substrate.

For evaluation of the retention of flexibility, a Mandrel test according to ISO 1519 with 3,2 mm diameter cylinder or a cupping test according to ISO 1520 with 10 mm diameter tool and 3 mm protrusion depth shall be used. Tensile testing (4.2.4) can also be used to evaluate the elongation at which coatings crack, if this happens before the breaking of the film. A coating fails if cracks become visible, which can be used as on/off criterion in the Arrhenius evaluation. In the case of the cupping test, the actual protrusion depth for creation of cracks may be considered as alternative evaluation: The endpoint of 50 % retention is reached, if the cracking is observed at half of the protrusion depth of the unaged coating.

4.4.1.4 Reporting requirements

For each material used as relied-upon insulation, report the method (TI or RTE/RTI) and the thermal endurance rating measured in °C.

Report the following:

a) The layer material, for which the thermal endurance has been evaluated;
b) The layer thickness and type of specimens tested, e.g., film sheets, free-standing coating, coating on metal sheet;
c) The TI or RTE (RTI) value obtained for the mechanical evaluation;
d) The TI or RTE (RTI) value obtained for the electrical evaluation;
e) It is also accepted to evaluate only the lowest of the values in c) and d) (if applicable) and to verify, that the other properties have a retention of larger than 50 % for that TI or RTE (RTI) value;
f) The evaluation test method and the level of retention (if applicable) used for evaluation of the properties of interest in c) and d);
g) If the evaluation test method for the mechanical TI or RTE (RTI) is not evaluated by elongation at break, the results of the thermal failsafe test (4.4.2) shall also be provided.

4.4.2 Thermal failsafe test

4.4.2.1 General

Traditionally, testing of mechanical endurance to thermal stress is limited to the evaluation of retention of tensile strength in one direction of the film only (MD or TD). However, the propensity to crack has been shown to be better correlated to elongation at break (ε_B) [1][1].

This test evaluates the thermal stability of a single material, using changes of ε_B in a single-temperature thermal ageing. This test complements the traditional evaluation of TI or RTE (RTI) as "failsafe test". The evaluation covers both directions of the film (MD and TD) for one elevated temperature and exposure time.

This test is not required if TI or RTE (RTI) values based on 50 % retention of elongation at break is provided.

NOTE This test represents a subset of typical test conditions in 4.4.1, when mechanical endurance to thermal stress would be evaluated for (both tensile strength and) elongation at break in MD and TD directions of the film.

[1] Numbers in square brackets refer to the Bibliography.

4.4.2.2 Procedure

Front- or backsheet samples shall be pre-treated with heat (option 2 or 3 of 4.1.2). No pre-treatment is required for individual (sub)layers of a multilayer construction.

Four sheets of materials are prepared, of sufficient size to provide at least five strips for evaluation by tensile testing (4.2.4), with two used for strips cut in the MD direction, and two for strips cut with the TD orientation.

One set of MD and TD sheets is used to measure of initial elongation at break of the unaged material. The other set of samples is exposed at (120 ± 2) °C for (2000 ± 24) h (humidity control is not required).

NOTE Background for the choice of failsafe test conditions is provided in [2]: Test duration and temperature were chosen to allow a "failsafe" extrapolation for materials down to activation energy of 45 kJ/mole for thermally activated processes resulting in loss of elongation at break.

It is recommended to have pre-treated material stored under standard conditions during the thermal failsafe test, so that the specimen preparation and evaluation of unaged and aged specimens are performed at the same moment. Sheets from both sets are cut into strips (both for MD and TD directions) and evaluated for ε_B as defined in 4.2.4.

4.4.2.3 Reporting

Report the results for elongation at break (4.2.4) after the thermal pre-treatment and after the thermal exposure (2 000 h at 120 °C).

4.4.3 Dimensional stability

4.4.3.1 Purpose

This test measures the irreversible deformation of front- or backsheets due to thermal exposure that may occur during processing of a module. It describes dimensional changes before and after exposure to specified temperatures for specified times and identifies the relaxation of the film from its fabrication state.

The procedure follows the method described for encapsulants in IEC 62788-1-5, using a larger sample size (due to the higher dimensional stability of front- and backsheets), and allowing for alternative sample supports (due to a lower tendency to stick to the underlying layer).

4.4.3.2 Apparatus

Use an oven (e.g. drying chamber) with air circulation as described in IEC 62788-1-5.

For measuring, use appropriate measuring equipment to guarantee the required resolution.

4.4.3.3 Procedure

Samples shall be used without thermal pre-treatment (4.1.2).

Cut three squares of 200 mm × 200 mm.

Measure the length of both directions (MD and TD) of the sample to the nearest 0,01 mm. Place the samples horizontally in the preheated (150 °C) oven without contact to the walls for 30 min at 150 °C (±2 °C).

Place the sample with the side designed to be on the outside of the module tested face down on the sample support, and in an appropriate way to ensure:

– Homogeneous temperature on both sides of the film samples;
– That the material is able to move freely, using a interleave material to avoid sticking to the test support.

EXAMPLES: fluorinated polymer, talc dusted paper, or sand.

After the samples have cooled to room temperature, measure the length of the sample to the nearest 0,01 mm in both the MD and TD directions as shown in Figure 6.

Dimensions in millimeters

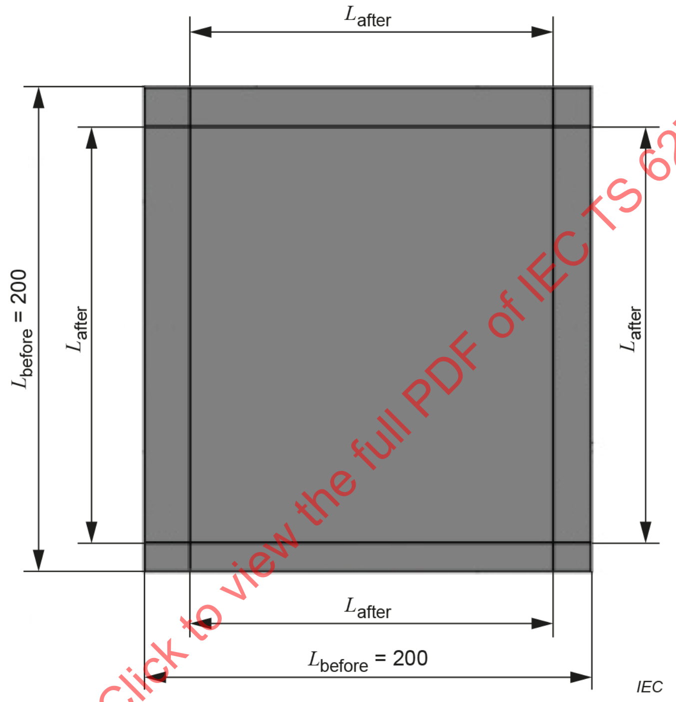


Figure 6 – Specimen before and after exposure

Calculate the change in length and width in relation to the original measurement in percent. The L_{after} exposure for a given direction (MD or TD) is the average of the two measurements in that direction.

$$\Delta L = 1 - \frac{L_{after}}{L_{before}} \quad (4\text{-}4)$$

where

L_{after} is the length after heating;

L_{before} is the length before heating.

4.4.3.4 Reporting requirements

Report ΔL [%] for both MD and TD directions.

4.4.4 Relative thermal expansion

4.4.4.1 Purpose

The coefficient of thermal expansion (CTE) gives information about the reversible deformation that may occur during operation of a PV module. This information may be helpful to identify matching materials in the design of a PV module.

The reversible thermal expansion coefficient of the material is measured after the film is relaxed by a thermal cycle. It is possible that CTE will be different for MD and TD directions.

4.4.4.2 Apparatus

Use a TMA device according to ISO 11359-1 and ISO 11359-2.

4.4.4.3 Procedure

Front- or backsheet samples shall be (pre-)treated with heat (option 2 or 3 of 4.1.2) as part of the procedure below.

Run two cycles:

Heat the specimen to 160 °C or the maximum lamination temperature recommended by the sheet manufacturer, whichever is smaller. Apply a holding time of 5 min (this simulates the effects of the module lamination process).

Reduce temperature to ambient and perform the test according to ISO 11359-2, method A or B. Perform the test in both the machine and transverse machine direction, with three replicates per orientation.

Using the second cycle, determine the coefficient of thermal expansion (CTE) in K^{-1} at 23 °C as described in ISO 11359-2, method A or Method B.

4.4.4.4 Reporting requirements

Report the mean CTE value and the standard deviation (± 1 σ) of three measurements at 23 °C indicating the method used (A or B). If a glass transition is observed, report the maximum temperature of the first test cycle.

4.4.5 Thermal conductivity

4.4.5.1 Purpose

The thermal conductivity of the polymeric front- or backsheet may be needed for calculations and simulations regarding the temperature management of a PV module. The method here shall be applied to measure the thermal conductivity of the final front- or backsheet product.

4.4.5.2 Procedure

No pre-treatment is required (4.1.2).

Follow ISO 22007-4.

4.4.5.3 Reporting requirements

Report the value of thermal conductivity of the multilayer front- or backsheet.

4.5 Electrical characteristics and insulation thickness

4.5.1 Breakdown voltage

4.5.1.1 Purpose

This test method provides methods for the verification of the breakdown voltage (V_{BD}) using direct current (DC) voltages [3].

NOTE A simple mathematical conversion from an alternating current (AC) to a direct current (DC) measurement does not provide a correct or acceptable result. For many materials, the DC breakdown voltage will be three or even more times higher than the AC breakdown voltage [4].

To qualify in accordance with IEC 62788-2-1:

- Selected RUI layer(s) within a front- or backsheet shall meet a minimum break down voltage (BDV) defined by the rated system voltage to qualify for basic or reinforced insulation.
- Front- and backsheets must meet a minimum BDV, defined by the module safety class, rated system voltage, and DTI thickness ratio, r_{DTI}. The BDV is measured before and after accelerated ageing (4.10).

4.5.1.2 General

As many backsheets have a DC breakdown voltage greater than the capacity of typical devices, two methods are offered:

- Method A) Withstand voltage test: the voltage is increased up to a (required) target level and then held for one minute.
- Method B) Breakdown voltage test: the voltage is increased until breakdown occurs or the maximum level of the test device is reached.

Either method A or B can be used, with the procedures as described in 4.5.1.6 and 4.5.1.7.

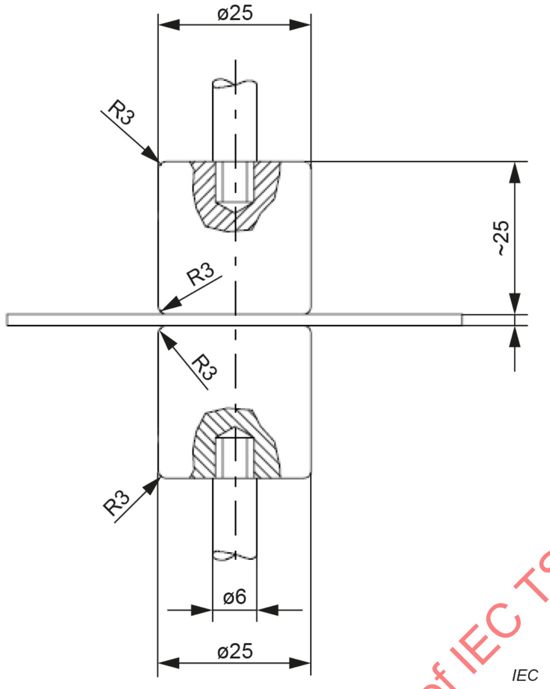
4.5.1.3 Apparatus

Use the electrical apparatus (step-up transformer) equipped with equal-diameter electrodes as described in IEC 60243-1 and apply the DC method given in IEC 60243-2.

The power generator shall be able to generate the target voltage. To protect the voltage source from damage it shall be equipped with a device that disconnects the power supply on breakdown of the specimen. It may consist of a current-sensitive element in the high-voltage supply of the electrodes.

To restrict damage by current or voltage surges at breakdown, a resistor with a suitable value may be used in series with the electrodes. The value of the resistor will depend on the damage that can be tolerated at the electrodes. The use of a very high-valued resistor may result in breakdown voltages which are higher than those obtained with a lower-valued resistor.

Dimensions in millimetres



SOURCE: IEC 60243-1:2013, Figure 1b

Figure 7 – Equal electrodes for dielectric strength test

The electrodes shall consist of two metal cylinders preferably of stainless steel or brass with the edges rounded to give a radius of 3 mm ± 0,2 mm. A fixture should be employed, which accurately aligns the upper and lower electrodes within 1,0 mm. Both electrodes shall be 25 mm ± 1 mm in diameter as well as height (see Figure 7, taken from IEC 60243-1). The diameters of the two electrodes shall differ by no more than 0,2 mm. The metal electrodes shall be maintained smooth, clean and free from defects at all times.

NOTE It has been found that larger variability of measured values is observed with asymmetric electrodes, which therefore do not represent an alternative electrode configuration [3].

4.5.1.4 Surrounding medium

Materials shall be tested in air or a surrounding medium selected to prevent flashover [4] [5]. The flashover voltage will depend on the size of the sample: for a 5 cm × 5 cm sample, flashover is estimated at > 35 kV. If used, the surrounding media should consist of mineral based transformer oil in accordance with IEC 60296. It is possible that in some parts of the world, IEC 60296 specified mineral oils will not be available. In such circumstances mineral oils specified in accordance with ASTM D3487 Type II oils are recommended for use [6]. Periodic exchange of the oil shall be performed based on visual inspection, e.g., when signs of impurities are observed (e.g. ash generated by the breakdown, foreign impurities, or colour changes caused by oxidation of the oil).

4.5.1.5 Pre-treatment

Front- or backsheet samples shall be pre-treated with heat (option 2 or 3 of 4.1.2). No pre-treatment is required for individual (sub)layers of a multilayer construction.

The DC breakdown voltage of front- and backsheets may vary with temperature and water absorption. Therefore, specimens are pre-conditioned for at least 24 h at 23 °C ± 2 °C and 50 % ± 5 % RH, as specified by the standard ambient atmosphere in IEC 60212.

4.5.1.6 Withstand voltage test (method A)

4.5.1.6.1 Determining the withstand test voltage

The withstand test voltage (V_w) shall be large enough to meet the minimum required breakdown voltage $[V_{BD}]_{req}$ from IEC 62788-2-1.

For an individual RUI layer selected for basic or reinforced insulation:

- For basic insulation:

$$V_w \geq [V_{BD}]_{req} = 1{,}0\ \text{kV} + 2 \times [V_{sys}]_{max} \tag{4-5}$$

- For reinforced insulation:

$$V_w \geq [V_{BD}]_{req} = 2{,}0\ \text{kV} + 4 \times [V_{sys}]_{max} \tag{4-6}$$

where

$[V_{sys}]_{max}$ is the target maximum system voltage, expressed in kV.

EXAMPLE: For a 1 500 V system voltage rating, V_w shall be greater than 4 kV for basic insulation or 8 kV for reinforced insulation.

For a front- or backsheet, due to the presence of layers which do not contribute to relied-upon insulation, the $[V_{BD}]_{req}$ is adjusted using the DTI thickness ratio r_{DTI} defined in IEC 62788-2-1 as the ratio of the t_{DTI} to the measured thickness t_{total} before the lamination protrusion test:

$$V_w \times r_{DTI} = V_w \times t_{DTI} / t_{total} \geq [V_{BD}]_{req} \tag{4-7}$$

NOTE For simplicity, this correction presumes a linear correction that is valid in first approximation only for polymeric, non-conductive materials.

The module safety class and target $[V_{sys}]_{max}$ determine $[V_{BD}]_{req}$ as described in IEC 62788-2-1. For module safety class II, double or reinforced insulation is required:

$$[V_{BD}]_{adj} \geq V_w \times r_{DTI} \geq [V_{BD}]_{req} = 2{,}0\ \text{kV} + 4 \times [V_{sys}]_{max} \tag{4-8}$$

where

$[V_{BD}]_{adj}$ is the adjusted breakdown voltage, expressed in kV.

A convenient approach to simplify testing is to use a minimum withstand voltage based on a worst case r_{DTI} using the minimum required DTI $[t_{DTI}]_{req}$ (see IEC 62788-2-1):

$$r_{\mathrm{DTI}} \geq \left[t_{\mathrm{DTI}}\right]_{\mathrm{req}} / t_{\mathrm{total}} \tag{4-9}$$

Example: for a 1 500 V system voltage rating and module safety class II, where $[t_{\mathrm{DTI}}]_{\mathrm{req}}$ = 300 µm, t_{total} = 400 µm, and thus r_{DTI} = 0,75, then V_{w} ≥ 10,7 kV will meet $[V_{\mathrm{BD}}]_{\mathrm{req}}$ = 8 kV.

4.5.1.6.2 Procedure

Unless otherwise specified, the test should be performed at 23 °C ± 2 °C. Three samples are measured.

Electrodes shall be applied to the specimen in such a manner that it does not damage (puncture) the specimen, but that sufficient pressure is used to ensure good contact between electrode and sample.

The test may be performed at either positive or negative polarity. A current limit in the range of 10 mA may be used.

A voltage is applied between the two electrodes and raised from zero at a uniform rate of approximately 500 V/s to the target test voltage, and held at that voltage for 60 s. If breakdown does not occur, this is considered a “pass”. If all three samples do not pass, repeat the test at a lower V_{w} (if possible) or use method B (recommended).

4.5.1.7 Breakdown voltage test (method B)

4.5.1.7.1 Procedure

Five tests shall be conducted and the breakdown voltage shall be determined from the median of the test results. If any test result deviates by more than 15 % from the median, five additional tests shall be carried out. The breakdown voltage shall then be determined from the median of the 10 results.

Unless otherwise specified, the test should be performed at 23 °C ± 2 °C.

Electrodes shall be applied to the specimen in such a manner that it does not damage (puncture) the specimen, but that sufficient pressure is used to ensure good contact between electrode and sample.

The voltage shall be raised from zero at a uniform rate of approximately 2 000 V/s until breakdown occurs, or to the maximum voltage level of the equipment. If the breakdown occurs in less than 10 s, then the ramping rate should be reduced in the following order, 1 000 V/s, 500 V/s, 200 V/s or 100 V/s, until the breakdown occurs after at least 10 s, i.e., the highest ramping rate in which the breakdown occurs after 10 s should be used. For materials that differ considerably in their breakdown voltage, some samples may fail before the designated test time. In this case, it is satisfactory if the majority of breakdowns occur after 10 s.

For complete backsheets a rate of 2 000 V/s is often suitable. For backsheets used in lower voltage applications, or for individual RUI layers, a slower ramp rate of 100 V/s to 500 V/s is suitable.

4.5.1.7.2 Criteria for breakdown

Electric breakdown is accompanied by an increase of current flowing in the circuit and by a decrease of voltage across the specimen. The increased current may trip a circuit breaker or blow a fuse. However, tripping of the circuit breaker may sometimes be influenced by flashover, specimen charging current, leakage or partial discharge currents, equipment magnetizing current or equipment malfunction. It is therefore essential that the local circuit breaker is well coordinated with the characteristics of the test equipment and the material under test, otherwise the circuit breaker may operate without the instrument achieving breakdown of the specimen, or fail to operate when breakdown has occurred and thus not provide a positive criterion of breakdown. Even under the best conditions, premature breakdowns in the ambient medium may occur, and observations shall be made to detect spurious breakdown of the ambient medium (transformer oil) during tests. If spurious breakdown is observed, it shall be reported.

4.5.1.8 Reporting requirements

Report the following:

For each measured individual RUI layer:

a) Name of material
b) Whether method A or B has been used including the following details:

   Method A:

   - The value of the V_{BD} as greater than or equal to the passed withstand voltage V_w.

     Example: If a sample passes using a V_w of 12 kV, report $V_{BD} \geq 12$ kV.

   Method B:

   - Select the appropriate option:
     i) If breakdown occurred on all samples, report the median of the measured DC breakdown voltage V_{BD};
     ii) If breakdown occurred for only a portion of the samples, report the BDV as greater than (or equal to) the median V_{BD} (based on the measured breakdown values);
     iii) If breakdown did not occur for any of the samples, report the BDV as greater than or equal to the maximum test voltage level.

        Example: Assume the use of a 6 kV generator and no breakdown occurred for any samples: the median breakdown shall be reported as $V_{BD} \geq 6$ kV.

   - The standard deviation (± 1 σ) as the measure of uncertainty;
   - The maximum test voltage of the equipment;
   - The ramping speed and type of mineral oil (if used) as described in 4.5.1.4.

For complete front- or backsheets:

a) Name and type of material (backsheet, frontsheet or material component), total thickness t_{total} and the DTI ratio r_{DTI} for the material tested.
b) Report, whether method A or method B has been used including the following details:

   Method A:

   - The value of V_{BD} as greater than the passed withstand voltage V_w
   - The adjusted V_{BD} for each set of set of V_{sys} and T_{98} ratings according to the analysis in IEC 62788-2-1.

Method B:

- Select the appropriate option:
  i) If breakdown occurred on all samples, report the median of the measured DC breakdown voltage V_{BD};
  ii) If breakdown occurred for only a portion of the samples, report the BDV as greater than (or equal to) the median V_{BD} (based on the measured breakdown values);
  iii) If breakdown did not occur for any of the samples, report the BDV as greater than or equal to the maximum test voltage level.

  Example: Assume the use of a 20 kV generator and the median is calculated as 19 kV, but for some of the samples no breakdown occurred, indicating that the breakdown strength exceeded 20 kV. In such cases, the median breakdown shall be reported as V_{BD} > 19 kV.
- The standard deviation (± 1 σ) as the measure of uncertainty;
- The adjusted V_{BD} for each set of maximum V_{sys} and T_{98} ratings according to the analysis in IEC 62788-2-1.

c) Ramping speed and type of mineral oil used;
d) The maximum test voltage of the equipment;
e) Any deviations from, additions to, or exclusions from the test method shall be reported.
f) Any other information relevant to a specific test, such as specimen conditioning and environmental conditions, including the oil temperature during testing, or the location of the failure (e.g. electrode periphery or centre, etc.), may be reported if considered relevant.

4.5.2 Lamination protrusion test (aka DTI test)

4.5.2.1 Purpose

This test evaluates the thickness of RUI layers after lamination with a protrusion. An 800 µm diameter solder wire is used to stress any materials which flow or compress under the heat and pressure of a lamination cycle. This simulates a worst-case protrusion such as solder peaks or inclined ribbons [7]. The output is a diagram showing the cross-sectional thicknesses of each layer after lamination.

This information is used for analysis by methods defined in IEC 62788-2-1, to provide the thickness of relied-upon insulation (t_{DTI}) as a function of the rated system voltage and module operating temperature.

The test is also used to identify layer materials in the front- or backsheet construction that are potentially in contact with protruding live parts under aforementioned lamination conditions and for which tracking material classes need to be determined (see 4.5.3).

4.5.2.2 Sample preparation

Cut materials to 210 mm × 148 mm (A5 format), with tolerances of ± 20 mm for both directions:

- Front- or backsheet (inner layer facing encapsulant);
- Encapsulant with thickness of 450 µm ± 100 µm;
- Release material (e.g., fluoropolymer film) with a thickness of ≤ 50 µm.

Cut a piece of solid solder wire without flux, having a diameter of 800 µm ± 50 µm and a minimum length of 15 cm. The melting temperature of the solder wire shall be at least 20 K higher than the maximum lamination temperature. To limit environmental concerns, lead-free solder is recommended, e.g. 96 % Sn / 4 % Ag. There shall be no significant deformation of the solder wire during the test.

With a piece of surface-structured PV glass 3,2 mm ± 1 mm thick, 210 mm × 148 mm with tolerances of ± 20, on the bottom (structure facing down), stack the materials as shown in Figure 8. Place the inner layer of the front- or backsheet facing the encapsulant.

See also Coupon H in Table A.1.

NOTE The diameter of 800 µm mimics the size of solder peaks in the case of manual soldering and also represents protrusions introduced by twisted ribbons or bend of ribbon, for which similar sized defects have been observed. The cylindrical wire geometry improves the reproducibility of the test compared to using a tip defect: i) a tip is difficult to reproduce and ii) the position of a tip is difficult to match in a cross-section, which is required to detect the minimum remaining thickness after test.

Laminate the stack with the temperature and pressure conditions described in 4.1.2 (option 3).

Remove the glass and release film from the stack after the lamination, see Figure 8.

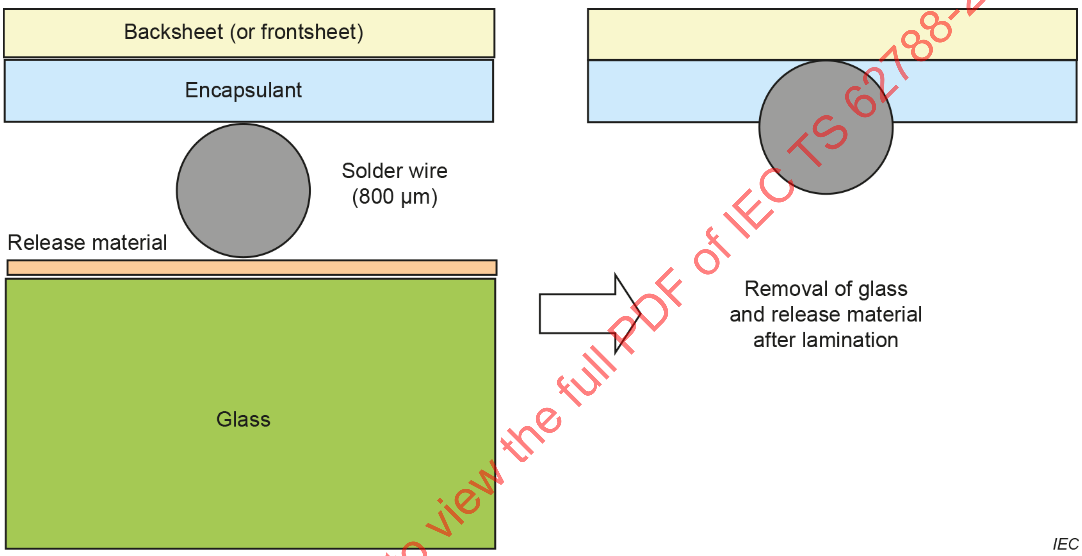


Figure 8 – Schematics of test specimen for DTI test before and after lamination

4.5.2.3 Apparatus

Tools suitable for cross-sectioning, e.g. a rotary or sledge microtome. A high-quality measurement would be obtained from micrographs of a polished cross-section of samples embedded in resin.

Suitable measurement tools include calibrated light microscopes, laser microscopes or SEM.

DTI is the minimum thickness value of the RUI layers from the cross-section measurement (see IEC 62788-2-1), from which the accuracy of the method rounded to 1 µm is subtracted.

4.5.2.4 Procedure

Cross-section the sample at three locations at a minimum 10 mm distance from each other along the wire, and a minimum distance of 10 mm from either any end of the wire (in case the wire ends within the laminated stack) or edge of the laminated stack.

If the solder wire has significant deformation, repeat with a different solder wire.

The cross-section should be orthogonal to the wire and obtained with a suitable method. For some cross-sectioning methods it can be useful to remove the embedded solder wire prior to sectioning. Ensure not to damage the backsheet when removing the solder wire.

Mount the prepared cross-section in the microscope. In the microscope picture or micrograph image, identify and label each individual layer, according to the layers given by the front- or backsheet manufacturer.

Identify the position of the minimum thickness in the trough created by the solder wire, and measure the thickness of each layer of the multilayer sheet at that minimum position. Save a copy of the cross-section image that indicates the measurement position and the minimum thickness value (see Figure 9).

Repeat for each cross-section and measure the thickness of each layer.

4.5.2.5 Reporting requirements

Report:

a) The composition of the solder wire, its melting temperature and absence of flux;
b) Thickness and type of encapsulant (e.g. EVA including fast- and slow-cure type, TPO type, silicone type);
c) Overall duration (time), temperature, and pressure of lamination cycle;
d) A microscopic image of the cross-section at which the absolute minimum thickness has been measured and in which the measurement position is indicated, as shown in Figure 9;
e) Identification of the material (layers) that are in contact with the solder wire;
f) Thickness of each layer after the lamination protrusion test;
g) The total thickness (t_{DTI}) of the RUI layers after the test as a function of $[V_{sys}]_{max}$ and $[T_{98}]_{max}$ ratings, according to the analysis in IEC 62788-2-1.

An example is provided in Figure 9. The perimeter of the removed solder wire is indicated by the dash-dotted line. If the solder wire is regarded as a live part, then the cross-section would indicate the contact points of the live part to interfaces between layers of the sheet, at which tracking could occur (see 4.5.3).

In Figure 9 these contact points with material interfaces are indicated by numbers 1 and 2 and the corresponding material interfaces are indicated by dashed and dotted lines, respectively.

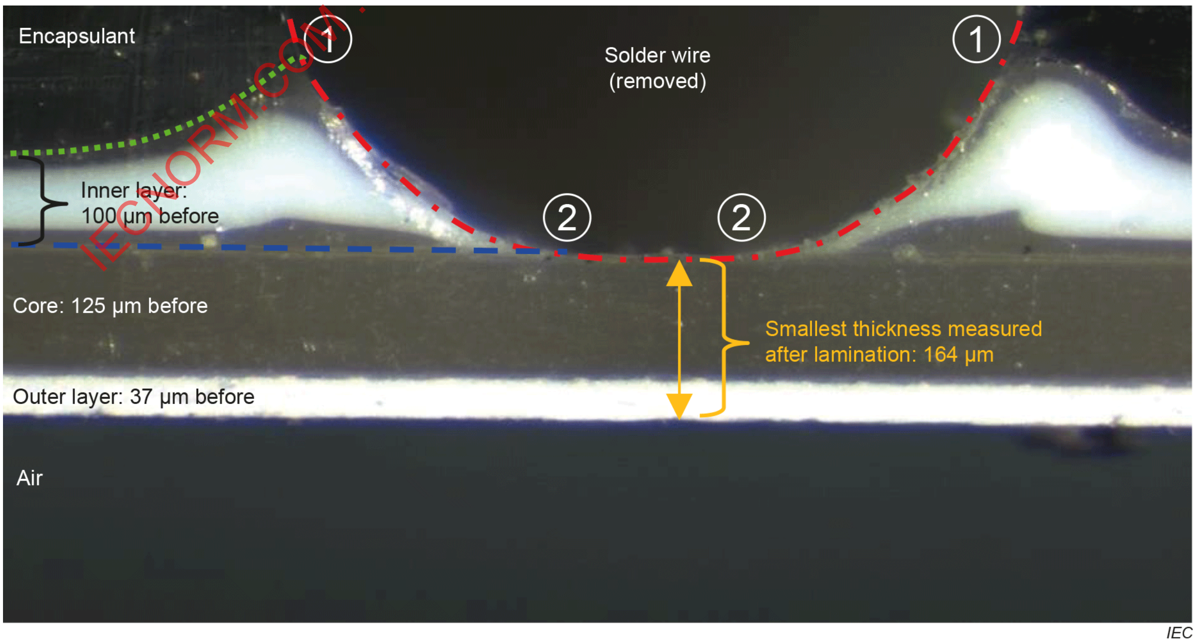


Figure 9 – Example of DTI cross-section of a backsheet

4.5.3 Comparative tracking index (CTI)

4.5.3.1 Purpose

This test evaluates the tendency of polymeric materials to electrically track when in contact with conductive parts. Any material interface which could be contacted with a live part shall be considered a tracking hazard. The CTI is used to categorize materials into material groups, for review of insulation coordination of a PV module in the IEC 61730 series. The material group designation of a layer is not required, but can reduce minimum spacing requirements for the module design in IEC 61730-1.

Any layers in contact with the solder wire of the lamination protrusion test are considered as susceptible to tracking and can be evaluated for creepage distance in the module design review, as indicated in Figure 10.

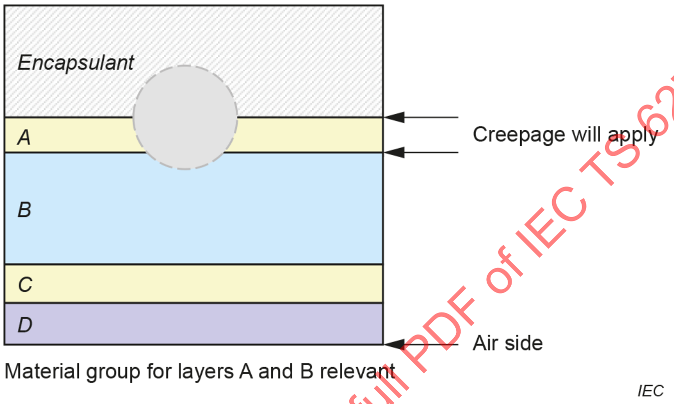


Figure 10 – Schematic indicating need for CTI measurement of materials A and B to determine creepage distances

4.5.3.2 Sampling

According to IEC 60112, 3 mm stacks of individual layers are used. Alternatively, 3 mm thick plates of the materials can be prepared.

4.5.3.3 Method

The comparative tracking index is determined according to IEC 60112 without determination of erosion depth.

The comparative tracking index (CTI) of the appropriate material layers of the front- or backsheet is evaluated according to IEC 60112. Relevant CTI values evaluated in accordance with UL 746C are accepted as an alternative to CTI values evaluated in accordance with IEC 60112 for determination of the material group (see IEC 61730-1):

Material Group	I	$600 \leq CTI$
Material Group	II	$400 \leq CTI < 600$
Material Group	IIIa	$175 \leq CTI < 400$
Material Group	IIIb	$100 \leq CTI < 175$

The values specified for the groups are reference values and based on the test voltage of IEC 60112. The test voltage is not in relation to any voltage (system voltage, working voltage, etc.) of a PV module or system.

IEC 60112 defines sample preparation. Each material belonging to a multi-layered front- or backsheet for which tracking has to be evaluated, shall be provided for test, either as stacked sheets or 3 mm plate-like specimen.

Stacking of multi-layered front- or backsheets representing different layer materials is not equivalent to stacking of sheets of the targeted material layer.

4.5.3.4 Reporting requirements

Report in accordance with IEC 60112:

a) A diagram of the front- or backsheet indicating the layers in contact with the solder bump from the lamination protrusion test, showing the material layers tested;
b) The CTI value;
c) The material group;
d) Sample stack preparation (stacked sheets or 3 mm plate-like specimen).

4.5.4 Volume resistivity

4.5.4.1 Purpose

This test method provides the volume resistivity of materials used as front- or backsheet. The test is performed on separate dry and wet preconditioned samples. This test is designed for room-temperature measurement, but it can also be utilized at higher temperatures.

Even though the concept of volume resistivity is more applicable for volumetric insulating materials such as encapsulants than for electrical insulation of cover sheets used as thin insulators, volume resistivity is used to indicate the intrinsic level of electrical insulation (or leakage currents) provided by a given material.

4.5.4.2 Sampling

Depending on the front- or backsheet construction, obtain films consisting of the complete sheet, and as many of the other individual layers as is reasonably possible and relevant to the final product. Use film specimens of the thickness used in the final product. Minimum sample sheet size shall be 100 mm × 100 mm. Test the samples at 1 000 V DC using Method A according to IEC 62788-1-2 with both wet and dry conditioning at 23 °C ± 2 °C. Each measurement will use the average and standard deviation (± 1 σ) of the measurement on five samples of each material.

If there is a conductive layer embedded in the backsheet, then the orientation of the sample is important because the two electrodes are normally of different dimensions. In this case, one should use custom electrodes with the same area (for example, an unguarded configuration with both electrodes being 50 mm in diameter), or report the results for the orientation with the higher resistivity where the smaller electrode is the current-limiting one.

For many front- or backsheet materials using common commercially available equipment, the resistivity will be so great that the measurement of volume resistivity may not be possible. In this case, report that the resistivity is greater than the value measurable with the instrument, identifying the corresponding maximum resistivity value for the instrument.

4.5.4.3 Procedure

Volume resistivity shall be measured according to IEC 62788-1-2.

4.5.4.4 Reporting requirements

Report the following:

a) Description and identification of each of the films tested, including specimen material composition and thickness;
b) Identification of the test method used (i.e. IEC 62788-1-2 Method A, wet or dry);

c) For specimens composed of multiple layers, indicate that the measured resistivity is an effective bulk resistivity;

d) The mean volume resistivity of five measurements and the standard deviation (± 1 σ) are reported in [Ω·m] following the reporting provisions in IEC 62788-1-2.

4.6 Optical characteristics

4.6.1 General

In addition to visual inspection, instrument characterization shall be used to determine optical characteristics as well as appearance related attributes.

a) The characterization of optical properties may help the PV module designer to select suitable front- and backsheets with respect to photon capture efficiency and thermal management.

   - Optical transmittance of the frontsheet directly affects PV module performance. The optical transmittance of the backsheet directly affects the performance of bi-facial PV module designs.
   - Module performance following from the reflectance of the sun-facing side of the backsheet depends on factors including: module design, distance between cells, module temperature, and type of mounting (roof or rack). For typical crystalline silicon (c-Si) modules, the combined optical and thermal effects result in reduced performance when using a black backsheet compared to the same PV module constructed with a white backsheet.
   - Module performance following from the reflectance of the airside of a backsheet depends on factors including: module design, module installation (roof/rack and inclination angle), level of albedo, ventilation, and module temperature. The indirect contribution (e.g. via albedo) is typically very small compared to sun-facing side contributions.

b) Appearance characteristics may be used to describe initial colour and gloss in addition to verbal classifiers, e.g., “white, grey, blue, black, etc.” or "glossy, matte" or their changes in the context of ageing tests.

   - ΔYI (delta yellowness index) or ΔE (via CIE L*a*b*) may be used to assess discoloration. ΔYI is generally accepted and recommended for characterization of white and transparent front- and backsheet materials, whereas ΔE is preferred for coloured and black materials.

     Yellowing can be induced by small changes in a small number of molecules and discoloration is therefore not necessarily correlated with degradation of mechanical or electrical properties [8]. For the same amount of yellow molecules, the optically-measured level of yellowing also depends on pigment (e.g., TiO_2) concentration and optical layer design of the backsheet. This correlation shall be assessed individually for every sheet type. Yellowness is typically well-correlated to total reflectance, but it may require substantial amounts of yellowing, to the point of the material looking brown, to decrease the reflectance by as much as 10 %. Thus, it is expected that yellowing will only correlate to very small changes (<< 1 %) in power output.

   NOTE 1 ΔYI and b* use different scales, therefore the parameter cannot be used interchangeably

   - Changes in gloss may be useful as precursor of chalking of the polymeric sheet.

NOTE 2 The applicability of gloss measurements depends on the composition of the front- or backsheet. Observation of gloss change in a sheet material that is initially of matte appearance is usually not resolvable. Comparison of gloss differences between systems of different compositions can be misleading. Suitability of measuring change of gloss may be limited to R&D context for following up ageing of specific systems.

4.6.2 Specimen preparation

4.6.2.1 Sampling of specimens

For optical characterization a number of three replicates is required, which are sampled according to Annex A. The total area of the three specimens for visual inspection (4.6.3) shall be (1 ± 0,1) m^2 for unaged samples. Suitable specimen dimensions for instrument measurements depend on the details of the measurements devices (4.6.4 to 4.6.8) including measurement port and specimen holder, and typically vary in a range of 5 cm × 5 cm to 10 cm × 10 cm.

4.6.2.2 Conditioning of specimens

Before determination of the optical characteristics of the sheets, either unaged or after ageing, samples shall be pre-conditioned to 23 °C ± 3 °C, 50 % ± 3 % RH, for a minimum of 24 h prior to visual assessment of instrument measurements as recommended in Class 2 of ISO 291.

4.6.3 Visual inspection

4.6.3.1 Purpose

To identify defects in the sheet or laminated sample that could confound testing or instrument analysis. The nature of those defects may change as a function of any pre-treatment, such as a lamination step or an ageing test.

4.6.3.2 Procedure

All visual examination tests shall be performed by observers with (corrected-to) normal vision at 30 cm to 50 cm viewing distance in reflection mode and under illumination levels of at least 1 000 lx, unless otherwise specified.

For visual inspection of pinholes in front- or backsheets or cracking of the inner layer of laminated specimens after ageing, a light box (i.e. a backlit unit providing diffuse illumination) with a light flux of at least 1 500 cd/m^2 shall be used. Specimens are placed into the light box and then inspected from airside and inner side in transmission mode, with (corrected-to) normal vision at 30 cm to 50 cm viewing distance using a magnifying glass providing a magnification between ≥ 5 x and ≤ 10 x. Mask the specimen observation area with an opaque material around the sample to avoid diffuse glare from the backlit unit that will reduce contrast sensitivity during the observer task and/or disturb camera-based image capture.

Visual inspection examines for the presence of the following conditions and/or defects:

a) Clean and smooth surface;

b) Bubbles or holes;

c) De-lamination (for a multilayer structure);

d) Wrinkles;

e) Cracks;

f) Impurities or significant defects;

g) Pinholes.

4.6.3.3 Reporting requirements

Make note of and report the presence or absence of any of aforementioned conditions (in 4.6.3.2) and their nature on three replicates of the sample under investigation.

A photograph is recommended for documentation.

4.6.4 Optical transmittance

4.6.4.1 Purpose

The optical transmittance of a front- or backsheet is relevant to estimate its effect on PV module performance (see 4.6.1) if the sheet is essentially clear or highly translucent. Optical transmittance is measured, if the main function of the sheet is to provide transmission of solar radiation (as opposed to reflection). If optical reflection is required to be characterized in addition, refer to 4.6.5.

NOTE Examples of clear backsheets include backsheets for use in bifacial PV modules.

For optical calculations in the context of a specific PV module design, the measured transmission curve of the front- or backsheet shall be provided. The solar (AM1.5) photon-weighted transmittance can be used as a general one-number comparison with alternative materials.

Before publication of IEC 62805-2 or IEC 62788-1-4, test methods for architectural glass were historically often employed in reports of transmittance of front- and backsheets: in one part, EN 410 makes use of the photopic response function V_λ that describes the brightness response of the human eye (with a peak sensitivity at 560 nm). However, V_λ is not representative for the sensitivity spectrum of PV-active material, and it should therefore not be used for yield considerations. EN 410 and ISO 9050 refer to the intensity-weighted solar spectrum, which does not correctly consider the elementary process of photon capture in a PV cell.

4.6.4.2 Apparatus, procedure and sampling

The hemispherical spectral optical transmittance of the front- or backsheet is measured as stipulated for solar glass in IEC 62805-2. Details of the integrating-sphere-based spectrophotometer realizing a directed/diffuse geometry as well as the measurement procedure are also defined in IEC 62805-2.

NOTE IEC 62788-1-4 describes solar transmittance measurements of encapsulants and defines the calculation of UV cut-off wavelength.

A sample sheet free of visual defects shall be prepared, large enough to cover the entrance port of the instrument with an overlap of at least 10 mm to every side: for a 25 mm Ø port the minimum sample size is thus 45 mm × 45 mm or 45 mm Ø circle. The sun-facing side of the frontsheet shall be orientated towards the directed light source.

For yield-related calculations, the representative solar range of 300 nm to 1 250 nm shall be measured with a maximum spectral resolution of 5 nm. Optionally, the solar photon-weighted transmittance of the frontsheet is calculated according to IEC 62805-2 to provide a one-number performance figure, even though that number is not specific for a particular PV design. The weighted summation with the AM1.5 spectrum shall be based on the 1 nm partition, for which linear interpolation of the transmission spectrum may be required.

4.6.4.3 Reporting requirements

Report the average (of the three replicates) of the spectral optical transmittance data as a graph or data table. Report the instrument geometry, e.g., 8°/d, and the side of the sheet that has been measured. Optionally, the representative solar (AM1.5) photon-weighted transmittance as in IEC 62805-2 may also be reported (in the range 300 nm to 1 250 nm).

4.6.5 Optical reflectance

4.6.5.1 Purpose

The optical reflectance of a reflective backsheet can be used to estimate its contribution to the PV module performance, if one function of the backsheet in the PV module design is to provide reflection of solar radiation (as opposed to transmission). The procedure applies to both sides of the backsheet; however, the effects on performance for the airside (e.g., via contribution to albedo in PV utility systems) are much smaller than those from the sun-facing side; therefore, only the sun-facing side is required to be measured. The measured spectral reflectance of the sun-facing side of the backsheet may be provided for optical calculations in the context of a specific PV module design. The solar photon weighted reflectance can be used as a general comparison between alternative materials. The optical reflection of a frontsheet can also be measured to determine for example reflection losses.

4.6.5.2 Apparatus, procedure and sampling

The hemispherical spectral optical reflectance of the front- or backsheet is measured as stipulated for solar glass in IEC 62805-2. Details of the sphere-based spectrophotometer realizing a directed/diffuse geometry, preferably 8°/d, and the measurement procedure are defined therein. In addition, it is required, that the illuminated area of the sheet material has a distance to the edge of the measurement port sufficiently large to limit unintentional reduction of reflected intensity by lateral light transport in the sheet.

NOTE Surface-related specular reflection is practically absent in optical contact of backsheet with a near-to-index-matching encapsulant. When measured in air, a rougher inner side can result in less specular reflection of the backsheet. However, reflective functionality of the backsheet in use is based on laminated state and the properties of the interface between encapsulant and inner side will determine the degree of specular reflection. Differentiation of specular and diffuse component based on the air interface of inner side of backsheet does not provide additional information for the functional characterization of backsheet [9].

Sample sheets free of visual defects shall be prepared, large enough to cover the entrance port of the instrument with an overlap of at least 10 mm to every side: for a 25 mm Ø port the minimum sample size is thus 45 mm × 45 mm or 45 mm Ø circle. The inner side of the (front- or) backsheet shall be orientated towards the directed light source. A sample backing with a reflectance of less than 1 % (e.g., light trap) shall be used during measurement.

For yield-related calculation the representative solar range of 300 nm to 1 250 nm shall be measured with a spectral resolution of 5 nm or less.

Optionally, the solar photon weighted reflectance of the (front- or) backsheet is calculated according to IEC 62805-2 to provide a one-number performance figure, even though that number is not specific for a particular PV design. The weighted summation with the AM1.5 spectrum shall be based on the 1 nm partition, for which linear interpolation of the reflectance spectrum may be required.

4.6.5.3 Reporting requirements

Report the average (of the three replicates) of the spectral optical reflectance data as graph or data table. Report the instrument geometry, e.g. 8°/d, and the side of the sheet that has been measured. Optionally, the representative solar (AM1.5) photon-weighted reflectance as in IEC 62805-2 may also be reported (in the range 300 nm to 1 250 nm).

4.6.6 Yellowness index

4.6.6.1 Purpose

This procedure quantifies the degree of yellowness of a test sample, and it serves as a means to compare changes in materials resulting from weathering exposure with a report of ΔYI. For interpretation of changes in YI see general remarks in 4.6.1 b).

The choice of the measurement geometry for yellowing follows the intended function of the sheet in the PV module. For essentially clear and low-scattering materials with transmissive function in the PV module (e.g. frontsheets and clear backsheets), YI is evaluated based on transmission measurements. For essentially opaque sheets with reflective function in the PV module, change of YI of the sun-facing side of the backsheet is evaluated in reflection geometry.

The characterization of discoloration via $\Delta L^*\Delta a^*\Delta b^*$ or ΔE_{ab} (CIE 1976) is a suitable alternative, with Δb^* an alternate to ΔYI, considering that Δb^* and ΔYI represent different scales.

NOTE A change of 1 Δb^* represents approximately a change of 2 ΔYI units.

For coloured backsheets, measurement of colour changes via CIE ΔE_{ab} based on reflectance measurements is preferred.

4.6.6.2 Apparatus, sampling and procedure

Determine the YI as in ISO 17223, starting from spectral transmittance or reflectance data measured on sample sheets. Details of the sphere-based spectrophotometer and the measurement procedure are defined there in ISO 17223. A range of spectral measurement of 360 nm to 830 nm with a spectral resolution of 5 nm or less shall be used. For report of changes after ageing tests, an instrument with a measurement range of 380 nm to 780 nm with a spectral resolution of 10 nm is also suitable. Alternatively, a colorimeter may be used.

NOTE 1 Details of instrument configuration can influence the "absolute" YI values measured. Such effects cancel out to first order when changes in yellowness index (ΔYI) are calculated. Examples of instrument configurations are illumination/detection geometry being diffuse/directed or directed/diffuse and distance of the borders of illuminated to detected specimen area in view of lateral light transport in the sheets. Capability of lateral light transport depends on multilayer stack design of the sheet.

Sample sheets free of visual defects shall be prepared large enough to cover the entrance port of the instrument with an overlap of at least 10 mm to every side: for a 25 mm Ø port the minimum sample size is thus 45 mm × 45 mm or 45 mm Ø circle.

The side of the sheet that shall be measured shall be orientated towards the light source. For reflectance measurements the half-space behind the sample sheet shall provide less than 1 % reflectance (e.g., by using a light trap).

The three tristimulus coefficients shall be determined using the CIE Standard D65 illuminant spectrum (as in ISO 11664-2) and the CIE 1964 XYZ colour space (for a human observer with a 10° field of view, as in ISO 11664-1). A colorimeter directly provides X, Y and Z. YI shall be calculated according to ISO 17223.

NOTE 2 Additional details related to the YI can be found in ASTM E313-10 [10] and ASTM E308-08 [11].

4.6.6.3 Reporting requirements

Report the average (of the three replicates) of YI values according to purpose (e.g. initial values or post-weathering evaluation). In the context of post-weathering evaluation, the difference in yellowness index ΔYI can be reported.

Report the measurement mode (reflection or transmission and the instrument geometry) and the side of sheet measured.

4.6.7 Colour measurement

4.6.7.1 Purpose

Colour measurements are suitable for appearance characterization of clear and opaque sheets, especially if coloured (e.g., black or blue). This procedure also quantifies changes of colour of a test sample, and it serves as a means to compare changes to materials resulting from weathering exposure with a report of colour change.

NOTE The coordinate b^* correlates with yellowness index (see 4.6.6).

4.6.7.2 Apparatus and sampling

Determination of CIE $L^*a^*b^*$ follows the procedure in ISO 11664-4 and starts from spectral transmittance or reflectance data measured on sample sheets. Details of the sphere-based spectrophotometer and the measurement procedure are defined in ISO 11664-1. A spectral measurement range of 360 nm to 830 nm with a spectral resolution of 5 nm or less shall be used. For report of changes after ageing, an instrument with a measurement range of 380 nm to 780 nm with a spectral resolution of 10 nm is also suitable. Alternatively, a colorimeter may be used.

NOTE Details of instrument configuration can influence the absolute values of colour coordinates L^*, a^*, and b^* measured. Such effects cancel out to first order when changes in colour coordinates (ΔE_{ab}) are calculated. Examples of instrument configurations are illumination/detection geometry being diffuse/directed or directed/diffuse and distance of the borders of illuminated to detected specimen area in view of lateral light transport in the sheets. Capability of lateral light transport depends on multilayer stack design of the sheet.

The choice of the measurement geometry for discoloration follows the intended function of the sheet in the PV module. For essentially clear and low-scattering materials with transmissive function in the PV module (e.g., frontsheets and clear backsheets), ΔE is evaluated based on a transmission measurement. For essentially opaque sheets with reflective function in the PV module, ΔE of the sun-facing side of the backsheet is evaluated in reflection.

Sample sheets free of visual defects shall be prepared large enough to cover the entrance port of the instrument with an overlap of at least 10 mm to every side: for a 25 mm Ø port the minimum sample size is thus 45 mm × 45 mm or 45 mm Ø circle.

The side of the sheet that shall be measured shall be orientated towards the light source. For reflectance measurements the half-space behind the sample sheet shall provide less than 1 % reflectance (e.g. light trap).

From the reflection or transmission spectra, respectively, the three tristimulus coefficients shall be determined using the CIE Standard D65 illuminant spectrum (as in ISO 11664-2), and the CIE 1964 XYZ colour space (for a human observer with a 10° field of view, as in ISO 11664-1). A colorimeter directly provides X, Y and Z. From X, Y and Z, the CIE L^*, a^*, b^* coordinates are calculated and from these the pairwise differences CIE ΔL^*, Δa^*, Δb^*, e.g., after versus before an ageing treatment. From the latter, the colour distance CIE ΔE_{ab} (1976) is determined in accordance with ISO 11664-4.

4.6.7.3 Reporting requirements

Report the average (of the three replicates) of absolute L^*, a^*, b^* values (D65/10°) according to purpose (e.g., initial values or post-weathering evaluation). In the context of post-weathering evaluation, colour changes ΔL^*, Δa^*, Δb^* or ΔE_{ab} can also be reported.

Report the measurement mode (reflection or transmission, the instrument geometry) and the side of sheet measured.

4.6.8 Surface gloss

4.6.8.1 Purpose

To characterize the initial appearance of the airside of the (front- or) backsheet, acknowledging that lamination condition may influence glossiness.

Change in gloss may be correlated to retention of mechanical or electrical properties, depending on the composition of the material and its weathering behaviour. In some cases, changes in glossiness can be used as precursor of chalking; however, it is possible that such assessment will not be easily resolved for materials that are matte at the outset.

4.6.8.2 Procedure

Measure gloss according to procedure and using instruments stipulated in ISO 2813 on three replicates.

The initial measurement result on 60° gloss determines whether gloss values at 20°, 60°, or 85° shall be collected, because the gloss scale is less sensitive below 10 gloss units (GU) or above 70 GU: If > 70 GU is measured with 60° gloss angle, the 20° gloss condition shall be used. If < 10 GU is measured with 60° gloss angle, the 85° gloss condition shall be used.

If change of gloss values shall be characterized, e.g., during an ageing test, then the same angle as for the initial gloss measurement shall be used for the complete measurement set.

4.6.8.3 Reporting requirements

Report mean and standard deviation (±1 σ) of gloss values and the measurement angle 20°/60°/85°, depending on initial glossiness of material.

In the context of post-weathering evaluation, gloss changes can also be reported, with the gloss angle for all measurements determined by the angle of the initial reading.

4.7 Diffusion characteristics

4.7.1 Permeability of water vapour

4.7.1.1 Purpose

Water vapour permeability of the front- or backsheet may be useful for the design of the PV module and is expressed as water vapour transmission rate (WVTR) [12].

The range of suitable WVTR for polymeric front- and backsheet materials depends on the PV module design. In some instances, the polymeric sheet has the function of providing a barrier function for liquid water while still letting water vapour pass, as well as by-products such as acetic acid. In other instances, again the polymeric sheet is regarded as an impermeable membrane with permeation rates 4 or 5 orders of magnitudes lower than common front- or backsheet materials. WVTR relevant to cells will also depend on the encapsulant.

4.7.1.2 Procedure

In all cases, for initial value and after exposure to a stress condition, the samples shall be pre-conditioned to room temperature and humidity conditions (i.e., 23 °C ± 3 °C, 50 ± 3 % RH) for a minimum of 24 h prior to testing as recommended in ISO 291.

Measurements shall be carried out according to IEC 62788-6-2, ISO 15106-1, ISO 15106-2, or ISO 15106-3. Use the test conditions of 38 °C and 90 % RH. Instruments that can directly measure at 38 °C and 90 % RH are preferred. Alternatively, instruments designed for stable measurements at condensing conditions 38 °C and 100 % RH can be used. In the latter case, the WVTR value obtained at 100 % shall be multiplied by the factor 90 % representing the ratio of targeted and measured humidity level.

NOTE The results from any of the three methods can differ due to different detection. It has not been proven which method is preferred. One study has reported an increase of 12 % WVTR on increasing test temperature from 38 °C to 40 °C (both at 90 % RH).

Temperature sensitivity of WVTR depends on the thermal activation energy for diffusion and moisture sorption, which is specific for the polymeric materials employed. In that context temperature dependence of WVTR can be of interest for PV module design.

4.7.1.3 Reporting requirements

Report the following:

a) the method used, i.e. IEC 62788-6-2, ISO 15106-1, ISO 15106-2 or ISO 15106-3;

b) the test conditions (temperature in °C and relative humidity in % RH);

c) the WVTR value in g/(m^2·day) for conditions of 38 °C and 90 % RH. In case of measurement at 38 °C and 100 % RH the measured value shall be multiplied by 90 % and the remark "90 % of value measured at 100 % RH" shall be added.

4.7.2 Permeability of oxygen

4.7.2.1 Purpose

Permeability of front- and backsheets to oxygen is expressed as oxygen transmission rate (OTR) and affects the transient concentration of oxygen in the PV module which, in turn, may contribute to degradation of materials or structures in the PV module or improve performance via oxygen bleaching of chromophores depending of the module's design and the materials used.

NOTE In a comparative study of various types of backsheets, OTR was found to correlate with the transmission rate of acetic acid (AATR). Accumulation of acetic acid in EVA-based modules has been associated in some PV module designs with increased levels of corrosion observed on electrodes.

4.7.2.2 Procedure

Oxygen transmission rate shall be measured according to ISO 15105-2.

4.7.2.3 Reporting requirements

Report the following:

a) the method used, i.e., ISO 15105-2;

b) the test conditions (temperature in °C and relative humidity in % RH);

c) the OTR value in g/(m^2·day).

4.8 Chemical characteristics

4.8.1 Resistance to solvents

4.8.1.1 Purpose

This procedure describes a solvent rub technique for assessing the solvent resistance of a front- or backsheet. The final cleaning of PV modules may require solvent cleaning, and by this method the manufacturer can qualify a cleaning solvent as its recommendation.

4.8.1.2 Apparatus

4.8.1.2.1 General

A solvent according to film manufacturer recommendation and a 100 % cotton cloth.

NOTE Isopropyl alcohol (IPA) and ethanol are examples of solvents recommended for cleaning of various backsheets.

4.8.1.2.2 Definition

Double rub: The act of rubbing a cloth in one complete forward and back motion over the investigated sheet surface.

4.8.1.2.3 Safety

Proper safety equipment: As detailed in the solvent safety datasheet (SDS), i.e., use of solvent-resistant gloves and respirator.

4.8.1.3 Procedure

a) The test method described here is in accordance with ASTM D5402, Method A (Standard Method) [13].

b) If the testing is being performed in a laboratory setting, then before actually testing the specimens, perform a sufficient number of double rubs with the index finger covered with a cotton cloth on a laboratory balance such that 1 000 g to 2 000 g of force is constantly being applied. This is the amount of pressure the operator shall apply when testing the specimens, and it will be considered as moderate pressure.

c) Select areas on the (coated) surface at least 150 mm long on which to perform the tests. Clean the surface with tap water to clean and remove any loose material and then allow the surface to dry.

d) Measure the dry-film thickness of the sample in the selected areas in accordance with the test method of ISO 4593. Mark a 150 mm × 25 mm rectangular test area on the undamaged, cleaned surface using a pencil or other suitable solvent resistant marker.

e) Fold the cotton cloth into a pad of double thickness and saturate it (dripping-wet condition) with the specified solvent. Do not allow more than 10 s to elapse before proceeding to the next steps.

f) Place the properly protected index finger into the centre of the pad while holding excess cloth with the thumb and remaining fingers of the same hand. With the index finger at an angle of 45° to the test surface, rub the rectangular test area with moderate pressure first away from the operator and then back towards the operator at the rate of about 1/s.

g) Continue rubbing the test area for a total of 25 double rubs. Take care to always apply within the designated test area. If additional solvent rubs are specified, reposition the finger on an unused clean portion of the cloth and re-saturate the cloth with the selected solvent to a dripping-wet condition. Do not allow more than 10 s to elapse before continuing the double-rub procedure on the designated test area for an additional 25 double rubs. Repeat this step until reaching the specified test criteria, such as until the substrate becomes visible, or until all double rubs have been completed. If multiple specimens are being tested in a laboratory, then it may be useful to occasionally check the pressure exerted on a balance with a dry cotton cloth between specimens.

If multiple specimens are being tested and fatigue sets in making it difficult to maintain the 1 000 g to 2 000 g force, then stop testing (after completing a specimen) until fatigue is gone.

4.8.1.4 Final measurements

Examine the test area by visual inspection. Check that the film has not been removed down to the substrate. Immediately inspect the middle 125 mm of the rubbed area, disregarding 13 mm at each end, for fingernail hardness and visual changes in appearance, comparing the rubbed area with an adjacent non-rubbed area.

4.8.1.5 Reporting requirements

Describe the cloth and solvent used. Report the number of double rubs as well as the visual quality before and after rubbing.

Provide additional information, such as temperature and humidity. Elapsed time between coating applications and conducting the test can affect test results and should be reported whenever possible.

4.9 Other characteristics

4.9.1 Ignitability – Purpose

Fire safety assessment as defined in ISO 11925-2 is not recommended on the component level, because test results obtained without the thermal mass of the module being present are likely to cause misleading results. Instead, IEC 61730-1 covers this issue with a full module or representative coupon test.

Therefore, a specific test for ignitability of front- and backsheets on the component level is not covered in this document.

4.9.2 Flammability – Purpose

Fire-safety assessment as defined in ISO 11925-2 is not recommended on the component level, because test results obtained without the thermal mass of the module being present are likely to cause misleading results. Instead, IEC 61730-1 covers this test item with a full module or a representative coupon test.

Therefore, a specific test for flammability of front- and backsheets on the component level is not covered in this document.

4.10 Accelerated ageing tests

4.10.1 Purpose

Accelerated ageing is used to verify the ability of the front- or backsheet to withstand simulated environmental stresses, including heat, moisture and UV radiation.

Ageing tests are typically combined with visual inspection as well as material tests before and after exposure in order to assess changes of material properties under ageing conditions. The correlation of accelerated tests with field failures of modules is still under investigation, i.e., the relationship is not known between material changes upon cumulative exposure dose of stress applied in the accelerated test and the same dose present in the field. The fact that the latter also depends on the mounting conditions as well as the climate in which the module is installed, adds to this variability. However, there is general agreement on the order of stress to represent an end-of-life, intermediate, or infant-mortality test.

- For an end-of-life test, a lifetime cumulative dose or stress level has been applied. In the post-evaluation test the absolute (i.e., minimum) retained value of mechanical and electrical properties is assessed. No extrapolation is necessary.
- For intermediate or infant-mortality tests, only a portion of the service life dose / cumulative stress has been applied. In the post-evaluation test, the changes in mechanical and electrical properties are measured and extrapolation is applied. In the event of deviation from linear (first order) degradation, additional measurements as a function of the important stress variables (temperature, humidity, UV) are required to characterize the non-linear degradation mode for a meaningful extrapolation.

Material changes may be observed in safety related material properties, such as mechanical and electrical characteristics. Materials that become brittle may for example correlate to cracking observed on fielded PV modules.

If adhesion is affected, the physical integrity of the backsheet composition or its integration in the PV module may be jeopardized, eventually giving rise to safety hazards. Ageing may also introduce discoloration or other changes in appearance, which are not necessarily correlated to loss of mechanical and electrical properties, but which may affect solar reflectance, resulting in degradation of a PV module's power output performance.

Thermal endurance of front- and backsheet materials is assessed by TI or RTE (RTI) measurement (4.4.1) in combination with the thermal failsafe test (4.4.2).

This Subclause 4.10 describes accelerated damp heat testing, UV weathering and abrasion testing for polymeric front- and backsheets for use in terrestrial PV modules.

To prepare unaged ("fresh") material representative for application, the front- or backsheet specimens under test shall be exposed to a thermal pre-exposure, which incorporates the thermal effects of the lamination step (see 4.1.2). These conditions may introduce physical relaxation and/or recrystallization of material and may therefore influence the initial values, based on which retained values are obtained.

4.10.2 Damp-heat ageing test

4.10.2.1 Purpose

The damp-heat (DH) test assesses the ability of the front- or backsheet material to withstand extreme levels of temperature and moisture, which is useful for highlighting likely failure modes. The DH test was originally developed to examine corrosion within modules, and it may sometimes be applied to examine general material robustness; the test does not simulate the conditions encountered in a module during field use.

To assess the endurance of the insulating function of front- and backsheets, the mechanical strength and DC breakdown voltage are assessed before and after the DH test.

4.10.2.2 Samples

Refer to Table A.1 for sample preparation. Choose Coupon A or Coupon B1 for DH incubation followed by tensile strength test or DC breakdown voltage test.

See 4.3 for sample preparation intended for adhesion testing after DH test. In the case of adhesion with encapsulant, the lamination should be done with a fresh front- or backsheet for lamination of coupon B2. For pluck and shear tests, the handles shall be adhered to the sheets after ageing in order to avoid unintended interactions of adhesive with sheet material during long-term DH exposure.

The number of specimens depends on the test plan for DH testing, i.e., required and optional post-evaluation methods.

For ageing procedures and post-evaluation of junction-box adhesives, refer to IEC 62790.

4.10.2.3 Procedure

Apply the test procedure MQT 13 of IEC 61215-2 with the following conditions:

- Chamber air temperature: (85 ± 2) °C
- Relative humidity: (85 ± 5) % RH
- Test duration: 1 000 h

Place the samples in an appropriate way in the chamber to ensure homogeneous temperature on each surface of the samples. For example, this is given when samples are placed free hanging in the chamber.

4.10.2.4 Testing the retention of properties by post-evaluation tests

During a DH test, polymeric materials are exposed to moisture levels far above any use case conditions. Therefore, material shall be pre-conditioned according to requirements of the post-evaluation test.

a) Material characterization required for UCF (see Table 7) includes:
   - Samples shall be visually evaluated before and after DH test according to 4.6.3;
   - Mechanical strength (tensile strength and elongation at break, both MD and TD) of replicate specimen shall be measured before and after DH (see 4.2.4);
   - Adhesion of components of the multilayer sheet (see 4.3) is measured on replicate specimens before and after DH;
   - DC breakdown (or withstand) voltage of replicate specimens shall be measured before and after DH (see 4.5.1).

NOTE For ageing procedures and post-evaluation of junction-box adhesives, see IEC 62790.

b) Optional material characterization (see Table 7) includes:
   - Instrument based optical characterization can be carried out, see 4.6.4 (transmission), 4.6.5 (reflection), 4.6.6 (yellowness), 4.6.7 (colour) and/or 4.6.8 (surface gloss). No extra replicates are required: optical measurements are non-destructive and can be performed on samples foreseen for mechanical or electrical testing before conducting those tests;
   - Adhesion to a matched material, such as encapsulant or edge seal (see 4.3.3.2) is measured on replicate specimens before and after DH.

4.10.2.5 Reporting

Report the following:

a) The ageing parameters (climate parameters T/RH % and duration in hours);
b) The results from the required post-evaluation tests as listed in 4.10.2.4 a);
c) Optionally, the results from post-evaluation tests as defined in 4.10.2.4 b).

Report absolute results from the material evaluation tests after DH and % retention of initial values.

4.10.3 UV weathering

4.10.3.1 Purpose

The purpose of the weathering test is to characterize the ability of front- and backsheets to withstand simulated natural daylight in combination with elevated temperature and moisture, at typical module operation temperature and humidity levels observed in the field.

In order to assess the endurance of the films, their mechanical strength and DC breakdown voltage should be measured before and after weathering.

Whereas the frontsheet is mainly exposed directly on its sun-facing surface to the solar spectrum, the backsheet may be exposed by:

a) Radiation incident on the sun-facing side of the backsheet, with flux and spectral distribution depending on the PV module design;
b) Radiation may also reach the airside of the backsheet via diffuse reflections from the environment (so-called albedo). In both cases, flux and spectral distribution depend on the environment and the mounting configuration (e.g., roof, rack) [14] [15]. This test method therefore provides two orientations for testing the backsheet, namely sun-facing side or airside oriented towards the test light source.

Some backsheet films, typically those having an asymmetric layer stack, are purposefully designed for durability within a laminated combination of glass and encapsulant, considering that those layers may already act as a (partial) UV filter during use. This test method therefore provides a choice for testing backsheet films in sun-facing orientation, with and without UV filter according to their intended use. Either option requires a specific choice of sample preparation.

4.10.3.2 Sample preparation

Front- and backsheet samples shall be sampled from a roll according to Annex A.

Sample preparation for weathering depends on the size of specimen holders and the material test methods to be evaluated after weathering. Refer to Table A.1, for sample preparation. In addition, Table 3 gives an overview of sample preparation for exposure of the sun-facing side of backsheets in view of intended post-evaluation.

Frontsheet (only one side is tested):

– The sun-facing (air-)side shall be exposed directly to the test light source.
– The inner side is not directly exposed.

Backsheet (both sides are tested):

– The air-side shall be exposed directly to the light source.
– The sun-facing (inner) side shall be exposed to the test light source, either directly or indirectly through a UV-filter with one of the following options:

  Option 0 – direct exposure without UV filter: In this optional method, the sun-facing (inner) side of the backsheet is exposed without a UV filter. See specimen A1 in Table A.1. This method can be selected for weathering of sheet material intended for optical characterization, mechanical strength testing, and dielectric strength testing.

  Option 1 – exposure with laminated UV filter:

  One realization of a representative UV filter is obtained by lamination of a design-specific laminate containing a transparent release material (TRM) as defined in 4.10.3.3, so that films can be sampled after weathering for subsequent material tests. For optical measurement, mechanical strength testing and electrical strength testing, Coupon B1 as defined in Table A.1 is selected. For adhesion peel testing, Coupon B2 is suited. For pluck test, lap shear test and fracture mechanics test (see Annex B), Coupon D applies (without TRM).

  Options 2 – exposure with optical UV filter:

  An alternate realization is the use of a separate optical filter with the intended UV cut-off characteristics. During weathering, the filter is located between the light source and the test specimens. This represents Coupon C as defined in Table A.1. This method can be selected for weathering of sheet material intended for optical characterization, mechanical strength testing, and dielectric strength testing.

Options 1 and 2 are intended to simulate the presence of UV filtering provided by a combination of PV glass and encapsulant, when the design of the backsheet requires such optical filtering function for long-term field use. A typical UV cut-off wavelength for PV glass and encapsulants is in the range 290 nm to 360 nm. See requirements in 4.10.3.3 for qualification of UV filters and transparent release material (TRM).

NOTE 1 In option 1, the sun-facing side of the backsheet is protected against eventual oxygen related degradation processes in a manner comparable to use in a laminated PV module; in options 0 and 2, it is not.

Table 3 – Overview of sample preparation for exposure of sun-facing (inner) side of backsheet depending on intended post evaluation (see Table A.1)

<table>
<tr><th colspan="2">Post evaluation</th><th colspan="2">Specimen construction using backsheet</th></tr>
<tr><td colspan="2" rowspan="2">Mechanical strength (4.2.4)
Electrical strength (4.5.1)
Optical characterization (4.6)</td><td>Separate sheet
→ options 0 and 2</td><td>Laminated sheet
with release → option 1</td></tr>
<tr><td>Coupon A
(without UV filter → option 0)

OR Coupon C
(optical UV filter → option 2)</td><td>Coupon B1
(full release)</td></tr>
<tr><td rowspan="3">Adhesion (4.3)</td><td>180° peel (4.3.4.1)</td><td>Not applicable</td><td>Coupon B2
(partial release)</td></tr>
<tr><td rowspan="2">Single cantilevered beam test (4.3.4.4)</td><td colspan="2">Laminated sheet without release → option 1</td></tr>
<tr><td colspan="2">Coupon D and E with specific handles = F3
(see Table A.1)</td></tr>
</table>

NOTE 2 Coupon G1 for adhesion T-peel test (see Table A.1) is not suited to obtain exposure on sun-facing side of a backsheet. To overcome that limitation, a polymeric frontsheet could be used as the counterpart of the backsheet to create a quasi-symmetric specimen for T-peel. Details of specimen construction are not covered by this document.

For the mechanical strength test as post-evaluation, the following requirements for sample preparation apply, in addition to those stipulated in 4.2.4.

Number of specimens depends on test plan for weathering testing, i.e., required and optional post-evaluation tests.

Cutting and trimming of sheet material intended for mechanical strength testing shall be done after weathering in order to avoid edge effects by ingress of moisture and UV. Portions of the sheet that were covered during weathering or that fall within a 5 mm distance to the covered area shall be trimmed, so that these are not present in the portion of specimen mounted within the initial grip distance.

For pluck test, lap shear tests, and fracture mechanics test (see Annex B), the corresponding handles (see F1, F2, and F3, respectively, as defined in Table A.1) shall be mounted to the sheets after ageing to avoid unintended ageing of the adhesive or interactions of adhesive with sheet material during long-term UV exposure.

NOTE 3 Junction-box adhesives in actual field use are hidden in between backsheet and junction box and therefore, they are barely exposed to UV (neither direct through the PV module nor via albedo). IEC 62790 describes ageing tests of junction-box adhesives.

4.10.3.3 Characterization of UV filters and transparent release material (TRM)

The diffuse transmission spectrum of the UV filter, e.g., optical filter glass or a laminated coupon "G/E/E/TRM" or "G/E/TRM/E", shall be measured in the range 300 nm to 1 250 nm following the procedure in 4.6.4. From the spectra, the 10 % UV cut-off value shall be determined according to IEC 62788-1-4 for reporting. Filter material is qualified for the test, if the cut-off wavelength is stable within ±3 nm comparing its measurement before and after UV exposure. For long exposure times, it is possible that UV filters will be required to be replaced by fresh filters of the same type. Stable filter material may be re-used in subsequent tests.

The transparent release material (TRM), see Table A.1, shall have:

a) A solar-photon-weighted transmittance ≥ 85 % in both spectral ranges:

- 280 nm to 2 500 nm, and
- 300 nm to 400 nm;

b) A thickness between 50 µm to 125 µm.

The calculation of a solar-weighted transmittance is described in IEC 62788-1-4 using the global photon flux (AM1.5) provided in IEC 60904-3.

Suitable materials include:

- Perfluorinated ethylene propylene copolymer (FEP) film;
- Ethylene tetrafluoroethylene (ETFE) film, as pure formulations without UV absorbers.

NOTE 1 Films thinner than 50 µm could introduce wrinkling during lamination, whereas films thicker than 125 µm could introduce an unnecessarily strong diffusion barrier, making the test less representative of actual use.

NOTE 2 Direct contact between TRM film and neighbouring layers could get lost locally during weathering exposure. If the material at the sun-facing side of the backsheet is susceptible to oxygen-induced degradation, this could introduce e.g., non-homogenous discoloration, even though on a level much smaller than when performing the weathering test without the frame-laminated TRM/E/G filter stack.

NOTE 3 It has been observed that up to 0,5 % and 0,8 % larger transmittance values are obtained for 125 µm thick films of FEP and ETFE, when measured in the limited spectral range of 300 nm to 1 000 nm instead of 280 nm to 2 500 nm.

4.10.3.4 Apparatus

A weathering apparatus according to IEC TS 62788-7-2 Method A that provides a spectral power distribution that simulates natural daylight as defined in ASTM D7869. Specimen holders without backing are required for UV exposure.

4.10.3.5 Procedure

The choice of temperature settings for the UV test procedure, which are listed in IEC 62788-7-2 as conditions A1 though A3, depend on the combination of two aspects:

a) The rated module operating temperature of a PV module in which the front- or backsheet under test will be applied;

b) The absorbance A of materials under test, which is obtained from measurement of total transmission T (4.6.4) and total reflection R (4.6.5) and calculated as solar (AM1.5) photon-weighted absorbance $A = 1 - T - R$. Low absorbing material (e.g., white or clear) has a solar-weighted absorbance of up to 20 % in the range 300 nm to 2 500 nm. Material with a solar-weighted absorbance of between 20 % and 80 % is called "coloured" (e.g., blue or grey). Material is called "black" if the solar-weighted absorbance is 80 % or above.

For white and clear front- and backsheet materials, the test shall be carried out according to the A3 condition of IEC TS 62788-7-2. For black or coloured backsheets, alternative test conditions A1 or A2 of IEC TS 62788-7-2 may be selected to provide a sheet temperature T_s of at least 65 °C, depending on the maximum rated module operating temperature $[T_{98}]_{max}$ (see IEC 62788-2-1 and IEC TS 63126) as shown in Table 4.

Table 4 – UV exposure conditions

Type of front-/backsheet	Rated module operating temperature		
	$T_{98} \leq 70$ °C (IEC 61730-1, default)	$T_{98} \leq 80$ °C (IEC TS 63126, level 1)	$T_{98} \leq 90$ °C (IEC TS 63126, level 2)
White/clear ($A \leq 20$ %)	A3	A3	A3
Black or coloured	A3 (A1 or A2 if $T_s > 65$ °C)	A3 (A2 if $T_s > 65$ °C)	A3

NOTE 1 When testing for $T_{98} \leq 70$ °C, conditions are selected to provide an estimated sheet temperature of (70 ± 5) °C during the test.

Standard UV weathering duration for uniform characterization form and datasheet reporting is:

- Frontsheet:
  - (4 000 −0/+48) h, sun-facing (air-)side only
- Backsheet:
  - (4 000 −0/+48) h, sun-facing (inner) side
  - (2 000 −0/+48) h, air-side
- Front- and backsheet:
  - (4 000 −0/+48) h – sun-facing (air-)side as frontsheet
  - (4 000 −0/+48) h – sun-facing (inner) side as backsheet

NOTE 2 IEC TS 62788-7-2 provides context for the choice of test conditions for clear, white and coloured backsheets.

If exposure through a UV filter has been chosen for the sun-facing (inner) side of a backsheet, the UV filter shall be placed between backsheet and light source.

4.10.3.6 Testing retention of properties by post-evaluation tests

After sampling from weathering test, pre-condition the material according to the requirements of the post-evaluation test.

a) Material characterization required for UCF (see Table 7) includes:
   - Visual evaluation (4.6.3) of the exposed side of samples before and after UV weathering;
   - Mechanical strength (tensile strength and elongation at break, MD only) of replicate specimens shall be measured before and after UV weathering (see 4.2.4).
b) Optional material characterization (see Table 7) includes:
   - Mechanical strength (tensile strength and elongation at break, TD only) of replicate specimen can be measured before and after UV weathering (see 4.2.4);
   - DC breakdown voltage of replicate specimen can be measured before and after UV weathering (see 4.5.1);
   - Instrument-based optical characterization can be carried out, see 4.6.4 (transmission), 4.6.5 (reflection), 4.6.6 (yellowness), 4.6.7 (colour) and/or 4.6.8 (surface gloss). No extra replicates are required: non-destructive optical measurements can be performed on samples foreseen for mechanical testing before conducting those tests;
   - Adhesion is measured on replicate specimens before and after weathering. Specimen preparation depends on the type of adhesion test envisaged:
     - Adhesion of components of the multilayer sheet (see 4.3.3.1);
     - Adhesion to a matched material, such as encapsulant or edge seal (see 4.3.3.2).

4.10.3.7 Reporting

Report the following:

a) Test parameters for the xenon-based weathering (method, parameters, duration cumulative radiant exposure) according to IEC TS 62788-7-2 method A3 for white/clear or selection of A1, A2, or A3 for black/coloured backsheet;
b) The specimen configuration (film or coupon according to Table A.1);
c) The UV filter configuration and UV cut-off (if applied);
d) Results from the required post-evaluation tests listed in 4.10.3.6 a);
e) Optionally, report results from post-evaluation tests in 4.10.3.6 b).

For d) and e), report the absolute results from the evaluation tests after UV weathering and % retention of initial values.

4.10.3.8 UVA testing

IEC TS 62788-7-2 method B also defines a UVA test using UVA-340 fluorescent sources for assessing UV durability of front- or backsheet materials. UVA-340 testing, however, is not regarded as an equal alternate to xenon-arc-based testing because of the difference in spectral power distribution, which may result in different material failure modes, depending on the action spectrum of the materials under test [16].

Filtered xenon is currently accepted as the best spectral match to natural daylight, and UV-induced failure can be tested without previous knowledge of the action spectrum of the specimen. Therefore, xenon weathering is required for datasheet reporting, whereas UVA-340 lamp testing may still provide useful information for other purposes during product development and module testing; an auxiliary test may be performed according to condition B3 of IEC TS 62788-7-2:2017, Table 2 for a duration of 1 000 h, 2 000 h or 4 000 h.

If this test is performed, post-exposure tests and data reporting shall comply with the requirements of 4.10.3.5 and 4.10.3.6, referring to condition B3 (or B2 / B1) in of IEC TS 62788-7-2:2017, Table 2 (UVA), instead of condition A3 (or A2 / A1) of IEC TS 62788-7-2:2017, Table 1 (Xenon).

Sample preparation for UVA testing is identical to that for UV xenon testing (4.10.3.2).

4.10.4 Abrasion test

Abrasion test methods are defined in IEC 62788-7-3, see also Annex C for more details specific to front- and backsheets.

4.11 Sequential UV/TC stress test ("solder bump test")

4.11.1 Purpose

The purpose of this test is to evaluate the propensity of (front- or) backsheets to crack or delaminate under application conditions. The test coupon is designed to introduce stresses in the (front- or) backsheet arising from protrusions and depressions inherent in module lamination [17]. Samples are prepared with both MD and TD orientation as these can have very different responses to mechanical stress. The environmental stress sequence is designed to replicate the sequential stresses found in the application environment, with a UV exposure providing heat, irradiance, and humidity (to degrade the materials), followed by thermal cycling which can then provoke cracking. Coupons are prepared for both front side and rear side UV exposure with both machine and transverse directions.

This test has been designed to test backsheet, but it may also be used for frontsheet materials.

This test also provides a way for encapsulant choice to be assessed within a matched component approach, as encapsulant choice can impact the results on the (front- or) backsheets due to either mechanical properties, chemical interactions, or UV filtering.

4.11.2 Sample construction

4.11.2.1 General

The test results are dependent on the type of encapsulant and lamination parameters. See the IEC TS 62788-1 series for further encapsulant characteristics. The most representative results are obtained with the bill of material as close as possible to the final module construction. For each material combination under test (e.g. backsheet and encapsulant), the following material for sample construction shall be used:

- Glass: Four pieces of glass representative of that used in the PV industry, sized to fit the specimen holder for the desired environmental chamber. Textured or float glass may be used. These pieces shall be sized at least 75 mm × 50 mm (these instructions assume rectangular pieces are used but that is not required).

NOTE 1 Sanding the edges and corners after cutting the glass will reduce the risk of cuts from sharp edges.

- Solder wire: Eight pieces of solid solder wire, without flux cores, having a diameter of 800 ± 50 µm and a minimum length of 60 mm and sufficient to span the glass when applied. The melting temperature of the solder wire shall be at least 20 K higher than the envisaged maximum lamination temperature. To limit environmental concerns, lead-free solder is recommended, e.g. 96 % Sn and 4 % Ag, but Sn/Pb based solder wire is acceptable.
- Backsheet (or frontsheet): Four pieces, 5 mm larger than the glass in each direction, with 2 pieces cut with the long edge in the machine direction, 2 pieces cut with the long edge in the transverse direction.
- Encapsulant: Four pieces cut to the same size as the backsheet pieces.

NOTE 2 The choice of encapsulant can have a strong effect on the test results due to the additives in the encapsulant.

- Frame: This is a temporary auxiliary part used only during lamination for holding the sample in place and minimizing the bending of the oversized (front- or) backsheet and solder wire at the edges of the sample during lamination. It shall have an interior opening slightly larger (> 1 mm on all sides) than the glass and be the same thickness as the glass. The sample and frame shall be easily separable. The frame should either be made from a non-stick material (e.g. Teflon®), or used in conjunction with a release material.

Background information for selection of solder wire and encapsulant is given in 4.5.2.

4.11.2.2 Sample preparation

The diagram in Figure 11 provides a side view of the structure of the coupon and represents the solder-bump coupon after lamination and before removal of the trench solder wire. The solder wire making the ridge will remain in the test coupon. The long axis of the glass is shown. Four samples are prepared, each with two pieces of solder wire as described in Figure 12, two with the (front- or) backsheet samples oriented with the machine direction (MD) aligned with the long axis of the glass, and two with the samples oriented with transverse direction (TD) aligned with the long axis of the glass.

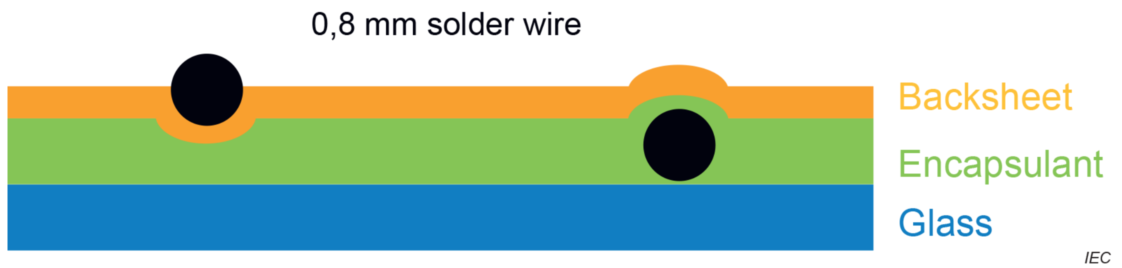


Figure 11 – Side-view schematic of solder-bump coupon sample after lamination

1) Place the glass in the frame. If textured glass is used, place the textured surface face up to be in contact with the encapsulant.

NOTE The orientation of glass texture towards the encapsulant reduces the optical distortion from the glass structure which makes the observer task during visual inspection of the specimen from the glass side easier.

2) Place one piece of solder wire on the glass spanning the whole width of the sample, parallel to and at more than 20 mm distance from the short end. This piece of solder wire will result in the formation of the "ridge" in the laminated sample. Fix the wire to the frame (polyimide tape is recommended) to prevent unintentional movement of the wire during handling and lamination.
3) Place the encapsulant sheet on the sample overlapping the glass on all sides.
4) Place the (front- or) backsheet on the sample over the encapsulant, with the target orientation (MD or TD) of the (front- or) backsheet relative to the long axis of the samples.
5) Place the second solder wire on top of the airside of the (front- or) backsheet parallel to the first piece of solder and at more than 20 mm distance from both the glass edge and the other solder wire. The solder wire shall extend beyond the edges of the glass but not necessarily beyond the edges of the oversized (front- or) backsheet. This piece of solder wire will result in the formation of the "trench" in the laminated sample. In context of the inspection task as defined in 4.11.2.6, the sample area in between the two solder wires is called "open area" (see also Coupon L in Table A.1).

4.11.2.3 Sample lamination

Use a conventional laminator with a flexible bladder in contact with the backsheet, with the conditions consistent with specifications of the (front- or) backsheet and encapsulant suppliers, see also 4.5.2.2.

4.11.2.4 Sample processing after lamination

After lamination, remove the airside solder wire and trim the excess encapsulant and backsheet from the sides of the sample.

NOTE 1 A hot knife makes cutting of both the solder and the polymer layers easy.

NOTE 2 Allowing the sample to cool fully before trimming with a hot knife reduces the risk of perimeter delamination.

Label the samples to identify machine direction and transverse direction, as well as exposure orientation: frontside (glass, frontsheet) or backside (backsheet, substrate). For rectangular samples, the specified material direction is aligned with the long direction of the glass. Make sure the identification marks do not obscure the ridge and trench region. Figure 12 shows the samples after lamination with the airside solder wire removed.

NOTE 3 Indelible sample identification can be made by scribing the glass.

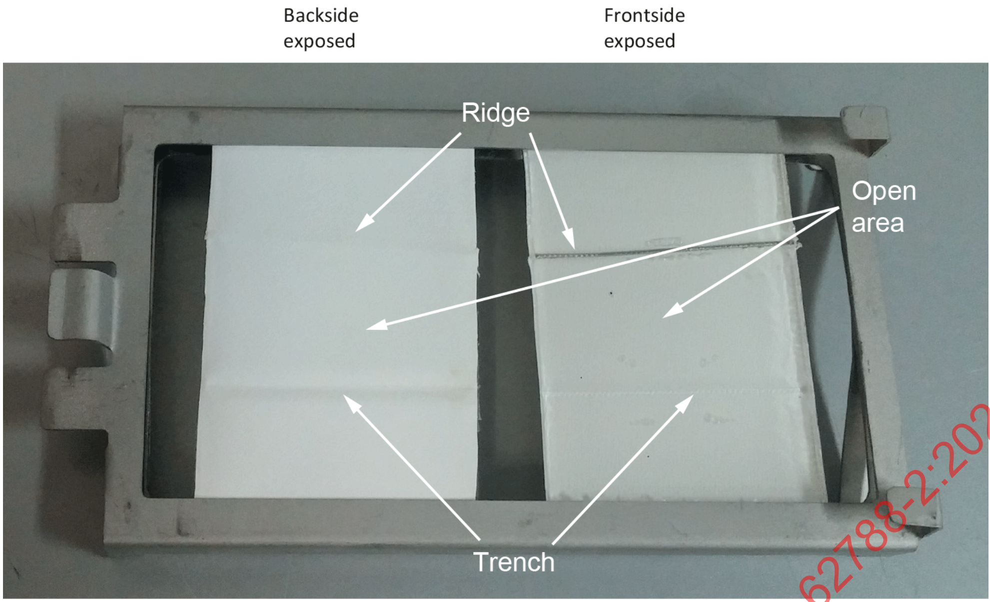


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Figure 12 – Example of "solder-bump coupons" in a specimen holder.

The solder wire making the ridge remains in the test coupon. The airside solder wire making the trench is removed. The coupon on the left is oriented for exposure of the backside (airside of backsheet) and the coupon on the right is oriented for cell-side exposure with glass side facing towards the Xenon lamp.

4.11.2.5 Sample exposure

Carefully clean the surface with a soft cloth prior to exposure to remove debris. Take care to avoid scratching the surface of the (front- or backsheet while handling the samples, particularly along the ridge line.

Prepared coupons are mounted in the specimen holders with the orientation foreseen. Depending on the design and the dimensions of coupon and specimen holders, some edges of the coupons may or may not be covered by the frame of the specimen holder in the weathering apparatus, representing "framed" or "frameless" edges of the coupon. This shall be considered during evaluation in view of UV radiation eventually optically coupling into open side of the glass, frontsheet, encapsulant and/or backsheet in case of "frameless" exposure. Samples shall be held such that at least one side of the samples is fully exposed to UV light.

EXAMPLE: Figure 12 shows "solder bump coupons" with the long edges exposed "frameless" and the short edges exposed "framed".

Samples shall be exposed to at least two test cycles consisting of sequential exposure to 1 000 h of UV weathering (UV1 000) according to condition A3 of IEC TS 62788-7-2 followed by 200 thermal cycles (TC200) of IEC 61215-2 MQT 11. Optionally, an additional number of cycles of the exposure sequence (UV1 000 + TC200) may be used to realize a more aggressive test. For samples that are not white or transparent, adjust UV exposure conditions as indicated in 4.10.3.

4.11.2.6 Sample evaluation

4.11.2.6.1 General

Samples shall be inspected before exposure to be free of any significant cracks and imperfections, i.e., any initial defects and imperfections shall not be rated higher than 1 or A according to Table 5. Any initial imperfections and defects shall be documented, but it is recommended that imperfect samples be replaced with new ones. Frequently in the trench region on the edges of the samples, the solder wire is unrealistically pressed into the encapsulant, creating a defect which shall be ignored.

Evaluate the specimens for cracks after all exposure cycles are completed. If more detail is desired, optionally perform the evaluation for cracks after all intermediate segments of TC or after all intermediate segments of TC and UV.

Observer conditions for visual evaluation are defined in 4.6.3. The visual inspection for cracks shall be conducted using both reflected light on the airside and transmitted light on the glass-side for all samples. Consideration of the details of the layer structure of the backsheet, including layer schematics as defined in 5.2, is required for visual evaluation.

Suitable apparatus for microscope examination includes calibrated light microscopes, laser microscopes or SEM (see 4.5.2.3).

Example of evaluation ratings are shown in Annex D. Any marks and staining due to condensation drops, contamination in the weathering device shall not be considered as degradation. Compare any observed defects to initial unexposed sample notes or photographs. Defects which are unchanged from the unexposed samples are not counted as degradation.

Evaluate the trench, ridge, and open areas separately in accordance with Table 5.

4.11.2.6.2 Evaluation of the airside using reflected light

- For initial overview, inspect the airside of the sample in transmission mode with the glass side facing the backlit unit. Note any areas with increased intensity as suspect locations for a more thorough microscopic inspection.
- Using magnification, examine the entire length of both the ridge and trench regions, and any areas that were noted as suspect.
- Distinguishing between scratches and cracks can be difficult, especially if single deep scratches are present. Different morphology and directionality of scratches and cracks shall be considered, which may depend on the material under investigation. A positive identification of cracks is required to change the rating. Be careful to minimize damage to samples due to handling.
- Take a whole-sample photograph. If cracks are observed during the magnified examination, micrograph and evaluate the worst examples of them.

4.11.2.6.3 Evaluation of the inner layers using transmitted light

- Place the sample on the backlit unit with the glass side facing up. Handle specimens with care so as not to unintentionally introduce additional defects on the (front- or) backsheet. Take a photograph of defects and characterize these as described in Table 5.
- For backlit examination, short (< 2 mm) cracks at the perimeter are considered part of the open area inspection. The presence of any cracks in the ridge or trench regions witnessed during backlit examination translates to a rating of C or D, depending on the severity of cracks in these areas. Document whether perimeter sections, where cracking is been observed, represent "framed" or "frameless" mode of UV exposure (see 4.11.2.5 and Figure 12).

- In this inspection, it does not matter if the crack is in an RUI or a non-RUI layer, both are unacceptable. Similarly, the backlit examination ratings will not be different for a crack through all the layers as opposed to a crack through one layer. That distinction is captured in the airside examination.
- Airside surface cracking will also count if visible under backlighting.

Table 5 – Characterization categories

Category number	Airside inspection (in reflection mode) – see 4.11.2.6.2 and Clause D.2
1	No observed degradation (for initial sample, note any scratches or imperfections).
2	Cracks not fully broken through any layers of the sheet (including crazing).
3	Cracks through any layer but not through all layers of the sheet, or minor amounts of delamination < 2 mm across.
4	Cracks fully broken through all RUI layers of the sheet, or signification delamination (> 2 mm).

Category Letter	Glass-side inspection (in transmission mode) – see 4.11.2.6.3 and Clause D.3
A	No observed degradation (if initial sample, note any scratches or imperfections).
B	Short cracks or delamination (< 2 mm) or imperfections around the perimeter. Only applicable to cracks at the perimeter of the open area. This rating is not applicable to the ridge and trench region.
C	Longer cracks or delamination (> 2 mm of length) around the perimeter or any crack/delamination along the trench or ridge AND/OR in the open area, cracks less than 10 mm long.
D	Cracks throughout the open area or few cracks longer than 10 mm. Or in the crack or trench region, more than 75 % of its length is cracked. Or delamination's > 2 mm not associated with the perimeter, ridge or trench.

Annex D provides examples for the characterization categories defined in Table 5.

4.11.2.7 Reporting requirements

Report the following:

a) Identification of test instruments and other equipment used;
b) The product identification of the test material (front- or backsheet, encapsulant, solder wire and glass) used;
c) Lamination conditions used;
d) Sample size used;
e) Mode of UV exposure of the coupon edges ("framed" or "frameless");
f) Details of exposure cycles used;
g) The UV cut-off wavelength of the glass used according to IEC 62788-1-7;
h) The UV cut-off wavelength of the encapsulant used according to IEC 62788-1-7;
i) The results and comments from the inspections, see example in Table 6.

Table 6 – Example table for recording inspection results after all intermediate UV and TC cycles with three test cycles of the sequential UV/TC stress test

Backsheet and Encapsulant Description.	Sample film orientation/Exposure side	Sample ID	Exposure	Date of examination	Air side inspection			Cell-side back-lit inspection			Comments
					Ridge	Trench	Open area	Ridge	Trench	Open area	
	Cell-Side/MD		1000hrs A3 / 000TC								
			1000hrs A3 / 200TC								
			2000hrs A3 / 200TC								
			2000hrs A3 / 400TC								
			3000hrs A3 / 400TC								
			3000hrs A3 / 600TC								
	Cell-Side/TD		1000hrs A3 / 000TC								
			1000hrs A3 / 200TC								
			2000hrs A3 / 200TC								
			2000hrs A3 / 400TC								
			3000hrs A3 / 400TC								
			3000hrs A3 / 600TC								
	Air-Side/MD		1000hrs A3 / 000TC								
			1000hrs A3 / 200TC								
			2000hrs A3 / 200TC								
			2000hrs A3 / 400TC								
			3000hrs A3 / 400TC								
			3000hrs A3 / 600TC								
	Air-Side/TD		1000hrs A3 / 000TC								
			1000hrs A3 / 200TC								
			2000hrs A3 / 200TC								
			2000hrs A3 / 400TC								
			3000hrs A3 / 400TC								
			3000hrs A3 / 600TC								

5 Uniform characterization form

5.1 General

The uniform characterization form (UCF) for front- and backsheets provides an extensive overview of mechanical, electrical, optical, and chemical characteristics that are related to safety, performance and processing of the front- or backsheet. For some safety and performance related properties, reporting of test results after ageing is required.

The UCF shall be prepared by a test agency having competence of testing and calibration. The UCF shall contain at least the material characterization tests listed as required, and it may contain results of optional characterization tests in addition. 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 performed;
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) A statement of the estimated uncertainty of the test results (where relevant);
m) Signature and (job) 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) Statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

5.2 Layer stack description

The UCF shall contain a drawing, which shows the construction (layer stack) of the front- or backsheet, in which the individual layers are labelled and named and their nominal thicknesses are given. Indicate the function of the layers in the layer stack, especially:

- Materials in layer stack that are relied upon for insulation;
- Adhesive layers.

5.3 Material test results and reporting requirements

The uniform characterization form (UCF) shall be given as a tabular overview of results according to Table 7. In the full document, the table is followed by details of the test conditions as defined by the reporting requirements per test item, referencing items via the UCF number in the first column of the table. A UCF provided according to this document shall at a minimum include the material evaluation and ageing tests for polymeric front- and backsheets marked as required (✓) in Table 7. Reported data shall include tolerances as given by reporting requirements of each test method indicated in the column "reference".

Table 7 – Uniform characterization form (UCF) for polymeric PV front- or backsheet.

UCF No.	Test name	Reference	Fresh	1 000 h DH test (4.10.2)	UV (Xenon) test (4.10.3) with exposure of	
					2 000 h airside[a]	4 000 h sun-facing side[b]
1	dimensions and tolerances [µm]	4.2.2	✓			
2	area weight and tolerances [g/m^2]	4.2.3	✓			
3	a) tensile strength [MPa] (MD)	4.2.4	✓	✓	✓	✓
	b) tensile strength [MPa] (TD)	4.2.4	✓	✓	○	○
4	a) elongation at break [%] (MD)	4.2.4	✓	✓	✓	✓
	b) elongation at break [%] (TD)	4.2.4	✓	✓	○	○
5	bond strength between layers of composition – or weakest link [N/mm] (for peelable layers)	4.3.3.1	✓	✓	○	○
6	bond strength between coatings or thin layers and film [rating scale] (for layers too thin or brittle to peel)	4.3.3.1	✓	✓	○	
7	bond strength between a specific encapsulant and sheet [N/mm]	4.3.3.2	○[d]	○[d]	○[d]	○[d]
8	bond strength between a specific junction-box adhesive and sheet [N/mm]	4.3.3.3	○[d]	see IEC 62790		
9	TI or RTE (RTI) [°C]	4.4.1	✓			
10	thermal failsafe test	4.4.2	✓			
11	dimensional stability in MD and TD [%]	4.4.3	✓			
12	relative thermal expansion [K^{-1}]	4.4.4	○			
13	thermal conductivity [W/m·K]	4.4.5	○			
14	DC breakdown voltage [kV]	4.5.1	✓	✓	✓	✓
15	distance through insulation (DTI) [µm]	4.5.2	✓[d]			
16	comparative tracking index (CTI)	4.5.3	✓			
17	volume resistivity [Ω·m]	4.5.4	○			
18	visual inspection	4.6.3	✓	✓	✓	✓
19	optical transmittance (for transparent/translucent sheets only)	4.6.4	✓	○	○	○
20	optical reflectance [c] (for reflective sheets only)	4.6.5	✓ (sun-facing)	○ (sun-facing)		○ (sun-facing)
21	yellowness index DYI [c]	4.6.6	○	○	○ (airside)	○ (sun-facing)
22	CIE $L^*a^*b^*$ (D65/10°) [c]	4.6.7	○	○	○ (airside)	○ (sun-facing)
23	surface gloss [c]	4.6.8	○	○	○ (airside)	○ (sun-facing)
24	water vapour transmission rate [g/m^2·day]	4.7.1	○			
25	oxygen transmission rate [g/m^2·day]	4.7.2	○			
26	resistance to recommended cleaning solvent	4.8.1	○			
27	sequential UV/TC stress test	4.11	○[d]			

✓ Required material characterization to provide UCF according to this document.

○ Optional material characterization.

[a] Airside exposure only for backsheet.

[b] Exposure of sun-facing side of backsheet with choice of UV filter (4.10.3.2).

[c] For optical characterization (UCF No. 18- 23) the (air/sun-facing) side for backsheets is indicated.

[d] Bill-of-material (BOM) specific tests.

6 Data sheet

6.1 Purpose

The data sheet shall provide an overview of material data from the uniform characterization form for a wider public.

6.2 Reporting requirements

At least the required material characterization from Table 7 shall be given in the datasheet.

For unique identification of the material, the product information according to a) and b) of Clause 7 shall also be reported in the datasheet.

7 Product identification sheet (label)

The following information is required on the product identification sheet:

a) Type designation of front- or backsheet;
b) Name, address and contact information of the manufacturers or importers;
c) Shelf age and storage conditions;
d) Transport conditions and their maximum duration, if deviating from storage conditions;
e) Identification of the inner side of the front- or backsheet that shall be laminated to the encapsulant in the PV module.

Annex A
(normative)

Sample preparation

A.1 Purpose

To prepare engineering samples (coupons) that are small in comparison to PV modules as well as mini-modules, and that are suitable for material testing as well as for weathering. Typically, these engineering samples do not contain live parts (e.g., cells, circuitry) because their purpose is material characterization and testing on the component level.

Lamination of engineering samples shall mimic typical PV module processing conditions as close as possible (temperature, duration and pressure of lamination step).

Tests on engineering samples should not replace system- or module-level tests, but they are intended for pre-qualification of component materials.

A.2 Sample constructions

A.2.1 General considerations

Specimen size in xenon chambers and UVA testers vary between manufacturers and model. Therefore, only general guidelines are given in this Annex A.

Typical specimen sizes suitable for specimen holders in weathering vary from 50 mm × 50 mm to 150 mm × 150 mm for carousel type instruments and up to 180 mm × 200 mm or 400 mm × 400 mm for flat-bed devices. In the latter, any obstruction of black panel thermometers (BPTs) or other sensors in sample plane shall be avoided.

NOTE Typical specimen holders size used in xenon weathering devices and UVA test instruments are e.g. 65 mm × 120 mm and 70 mm × 150 mm. Be aware that specimen area exposed can be considerably smaller, e.g. 65 mm × 90 mm.

Net sample size shall comply with the minimum sample dimension requirements of material evaluation test method (180° peel, T-peel, DC breakdown voltage, optical, tensile strength). This is especially relevant for sheet material that shall be released from a G/E/E/TRM/BS coupon (see Coupon B1). It should be considered that areas near to edges might have been covered at least partially (by the sample holder) and would not be representative of a weathered sheet.

Further information on specimen preparation for weathering is found in IEC TS 62788-7-2.

A.2.2 Materials and procedures

For specific testing of a front- or backsheet, the engineering sample shall be constructed from the same materials as in the envisaged PV module design, but without active cell or circuitry elements. Material selection shall be reported.

For generic testing, other materials typical for PV module design are used. These can be chosen using the guidelines given in this document and shall be reported accordingly. Table A.1 gives an overview of specimen preparation.

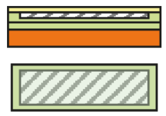
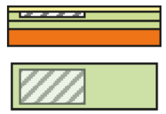
For testing of the backsheet the following is recommended: Unless backsheet films are tested specifically, a coupon is typically constructed using a PV glass superstrate and a fast curing EVA-type encapsulant. Adhesion of both the glass and backsheet to encapsulant depends on both outer sheets, the encapsulant and lamination conditions. Even if glass-to-encapsulant adhesion is outside the scope of this document, the unlikely presence of a weakest link at the glass/encapsulant interface may limit results obtained for the stack. Depending on the purpose, one or two layers of encapsulant may be used. Ideally, samples with one and two encapsulant layers should be prepared and tested to simulate the material stack inside and outside the cell area, respectively. The resulting thickness of the encapsulant layer after lamination shall be clearly stated for each sample.

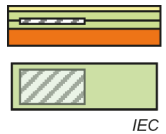
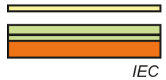
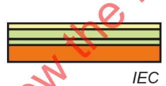
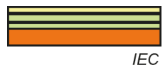
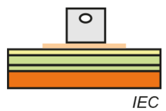
Furthermore, auxiliary materials, such as UV-transparent release materials (TRM), may be used during the lamination process, to facilitate access to sheet material or interfaces for adhesion testing. Actual UV-filter function of the G/E/E/TRM or G/E/TRM/E laminate is characterized by their combined (i.e., laminated) UV-transmission characteristics (in optical contact and without air layers between the components).

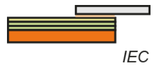
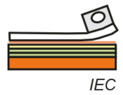
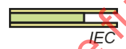
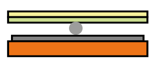
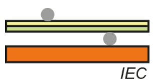
Aluminium serves as a rigid base material or is used as a handle for adhesion testing. In that context, a suitable epoxy adhesive provides a strong link between the aluminium handle and the backsheet.

NOTE Wear suitable gloves when handling coupons because they can have sharp edges. Glass coupons can also break during treatment, especially if initial flaws or damage exists. Encapsulant can be displaced (squeezed out) under long-term heat testing or become sticky, such that coupons stick to sample holders. Avoid use of uncontrolled force when loosening such coupons. Handling of many heated samples can cause burns to hands: burns can occur if skin temperature is raised to 44°C or above for long enough periods.

Table A.1 – Overview of sample preparation suitable for material tests

	Description	Stack	Reporting requirements	Sketch	Preparation
A0	Individual layer	Film	Laminator conditions (if applicable)		Condition sample in a laminator according to suppliers' recommendations (if applicable)
A1	Backsheet or frontsheet film	Film	Laminator conditions (if applicable)		Condition sample in a laminator according to suppliers' recommendations (if applicable)
B1a	Laminated coupon with BS and fully releasable representative UV filter (for tensile and optical testing)	G/E/E/TRM/BS	Laminator conditions Description of stack PV Glass Type of encapsulant Transparent release material Type of BS UV cut-off of TRM/E/E/G stack		Laminate a stack as follows: backsheet sample, transparent release material (TRM), two layers of encapsulant, PV glass. Make TRM smaller than encapsulant, so that an encapsulant frame of about 5 mm to 10 mm is created at all sides. This coupon reduces the effect of oxygen during test as in application. Measure UV transmission of G/E/E/TRM. To release sheet after ageing test: cut central part of BS film within the EVA frame and release film from coupon.
B1b	Laminated coupon with BS and fully releasable representative UV filter (for tensile and optical testing)	G/E/TRM/E/BS	Laminator conditions Description of stack PV Glass Type of encapsulant Transparent release material Type of BS UV cut-off of TRM/E/E/G stack		Laminate a stack as follows: backsheet sample, encapsulant, transparent release material (TRM), encapsulant, PV glass. Make TRM smaller than encapsulant, so that an encapsulant frame of about 5 mm to 10 mm is created at all sides. This coupon reduces the effect of oxygen during test as in application. Measure UV transmission of G/E/TRM/E. To release sheet after ageing test: cut central part of BS film within the EVA frame and release film from coupon.
B2a	Laminated coupon with BS and partially releasable representative UV filter (for adhesion peel testing)	G/E/E/TRM/BS	Laminator conditions Description of stack PV Glass Type of encapsulant Transparent release material Type of BS UV cut-off of TRM/E/E/G stack		Laminate a stack as follows: backsheet sample, transparent release material (TRM), two layers of encapsulant, PV glass Make TRM smaller than encapsulant, so that an encapsulant frame of about 5 mm to 10 mm is created at all sides and let TRM cover max. half of the length. This construction reduces effect of oxygen during test as in application. Measure UV transmission of G/E/E/TRM.

	Description	Stack	Reporting requirements	Sketch	Preparation
B2b	Laminated coupon with BS and partially releasable representative UV filter (for adhesion peel testing)	G/E/TRM/E/BS	Laminator conditions Description of stack PV Glass Type of encapsulant Transparent release material Type of BS UV cut-off of TRM/E/E/G stack		Laminate a stack as follows: backsheet sample, encapsulant, transparent release material (TRM), two layers of encapsulant, PV glass Make TRM smaller than encapsulant, so that an encapsulant frame of about 5 mm to 10 mm is created at all sides and let TRM cover max. half of length. This construction reduces effect of oxygen during test as in application. Measure UV transmission of G/E/E/TRM.
C	Backsheet with separate representative UV filter (for tensile and optical testing)	Filter/air/BS	Laminator conditions Description of stack Filter with defined UV cut-off C i) G/E/E stack C ii) Optical filter glass		Condition sample in laminator to simulate a lamination cycle typical for envisaged use of the backsheet. Mount filter between light source and BS film (sun-facing side towards light source). Measure UV transmission of UV filter and control UV transmission of filter on regular basis, especially if UV filter is being reused.
D	Laminated coupon with BS and representative UV filter	G/E/E/BS	Laminator conditions Description of stack PV glass Type of encapsulant(s) Type of BS UV cut-off of E/E/G stack		Laminate a stack consisting of the following: backsheet sample two layers of encapsulant PV glass
E	Laminated coupon with FS	FS/E/E/RS	Laminator conditions Description of stack Type of FS Type of encapsulant(s) Type of substrate		Laminate a stack consisting of the following: frontsheet sample two layers of encapsulant rear-side substrate (rigid)
F1	Adhesion pluck test coupon	G/E/E/BS/ Adh/H/ (T-block)	In addition to D or E: Adhesive = epoxy for weakest link test of coupon OR Adhesive = junction box adhesive (only for D)		Prepare coupon D or E. For adhesion pluck test after ageing, apply epoxy/junction-box adhesive and pluck T-block after ageing

	Description	Stack	Reporting requirements	Sketch	Preparation
F2	Lap-shear test coupon	G/E/E/BS/ Adh/H/ (plate)	In addition to D or E: Adhesive = epoxy for weakest link test of coupon OR Adhesive = junction box adhesive (only for D)		Prepare Coupon D or E. For lap-shear test, after ageing apply epoxy/junction-box adhesive and lap-shear plate after ageing.
F3	Fracture mechanics	G/E/E/BS/ Adh/H (tapered beam)	In addition to D or E: adhesive = epoxy or cyanoacrylic		Prepare Coupon D or E. In case of post evaluation of aged coupons, apply epoxy or cyanoacrylic to mount tapered cantilever plate (titanium or PMMA) after ageing.
G1	T-peel specimen (for encapsulant)	BS/E/BS or FS/E/FS	Laminator conditions Description of stack Type of BS OR FS Type of encapsulant		Laminate an encapsulant symmetrically sandwiched with front- or backsheet, with their inner sides facing towards encapsulant. Prepare encapsulant layer about 1/3 shorter than sheets to create handles for gripping.
G2	T-peel specimen (for adhesives used on the outer layer of BS OR FS),	BS/Adh/BS or FS/Adh/FS Adh = e.g. junction box adhesive / sealants)	Laminator conditions Description of stack Type of BS OR FS Type of adhesive		Sandwich the adhesive symmetrically in between BS (OR FS), with the outer layers of BS (OR FS) facing towards the adhesive. Apply adhesive to only two-thirds of the length of the BS (OR FS) to create handles for gripping. Let adhesive cure according requirements.
H	Lamination protrusion test	G/(rm)/solder wire/E/BS	Laminator conditions Description of stack Backsheet Encapsulant Solder wire 0,8 mm Ø 50 µm Release material Glass		Layer stack for DTI test After lamination: Release BS/E with embedded wire from glass. Remove wire without damage of the backsheet.
L	Solder bump test	solder wire/ BS/solder wire/E/G	Laminator conditions Description of stack Solder wire 0,8 mm Ø Backsheet Encapsulant Solder wire 0,8 mm Ø Glass		Layer stack for solder bump test After lamination: Remove upper solder wire without damage of the backsheet.

	Description	Stack	Reporting requirements	Sketch	Preparation
M	Mini module	G/E/PV-structure/ E/BS	Laminator conditions and Description of stack Glass Cell elements		Layer stack for visual inspection, observing eventual chemical interaction (under ageing conditions) under non live conditions.

Adh: adhesive

BS: backsheet

FS: frontsheet

E: encapsulant

G: glass

H: handle specific for an adhesion test

RS: rigid support

PV-structure: (parts of) PV cells and/or electrical connections typical for PV module

TRM: transparent release material
(dimensioned 0,5 cm to 1 cm less than stack on all sides)

RM: release material