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Edition 1.0 2017-08

TECHNICAL SPECIFICATION

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

colour inside

IEC TS 62788-2:2017-08(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 2: Polymeric materials – Frontsheets and backsheets

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62788-2, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1189/DTS	82/1243A/RVDTS

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

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.

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

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

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INTRODUCTION

Backsheets provide the electrical insulation at the backside of a 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 front side of the module facing towards the sun. Both can be made from glass or polymeric material.

Polymeric backsheets and frontsheets 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 may provide extended protection of the RUI against the environmental factors or adhesive functionality. As an integral part of the PV module, backsheet and frontsheet shall provide their durable electrical insulating function in presence of the other components of the PV module, such as light-to-current conversion element (the "cell"), electrical circuits and connectors, frontsheet and encapsulant, sealing material, junction boxes, etc. These elements may introduce additional stresses on the backsheet or frontsheet (e.g. by chemical interactions or introducing thermal load or mechanical stress) or alter environmental stresses (e.g. filtering of UV radiation reaching the sun-facing side of the backsheet).

It is impractical to conduct all endurance tests for frontsheet or backsheet component on module level. Instead, testing is performed directly on these components for pre-qualification of the materials as such, as e.g. given by the thermal endurance test required for material intended for use as relied-upon-insulation, that is qualified by IEC 60216 (see IEC 61730-1:2016, 5.5.1.3.3) and results in RTE/RTI/TI ratings of ≥ 90 °C or maximum operating temperature (whichever is greater). In the case of thermal pre-qualification of backsheet and frontsheet only dielectric and mechanical material tests apply for RTE/RTI/TI assessment.

In analogy to RTE/RTI/TI, it is desirable to also obtain pre-qualification of backsheet and frontsheet films to provide durable electrical insulation after exposure to additional environmental factors, such as:

a) Elevated moisture and temperature (damp heat), or

b) UV-weathering in a manner representative of the field conditions. These tests can either be conducted direct on the backsheet or frontsheet films or on dedicated test coupons as engineering type specimens, which are prepared from the same materials and produced under comparable processing conditions (i.e. lamination) as the PV modules.

   - The portion of the backsheet that contributes to the relied upon insulation should be evaluated for d.c. voltage (V) breakdown strength according to IEC 60243-1 and IEC 60243-2, and meet the requirements as described in 5.6.4.3 of IEC 61730-1:2016. In this document a suitable choice of test parameters for the assessment of polymeric frontsheet and backsheet is defined.
   - The relied upon insulation material shall have a minimum thickness, also known as distance through insulation (dti) defined in the "thickness in thin layers" rows of Tables 3 and 4 in 5.6 of IEC 61730-1:2016.
   - Materials relied upon for insulation are further categorized into Materials Groups I, II, or III, according to CTI values describing potential tracking along interfaces that may get in contact with live parts.
   - Durable adhesion between components of the backsheet or frontsheet is needed to preserve the integrity of the sheet material in field conditions. Also, preservation of adhesion to other components of the module such as encapsulant and edge seal or adhesion to the junction box adhesive are important. Different test geometries may apply depending on the interface under test and construction of the sheet material.

Other characteristics of frontsheet or backsheet might be relevant for the electrical yield (e.g. optical transmittance or reflectance) or module producibility (e.g. lamination process).

This document defines test methods required for reporting of properties of polymeric frontsheet and backsheet in a datasheet. Those properties are related to safety and yield of the assembled PV module and may be applied to backsheet/frontsheet before and after specific ageing tests as mentioned before.

In analogy to RTE/RTI/TI testing, the test methods in this document are intended to be used in procedures for pre-qualification and/or quality assurance of frontsheet and backsheet components with respect to their endurance under damp-heat and UV weathering stresses – once these pre-qualification procedures are agreed on and implemented in alignment with the pertinent standards IEC 61730 and IEC 61215, in which the safety requirements on PV module level are defined.

NOTE At the time of writing this TS, an amendment project for IEC 61730-1 is in preparation, in which requirements for measurement of dti (distance through insulation) and resistance against weathering are planned based on methods defined in this document IEC TS 62788-2 as well as IEC TS 62788-7-2.

The test methods in these TS provide additional information on material properties and endurance of backsheet and frontsheet components that cannot be assessed in the tests on PV module alone.

Furthermore, optional characterization test methods are defined, addressing properties of backsheet and frontsheet that are of informative nature, e.g. in the context of PV module design, but which are not directly safety, yield or processing related.

Test methods for characterization of components of backsheet and frontsheet are described, which are useful in R&D context.

All of these test methods are set into perspective by indicating their use and limitations.

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 and chemical) of non-rigid polymeric materials intended for use in terrestrial photovoltaic modules as polymeric frontsheets and backsheets.

The test methods in this document define how to characterize backsheet and frontsheet 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 encapsulant or adhesives. The methods described in this document support the safety and performance related tests defined on PV module level as defined in the series IEC 61730 and IEC 61215.

This document also defines test methods for assessment of inherent material characteristics of polymeric backsheets and frontsheets or their components, which may be required in datasheet reporting or may be useful in the context of product development or design of PV modules.

Rigid polymeric sheet materials (also providing mechanical support) may require further consideration.

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

IEC 60112:2003, *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 – Properties of thermal endurance – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2:2005, *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 60243-1:2013, *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 60904-3:2016, *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 61189-3, *Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 3: Test methods for interconnection structures (printed boards)*

IEC 61215-1:2016, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61215-2:2016, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

IEC 61730-1:2016, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC 61730-2, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

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

IEC 62788-1-2, *Measurement procedures for materials used in photovoltaic modules – Part 1-2: Encapsulants – Measurement of volume resistivity of photovoltaic encapsulants and other polymeric materials*

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 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 (all parts): *Plastics*

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

ISO 536:2012, *Paper and board – Determination of grammage*

ISO 2409:2013, *Paints and varnishes – Cross-cut test*

ISO 2808, *Paints and varnishes determination of film thickness*

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

ISO 4587:2003, *Adhesives – Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies*

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*

EN 821-2, *Advanced technical ceramics – Monolithic ceramics, thermo-physical properties – Part 2: Determination of thermal diffusivity by the laser flash (or heat pulse) method*

ASTM D374–16, *Standard Test Methods for Thickness of Solid Electrical Insulation*

ASTM D3487-16, *Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus*

ASTM D 5402-06, *Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs*

ASTM D7869-17, *Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings*

ASTM E1461, *Standard Test Method for Thermal Diffusivity by the Flash Method*

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 TS 61836, IEC 61730-1 and IEC 61140, 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, that tends progressively to remove material from its surface

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 Clause A.1.

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

3.4
backsheet
BS
outer layer of the PV module, located on the back of PV module and providing protection of the inner components of the module from external stresses and weather elements, as well as electrical insulation

3.5
bond strength
force required to separate an adhesive from an adherent

3.6
breakdown voltage
voltage at which electric breakdown occurs under prescribed test conditions, or in use

Note 1 to entry: Breakdown voltage depends on whether direct or alternate current (d.c. or a.c.) is applied.

[SOURCE: IEC 60050-212:2010, 212-11-34]

3.7
cohesive failure
crack propagating within the adhesive during adhesion test, e.g. peel test

Note 1 to entry: See also Clause A.1.

3.8
comparative tracking index
CTI
numerical index value related to the maximum voltage which a material can withstand without a permanent electrically conductive carbon path tracking 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: clarified that CTI is an index value to evaluate material groups]

3.9
distance through insulation
dti
thickness value required for relied upon insulation based on thin layers of insulating material

3.10
effective hemispherical reflectance of photon irradiance
ratio of the total reflected photon irradiance to the incident photon irradiance in the wavelength range of 300 nm to 1 250 nm, weighted with the solar spectrum. Reflectance is collected over an entire hemisphere for detection

SEE: IEC 62805.

3.11
effective hemispherical transmission of photon irradiance
ratio of the total transmitted photon irradiance to the incident photon irradiance in the wavelength range of 300 nm to 1 250 nm, weighted with the solar spectrum. Transmittance is collected over an entire hemisphere for detection

SEE: IEC 62805.

3.12
elongation at break
strain, at which the specimen under test breaks

3.13
frontsheet
FS
outer layer of the PV module, located on the sun-facing side or front side of PV module and providing protection of the inner components of the module from external stresses and weather elements, as well as electrical insulation

3.14
inner side <of frontsheet or backsheet>
side of the frontsheet or backsheet that is laminated to the encapsulant

3.15
junction box
combination of parts, such as boxes, covers, cover-plates, lids, box extensions, accessories, etc., providing after assembly and installation at the photovoltaic-module as in normal use, an appropriate protection against external influences, and a defined protection against contact with enclosed live parts from any accessible direction

SEE: IEC 62790.

3.16
material group
category of insulation materials according to IEC 60664-1 as defined by the results of the CTI test

3.17
optional test
test, which is not required for the datasheet but may be performed if agreed upon between parties

Note 1 to entry: If performed, the test shall be done according to the recommended procedures in this document.

3.18
polymeric material
materials that are either natural or synthetic and are primarily composed of chained molecules of monomers, combinations of monomers, combined polymers and may contain cross-linking agents, fillers, colorants, and other materials

3.19
release material
rm
film material with a thickness of 50 µm to 250 µm that is inserted in a layer stack before lamination to render the adhesion between interfaces inactive

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

3.20
relied upon insulation
RUI
insulation system that provides the protection against electric shock in final application as defined in IEC 61730-1

3.21
required test
test which is required to be performed in order for the backsheet or frontsheet to be considered in compliance with this document and for module qualification according to IEC 61730-1 and IEC 61215-1

3.22
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]

3.23
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]

3.24
sun-facing side <of frontsheet or backsheet>
side of the frontsheet or backsheet that is oriented in direction of the sun-facing front side of the PV module

3.25
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

3.26
tensile strength at break
stress at which a specimen starts to break under tensile load

Note 1 to entry: It is expressed in Pascals (force per cross-section area).

3.27
transparent release material
trm
release material with a AM1.5G 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 (as defined in 8.2 of IEC 60904-3:2016)

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

3.28
water vapour permeability
WVTR
rate of moisture 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

The following test procedures are used to assess mechanical, electrical, thermal, optical and chemical performance properties of polymeric materials intended for use in terrestrial photovoltaic modules as polymeric frontsheets and backsheets.

Test methods may be categorized as follows:

a) Tests in IEC TS 62788-2 required under IEC 61730-1, IEC 61730-2 and IEC 61215-1 and IEC 61215-2 for relied upon insulation in datasheet reporting (see 6.2).
b) Tests in IEC TS 62788-2 in the uniform characterization form (UCF) of the material (as defined in Table 3 in Clause 5). In addition to those needed to comply with IEC 61730 or IEC 61215 in a) above, the UCF covers inherent material characteristics, which may be of

interest for module designers or manufacturers (e.g. properties relevant for module production or PV module design).

c) Tests in IEC TS 62788-2, or characterization tests defined elsewhere, that are agreed on between parties for custom material characterization.

Frontsheets and backsheets are typically composed of layered materials, such as films, adhesives or coatings, in which at least one material layer delivers the relied upon electrical insulation and other layers may provide extended protection of the relied upon insulation against the environment.

Frontsheets and backsheets shall withstand all mechanical, electrical, thermal and environmental stresses and meet the relevant requirements of 5.5.2 of IEC 61730-1:2016.

If these polymeric frontsheets and backsheets are used as relied upon insulation they shall at a minimum fulfil the requirements of 5.6.4.3 for insulation in thin layers as in IEC 61730-1:2016 (Table 3) and the requirements in 5.5.1.3 of IEC 61730-1:2016. The values for TI, RTI or RTE according to 5.5.1.3.3 of IEC 61730-1:2016 shall be evaluated under consideration of particular requirements for flexible multilayer sheets given in IEC 60216-2. Furthermore, these materials shall have sufficient CTI ratings to prevent tracking along backsheet and frontsheet interfaces while in contact with active electrical conductors according to 5.6.3 of IEC 61730-1:2016.

Adhesion of the frontsheet and backsheet, e.g. to the encapsulant or glass, shall be adequate for the module to operate safely outdoors for its design life. Compliance is checked on module level by visual inspection (MST 01 of IEC 61730-1) after preconditioning. To simulate some forms of long-term behaviour and resistivity to environmental stresses, some tests are repeated after specific accelerated ageing conditions.

In addition, this document stipulates ageing tests on engineering samples containing frontsheet or backsheet material for the purpose of component endurance characterization.

There are only limited data available that correlate test results from accelerated test with service life failures observed in the field. In addition, ageing tests are often conducted on representative coupon samples, not PV modules. This applied stress and therefore the results may be different for coupons and modules aged in the same accelerated test conditions. One example is sample size, which limits strain and therefore mechanical stresses. Another example is lacking direct contact to other components in the PV module, which may introduce additional chemical interactions.

4.2 Mechanical characteristics

4.2.1 General

The tests shall be conducted under the standard atmospheric conditions of IEC 60068-1, unless otherwise specified.

4.2.2 Thickness

4.2.2.1 Purpose

This test is performed in order to characterize the frontsheet or backsheet by its thickness.

4.2.2.2 Sampling

See Annex E for sampling of film. From the film samples, cut the test specimen, about 100 mm wide, across the whole width of the sample. The sample should consist of representative backsheet or frontsheet in its final product form. When required, take specimens at positions approximately 1 m apart in the longitudinal direction (machine extrusion direction MD) of the sample. The specimens shall contain no creases except those necessary for folding the film for presentation or packaging purposes. The specimens shall contain no other defects.

4.2.2.3 Apparatus

Thickness measuring device, capable of measuring to the following accuracies:

- d ≤ 100 µm with accuracy ± 1 µm;
- 100 µm < d ≤ 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.

4.2.2.4 Procedure

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 D374-16 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, for example 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 untrimmed rolls.

4.2.2.5 Reporting requirements

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

4.2.3 Area weight

4.2.3.1 Purpose

This test is performed in order to characterize the frontsheet or backsheet by its area weight.

4.2.3.2 Sampling

See Annex E for sampling of film. Sample three test specimens each having square dimensions of 100 mm x 100 mm. When required, take specimens at positions approximately 100 mm apart from the transverse edge. The specimens shall contain no creases except those necessary for folding the film for presentation or packaging purposes. The specimens shall contain no other defects.

4.2.3.3 Apparatus

The balance should have an accuracy of 10^{-4} g.

4.2.3.4 Procedure

Conduct the test according to ISO 536:2012.

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/m^2 and the standard deviation.

4.2.4 Tensile strength / elongation at break

4.2.4.1 Purpose

To determine the tensile properties of backsheets and frontsheets less than 1 mm thick, under defined conditions.

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

Cracking of backsheet in field use has been observed when backsheet has become brittle. A quantitative correlation between tensile strength and elongation at break values (absolute or retained) that correlate with mechanical failures ("cracking") in fielded module does not yet exist and is under investigation for use as pass/fail in a future amendment of 61730-1.

NOTE Theoretical inspection of relevant strain scenarios for backsheet and frontsheet, such as differential thermal expansion or maximum curvature, result in estimates of less than 10 % elongation at break (absolute, not retained) being critical. However, stresses seen by backsheet materials in the field also include mechanical stresses related to backsheets conforming over tabbing wires, etc. Published field studies have shown that such conformational stresses can initiate cracking failures in backsheets, and this mechanism is unrelated to just thermal expansion or flexing of the module during normal operation.

4.2.4.2 Sampling

See Annex E for sampling of film.

For mechanical testing of films (< 1 mm thick) ISO 527-3 recommends specimen type 2, i.e. 10 mm ± 1 mm bars, at least 150 mm long with initial grip of 100 mm ± 0,5 mm for a 50 mm gauge.

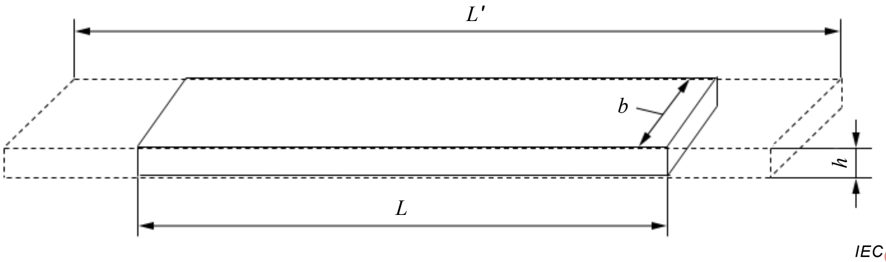
The following alternative strip lengths are allowed:

- For materials with high elongation at break of > 200 %, grip distance may be reduced to 50 mm.
- In order to account for the practical limitation of specimen size in specimen holders of weathering test chambers (see 4.10), the initial grip distance of 50 mm is also acceptable for evaluation of mechanical strength of material after weathering (see 4.10.3). In that case a total specimen length of > 100 mm is required.

Alternative strip widths are 12,5 mm ± 1 mm and 15 mm ± 1 mm.

Dumb-bell shaped specimens are preferred for quality control purpose due to better reproducibility of test results. The narrow portion of dumbbell specimen should then have width b as given before and in Figure 1.

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, both length and width of strips. It is recommended to use the same specimen dimensions within a test plan including various ageing tests.



b width	10 mm [12,5; 15][a] ± 1 mm
h thickness	≤ 1 mm
L initial grip distance	100 [50][b] mm ± 0,5 mm
L' total length	> 150 [> 100][b] mm

[a] alternative widths in square brackets [ ].

[b] alternative length in square brackets [ ].

Figure 1 – Specimen type

For each measurement (before or after an ageing test) prepare at least 5 specimens in machine extrusion direction (MD) and 5 specimens in transverse machine direction (TD) by cutting or punching so that the edges are smooth and free from notches. In case of weathering, only 5 specimen in MD direction are required for measurement after ageing, whereas measurement of 5 specimen in TD direction are optional. See additional requirements of sample preparation for materials from weathering tests in 4.10.3.

Razor blades, suitable paper cutters or other devices capable of cutting the specimens to the proper width and producing straight, clean, parallel edges with no visible imperfections shall be used. Punch dies and/or cutting equipment shall be kept sharp by regular honing, and a suitable backing material shall be used with punch dies to ensure a clean-cut edge.

4.2.4.3 Conditioning

Condition the specimens prior to the test at 23 °C ± 2 °C and 50 % ± 5 % relative humidity as in ISO 291 for at least 24 h immediately before the test. This is especially relevant after materials have been previously subjected to a damp-heat or other weathering test, as excess levels of residual moisture may otherwise affect test results.

4.2.4.4 Apparatus

A mechanical load frame as in ISO 527 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 rate of the displacement for the crosshead remains essentially constant under fluctuating loads.
- The machine equipped with suitable grips capable of clamping the specimens firmly and without slipping throughout the test.

- The machine shall be autographic, i.e. giving a chart that can be read in terms of centimetres of crosshead displacement as one coordinate and applied load as the other coordinate.

Direction registration of sample displacement by a mechanical, laser or video facilitated gauge is recommended. The use of an extensometer is recommended for more accuracy.

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

4.2.4.5 Procedure

Conduct the test in the same atmosphere used for conditioning the test specimen.

Measure the width to the nearest 0,10 mm and the thickness to the nearest 0,02 mm based on the average of 5 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 shall 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. The configuration of the grips should prevent breaking of the film at the edges of the grips.

Set an initial grip distance of 100 mm. Optionally 50 mm grip distance may be used if the elongation at break is > 200 % or for post evaluation of weathered specimen, where minimum length of specimen may be limited to > 100 mm to account for restricted size of specimen holder.

The testing speed is 50 mm/min.

NOTE Variation of test results is increased at higher speed.

Record the force and the corresponding values of the increase of the gauge length and of the distance between grips during the test.

Determine all relevant stresses and strains from the stress-strain curve. Data from specimens where grip slippage occurs, or where failure occurs within 10 mm of either grip, or where an obvious fault has resulted in premature failure, shall not be included in the analysis. Repeat tests shall be carried out on new specimens.

4.2.4.6 Final measurements

a) Tensile strength at break, σ_B: The tensile strength is the stress at which the test specimen ruptures. It shall be expressed in Mega Pascals (MPa) and calculated based on the original cross-sectional area of the specimen.

b) Elongation at break, ε_B: The strain value, i.e. increase in length per unit original length of the gauge, at the tensile stress at break.

4.2.4.7 Reporting requirements

Report the median values and standard deviation, for MD and TD specimens, of

- tensile strength at break σ_B
- elongation at break ε_B

Report specimen length, specimen width, specimen shape and initial grip distance.

Trace the context of testing, i.e. whether results have been obtained from “fresh” specimens, after some pre-processing (lamination) or after particular ageing tests (see 4.10).

4.2.5 Curling

4.2.5.1 Purpose

Curling of frontsheet or backsheet during module lamination may undermine the reliability of the module, for example by introducing bubbles, wrinkles and so on.

NOTE The presence of curling may indicate that internal stress in a multilayer construction is not balanced, i.e. stress-free. Degree of curl may depend on position of sample on the roll.

4.2.5.2 Procedure

The degree of curling is to be measured and reported according to IEC 61189-3. See 9.4 Test 3 M04 (bow).

4.2.5.3 Reporting requirements

Report degree of curl according to test method defined by aforementioned procedure.

4.3 Adhesion testing

4.3.1 Purpose

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

It is therefore needed to examine adhesion strength before and after environmental stress tests in order to assess its relative change for the interlayer adhesion of the multilayer frontsheet or backsheet composite as well as the frontsheet and backsheet adhesion to other materials in a PV module.

Results from adhesion tests can be strongly dependent on test parameters (rate, temperature), test geometry, sample preparation procedure and material properties, which may change during ageing. It is therefore important to correlate the stresses applied in the ageing test to those found in field application; quantitative comparison of absolute adhesion strength between different materials or sheet constructions may be limited. 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.

NOTE The adhesion test methods described below and their recommended use are described in the informative Annex A.

4.3.2 General

Adhesion testing of a multilayer stack will in general result in failure at the “weakest link” of the stack. This provides a quantitative value of the bond strength at a single interface (or alternatively, the cohesive strength of one material), and also provides a minimum value for all other interfaces and materials in the stack.

Multilayer stack may refer to:

a) the multilayer construction of the backsheet or frontsheet, which contains layers serving as relied-upon electrical insulation and eventually other layers providing extended protection against environmental stresses or adhesive function between the composite layers, or

b) the material construction consisting of the components of a PV module, such as for example a laminate of glass, encapsulant and backsheet.

   Testing of adhesion of backsheet or frontsheet to encapsulant, edge seal or junction box adhesive requires selection of another material to which adhesion strength shall be evaluated: the measured adhesion strength may depend on the other material(s) as well as the processing or curing conditions for the different components.

Characterization of the "interface of interest" can be made with proper selection of adhesives and adherents, so that these interfaces have bond strength higher than the "interface of interest", or – in the case of very high bond strengths – high enough to demonstrate bond strength sufficient for the application (with appropriate safety margins).

Another approach is the production of engineering samples consisting only of the material layers of interest, in order to specifically examine interfaces or materials that may otherwise not be queried during "weakest link" testing.

In order to apply this method to backsheet or frontsheet multi-layer constructions, one needs access to the 'components of construction', which is typically possible only for the producer of the sheet. Otherwise testing adhesion of a frontsheet or backsheet as such has to be performed on the complete sheet.

Depending on the various adhesive interfaces involved, different adhesion tests are suitable. The choice depends on the construction of the backsheet or frontsheet, selecting from different test geometries designed for assessment of adhesion between rigid or flexible materials.

- Adhesion between one rigid and one flexible layer (e.g. aluminium rail to backsheet or glass/encapsulant to backsheet): e.g. 180° peel or T-pluck test
- Adhesion between two flexible adhering layers: e.g. 90° peel test (performed as T-peel) and 180° peel test (with or without a rigid substrate as backing)

These tests typically require a test apparatus by which a mechanical load can be applied to the layer stack, and which also has provisions to record the force and displacement during the test (see 4.2.4.4). The portions of the stack comprising the "materials of interest" shall be prepared in accordance with manufacturer's instructions, and those preparation conditions reported. For T-pluck and lap shear test, other auxiliary materials ("handles") shall be selected as to have high adhesion, such that the strength of the weakest link, representing a minimum value, is sufficient for the application. For 180° peel and T-peel samples are prepared as to introduce the adhesion test force at the interface of interest, e.g. by limiting the adhesion locally (e.g. insertion of a release liner or adhesive layer sized differently than other layers).

NOTE Variants of 90° peel tests other than T-peel, such as 90° wheel, 90° with sledge or 90° static peel tests are acknowledged, but not addressed in this document.

Finally, the cross-hatch tape test ISO 2409 represents a manual test to assess adhesion of coatings and thin film layers, that are too thin or brittle to conduct peel testing (i.e. cohesive strength of thin film turns out to be the weakest link).

4.3.3 Sample preparation

Specimen preparation covers the following aspects:

a) Sampling of the frontsheet or backsheet films from the production process (see Annex E), especially including samples from different positions across the machine direction.
b) Samples shall be prepared for either MD or TD direction of the sheet material, and the orientation of the sample tracked and reported, as this may influence results.

c) Preparation of a specimen construction that fulfils the different requirements of a certain adhesion test method, such as insertion of release liners and construction of test samples with auxiliary materials (glass, aluminium, etc.).

d) For lamination of backsheet or frontsheet to an encapsulant the requirements for the lamination procedure given for the dti test (4.5.2) apply.

e) In a preparatory step, identification of a suitable generic glue (epoxy) and surface preparation procedures for auxiliary materials may be required.

f) Also the choice for suitable "partner" (handle or substrate) materials shall be considered, as well as the realization of processing conditions for the engineering samples that should mimic as close as possible the envisaged PV module processing parameters with respect to lamination. See Annex B for details of sample preparation specific for each method.

Carefully inspect the specimens prior to measurement following the procedure for visual assessment defined in 4.6.2.

4.3.4 Sample conditioning

In all cases, for fresh and weathered specimens, the samples shall be 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.

4.3.5 Apparatus and procedure

A mechanical load frame as in ISO 527 shall be used, capable of providing the conditions defined in 4.2.4.4.

Self-aligning grips or their connections (including universal swivel joints) should be used when possible.

The samples should be mounted in the apparatus using the appropriate fixtures, which are specific for the test geometry chosen (see 4.3.6 and Annex B).

Separate specimens shall be tested at the crosshead separation rate of 50 mm/min, proceeding until bond rupture or cohesive failure is observed.

The test shall be conducted at ambient conditions (23 °C ± 3 °C, 50 % ± 3 % RH).

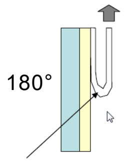
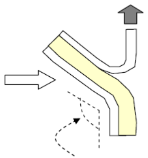
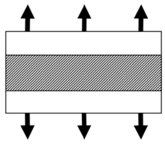
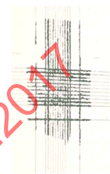
A total of at least five replicate specimens shall be tested and used for final calculations.

4.3.6 Adhesion tests for interfaces of backsheet and frontsheet

4.3.6.1 General

An overview of required and optional adhesion tests for the various interfaces of frontsheet and backsheet is shown in Table 1. Details of sample preparation and specific procedure details of the various test methods defined below are defined in normative Annex B.

Table 1 – Overview of adhesion tests

Interface under test	Adhesion test				
	180° peel test with backing Clause B.1	T-peel test Clause B.2	T-pluck test Clause B.3	lap shear test Clause B.4	cross-hatch tape test Clause B.5
					
1) adhesion between individual components of a frontsheet or a backsheet (4.3.6.2)	required[a]	not applicable	not applicable	not applicable	not applicable
2) test of weakest adhesion link within a finished frontsheet or backsheet (4.3.6.2)	optional[a]	not applicable	required	not applicable	not applicable
3) adhesion test of layers too thin or brittle to peel (4.3.6.2)	not applicable	secondary[d]	secondary[d]	not applicable	required[b]
4) adhesion of a backsheet or frontsheet to an encapsulant or edge sealant (4.3.6.3)	or required[c]	or required[c]	optional	not applicable	not applicable
5) adhesion of backsheet to a junction box adhesive (4.3.6.4)	not applicable	optional	required	optional	not applicable

[a] for layers that can be peeled.

[b] for coatings or thin layers too thin or brittle to peel.

[c] at least one of the two test methods “or required” has to be applied and reported.

[d] secondary test, if suitable tape providing sufficient adhesive strength is not available.

4.3.6.2 Adhesion between layers of composition

4.3.6.2.1 Purpose

The adhesion strength shall be determined between specific layers of composition of a backsheet or frontsheet construction. Use of the test may be limited to the producer of sheet material, as components and adhesives may not be accessible for test specimen construction by 3rd parties.

4.3.6.2.2 Method

For assessment of adhesion of specific interface between specific layers of compositions, 180° peel with a backing plate and partial purposeful insertion of releaser liner shall be applied (see Clause B.1). This test procedure requires specific sample preparation that may only be applied by the producer of the material(s). If specific interface cannot be tested, then "weakest link" shall be applied.

The minimum adhesion strength between any layers of a backsheet or frontsheet construction shall be determined.

a) For assessment of the "weakest link" a pluck test (see Clause B.3) shall be applied. The pluck test may also be applied to extruded sheets.

b) Optionally, a 180° peel test (see Clause B.1) can be used. The latter can only be performed to determine the adhesion strength between layers of the sheet, if the sheet construction can be split by manual manipulation (knife, fingernails or other suitable instruments) such that separate specimen layers can be gripped.

The adhesion of coatings or thin layers, where aforementioned methods cannot be applied, shall be determined with the cross-hatch tape test (see Clause B.5).

EXAMPLE 1 Manual peeling for creation of separate layers for gripping is not possible, which applies for coated layers, but also for thin films with thickness below about 15 μm.

EXAMPLE 2 Yield strength of individual layers in the stack is limited, which may e.g. result in elongation of >200 % or cohesive fracture of that compliant layer, rather than having the force applied to the adhesive interface under interest.

In case of a multilayer sheet construction, the weakest link between all layers on the scored face of the backsheet or frontsheet is tested, as cross-hatch cutting will penetrate down to the substrate of the sheet.

If a suitable tape with the required initial adhesion for the interface under test is not available, then a T-peel test or a T-pluck test can be used as secondary method to assess the adhesion strength of the inner layer or the outer (= air side) layer of the frontsheet or backsheet, respectively. In that case the adhesion test follows the T-peel and T-pluck procedure without applying the cross-hatching.

NOTE Results from adhesion tests based on 180° peel and cross-hatch tape adhesion test cannot be compared quantitatively. See Annex A.

4.3.6.3 Adhesion between sheet and encapsulant or edge sealant

4.3.6.3.1 Purpose

To assess the adhesion strength between a frontsheet or backsheet and another matching material, such as an encapsulant or a selected edge sealant. The adhesion values are dependent on the type of encapsulant or edge sealant and lamination parameters.

4.3.6.3.2 Methods

a) 180° peel with rigid backing (see Clause B.1) or T-peel (Clause B.2) are required for datasheet reporting.

b) T-pluck test (see Clause B.3) is an optional test.

Depending on the type of front- or backsheet sheet T-peel may result in smaller to equal peel strength values in comparison to 180° peel, but in many cases still allows to evaluate adhesion of aged materials, in which the sheet material may have already become too brittle to be analysed by 180° peel test. Applying and reporting results of both methods, 180° peel and T-peel, may therefore provide additional information about the evolution of adhesion strength after ageing.

4.3.6.4 Adhesion between backsheet and junction box adhesive

4.3.6.4.1 Purpose

The adhesion strength of the adhesive used for mounting of the junction box to the outer layer (air side) of a backsheet shall be determined. The adhesion strength values are dependent on the type of junction box adhesive and may also depend on the sample preparation.

4.3.6.4.2 Methods

a) Pluck test (see Clause B.3) is required for datasheet reporting.
b) Lap shear test (see Clause B.4) is an additional optional test.
c) T-peel (see Clause B.2) or 180° peel (see Clause B.1) are recommended for "screening" only (e.g. sheet manufacturer's internal tests or R&D testing).

NOTE Pluck test and lap shear test can be applied for "screening", too.

4.3.7 Reporting requirements

4.3.7.1 Reporting requirements for adhesion tests

Report the following:

a) mean of the stress in (N/cm) as described for each test, and the standard deviation.
b) test method:
   - 180° peel test (Clause B.1)
   - 90° T-peel test (Clause B.2)
   - T-pluck test (Clause B.3)
   - Lap shear test (Clause B.4)
   - X-hatch tape test (Clause B.5)
c) direction MD or CD of the specimen
d) failure mode and type of failure (cohesive / adhesive)

NOTE In case cohesive failure, peak load (N/cm^2) does not represent the bond strength between (components of) frontsheet / 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 glues and handles (glass, aluminium, etc.)
g) sample pre-conditioning
h) temperature of test (required is 23 °C / 50 % RH, optional 70 °C).

Trace the context of the adhesion test, such as: fresh, after ageing (DH testing, weathering).

4.3.7.2 Reporting requirements for cross-hatch tape test

- report class of area loss after cross-hatch test by comparison to the visual ruler in Table 1 of ISO 2409:2013 (see Clause B.5).

- 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.

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 are likely to be applied 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

The thermal ratings shall be acquired according to IEC 60216-5 (RTE), UL 746B (RTI) or IEC 60216-1 (TI).

In IEC 60216-2 the recommended properties for flexible material combinations (like multi-layer backsheets) are tensile strength and d.c. dielectric breakdown strength, both with a recommendation of retaining at least 50 %. Typically, a mechanical-impact rating is not required.

In historical tests of RTE/RTI/TI, a.c. breakdown voltage test may have been applied, whereas d.c. mode is preferred for envisaged use case in PV modules as stipulated in 4.5.1. Depending on material a.c. breakdown values are typically 3 to 5 times smaller than d.c. breakdown values. Impact on RTE/RTI/TI rating may be limited, since analysis is based on relative retention.

The requirements for relied upon insulation are defined in IEC 61730-1:2016, 5.5.1.3. and the evaluation of multilayer constructions is defined in IEC 61730-1:2016, 5.6.4.3.

4.4.1.3 Reporting requirements

Report the method (RTE, RTI or TI) and the thermal endurance or index value measured in °C.

Report whether test was performed on components of backsheet separately or a multilayer backsheet as a whole.

4.4.2 Dimensional stability

4.4.2.1 Purpose

To determine the irreversible deformation of frontsheet or backsheet sheets due to thermal exposure that may occur during processing of a module. It describes dimensional changes before and after exposure to specified temperature for specified time and identifies the relaxation of the film from its fabrication state.

The procedure follows IEC 62788-1-5, in which a similar test method for encapsulants is described. The procedure is adopted for larger sample size, since backsheet and frontsheet have typically higher dimensional stability than encapsulants. Furthermore, many backsheets and frontsheets have at least one side that is barely sticky. Therefore, alternatives for sand are allowed to provide free movement of material under dimensional change.

4.4.2.2 Sampling

The test specimen shall be a square of 200 mm x 200 mm. Two sheets shall be tested across the width of a roll (see Annex E). The specimen is measured from edge to edge before and after the dimensional stability test (see Figure 2) in machine direction (MD) and in transverse machine direction (TD).

Dimensions in millimetres

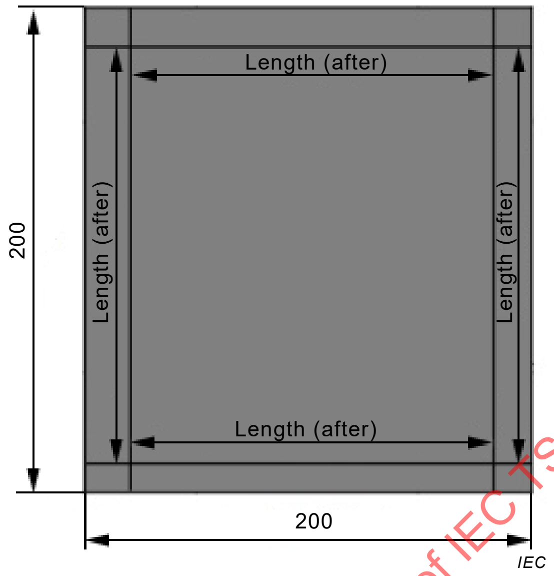


Figure 2 – Specimen before and after shrinkage

4.4.2.3 Apparatus

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

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

4.4.2.4 Procedure

Measure the length (MD, TD) of the sample on both edges from corner to corner 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 samples in an appropriate way to ensure:

- Homogeneous temperature on both sides of the film samples.
- There is no influence of the weight of the samples on the results, i.e. hanging of films is not an option.
- For multi-layer backsheets and frontsheets the material designed to be on the outside of the package should be tested face down on the sample support.
- Free movement of material on its support during dimensional change, i.e. sticking has to be avoided. Examples of interleave material to avoid sticking of test material and sample support are craft paper, fluorinated polymer, talc dusted paper and sand.
- No contact to the walls of the oven.

4.4.2.5 Final measurements

Let the samples cool down to room temperature and measure the length (MD, TD) of the sample to the nearest 0,01 mm.

Calculate the change in length and width in relation to the original measurement in percent. The dimensional stability of both directions is the average of the two measurements.

$$\Delta L\ [\%] = (1 - \frac{length_{\text{after}}}{length_{\text{before}}}) \times 100$$

where

$length_{\text{after}}$ is the length after heating;

$length_{\text{before}}$ is the length before heating.

4.4.2.6 Reporting requirements

Report change of relative dimension ΔL [%] for both, MD and TD direction.

4.4.3 Relative thermal expansion (CTE)

4.4.3.1 Purpose

The CTE (Coefficient of Thermal Expansion) gives information about the reversible deformation due to diurnal thermal cycles that may occur during operation of a PV module. This information may be helpful to identify matching materials in design of a PV module. The method here shall be applied to measure the CTE of backsheet or frontsheet product (or its components).

In order to measure the reversible thermal expansion coefficient of the material, the film needs to be relaxed from its production site by thermal cycling. CTE may be different for MD and TD direction.

4.4.3.2 Apparatus

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

4.4.3.3 Procedure

The test is performed according to ISO 11359-2. Repeat the test on 3 samples.

For relaxation of eventual internal stresses arising from the production process of polymer films it is required to run two thermal cycles and to determine thermal expansion from the 2^{nd} thermal cycle only. The first temperature cycle shall simulate a lamination cycle with heating of the specimen up the 160 °C or the maximum lamination temperature recommended by the sheet manufacturer, whatever is smaller. Apply a holding time of 5 min at maximum temperature to mimic the lamination process.

NOTE 1 The results from this 1^{st} cycle give information about dimensional change in addition to 4.4.2.

In the 2^{nd} cycle, the temperature shall be cycled between ambient temperature and 160 °C or RTE/RTI/TI, whatever is smaller.

NOTE 2 The upper temperature limit has been defined to prevent melting of the material.

Perform the test in both, machine and transverse machine direction. Use at least 3 replicates per orientation in order to assess dispersion of results.

4.4.3.4 Final measurements

Select the 2^{nd} measured curve and determine the relative thermal expansion α in K^{-1} at 23 °C.

Give reference to the calculation without (= method A) or with (= method B) reference specimen.

In case of a test specimen exhibiting a glass transition, calculate the coefficient additionally before and after the glass transition.

4.4.3.5 Reporting requirements

Report the mean CTE value and the standard deviation of 3 measurements at 23 °C indicating the method used (A or B). Indicate the presence of a glass transition. Report the maximum temperature of 1st and 2nd test cycle and the holding time at maximum temperature. Optionally the curve of CTE between ambient and maximum test temperature may be reported.

4.4.4 Thermal conductivity

4.4.4.1 Purpose

The thermal conductivity of the polymeric frontsheet 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 backsheet or frontsheet product.

4.4.4.2 Procedure

According to EN 821-2 and ASTM E1461.

4.4.4.3 Reporting requirements

Report the value of thermal conductivity of the multilayer frontsheet or backsheet.

4.5 Electrical characteristics

4.5.1 Breakdown voltage

4.5.1.1 Purpose

This test method provides the measurement of the dielectric strength of a frontsheet or backsheet designed for use in photovoltaic (PV) modules, using direct current (d.c.) voltages. It should be noted that for most materials the d.c. breakdown value is higher than the peak value of the power frequency breakdown voltage; for many materials, the d.c. breakdown voltage will be three or even more times higher than the alternating current breakdown voltage[1] 1.

The dielectric breakdown shall be determined for the part of the backsheet that is qualified as relied upon insulation (see the evaluation of multilayer constructions as defined in IEC 61730-1:2016, 5.6.4.3.). If layers are present, that do not contribute to RUI, choose either of the following methods:

Method A: Measure the relied upon component as such or remove the part of a multilayer sheet construction that is not qualified as relied upon insulation, e.g. peel of a soft inner layer that may be displaced in the dti test (see 4.5.2).

Method B: Determine the ratio of thickness of layers in the sheet construction that contribute to RUI (t_{RUI}) to the overall thickness (t_{total}) of the sheet as verified by dti test (see 4.5.2).

In case of method B the d.c. breakdown voltage value, that is measured on the complete multilayer sheet including parts not contributing to RUI, is multiplied by the ratio t_{RUI} / t_{total} to provide a linear correction, which is valid only for polymeric, non-conductive materials.

1 Numbers in square brackets refer to the Bibliography.

4.5.1.2 Specimens

Prepare 10 samples of at least 50 mm x 50 mm size from sheets of frontsheets or backsheets films or a component that is intended to be used as relied upon insulation. Sample surfaces should be smooth while being held between flat, planar surfaces. Samples shall be free of volumetric defects, e.g., bubbles or voids.

In case of Method A remove the part of the multilayer sheet that does not provide relied upon insulation.

Measure average thickness of the test specimen as defined in 4.2.2.

4.5.1.3 Preconditioning

The d.c. breakdown voltage of backsheets and frontsheets 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 % relative humidity, as specified by standard ambient atmosphere in IEC 60212.

4.5.1.4 Number of specimens

Ten specimens shall be tested and the d.c. breakdown voltage determined from the median of the results. If any point in the calculation of the median is larger than the limit of the voltage generator, the median should be reported as larger than (>) the median.

EXAMPLE Assume use of a 100 000 V generator and the median is calculated as 95 000 V, but for some of the samples no breakdown occurred telling that the breakdown strength exceeded 100 000 V. In such cases the median breakdown shall be reported as >95 000 V.

4.5.1.5 Procedure

See Annex C.

4.5.1.6 Reporting requirements

Report the following:

a) Name and type of material (backsheet, frontsheet or material component), total thickness and the thickness ratio t_{RUI} / t_{total} for the material tested.

b) Report, whether method A or method B has been used.

   - For Method A: report the median of the measured d.c. breakdown voltage of the material(s) as measured for its (their) given thickness in kV and the standard deviation as measure of uncertainty. In addition, report the d.c. breakdown voltage per thickness (kV/mm).
   - For Method B: report the median of the measured d.c. breakdown voltage value measured for the multilayer sheet multiplied with the thickness ratio t_{RUI} / t_{total}. Also report the standard deviation as measure of uncertainty.

c) Report ramping speed and type of mineral oil used as described in Annex C.

d) Report any deviations from, additions to, or exclusions from the test method and any other information relevant to a specific test, such as specimen preconditioning and environmental conditions, including the oil temperature during testing; the location of the failure (e.g. electrode periphery or center, etc.) may be reported if considered relevant for the specific test.

4.5.2 Distance through insulation (dti)

4.5.2.1 Purpose

This test is conducted to ensure a minimum thickness of relied upon insulation in a polymeric frontsheet or backsheet after a lamination process, including an artificial metallic defect to simulate a worst case scenario. A solder wire with a diameter of 800 µm has been selected to simulate a reasonably worst case, such as e.g. solder peaks or inclined ribbons [2].

NOTE 1 This method represents a practical pre-qualification of dti on component level. It may not guarantee that frontsheets or backsheets in final application on modules will comply with IEC 61730-2:2016 MST 04, e.g. because of "poor module work craftsmanship".

NOTE 2 The insulation thickness test MST 04 of IEC 61370-2:2016 is performed on modules after they have been conditioned in sequence B of IEC 61370-2:2016. In a Round Robin study it was shown that dti results for backsheets tested for insulation thickness on component level were identical when tested with and without application of sequence B prior to the dti test.

4.5.2.2 Sample preparation

The frontsheet or backsheet test specimen should approximately be 210 mm x 148 mm (A5 format) with tolerances of ± 20 mm for both directions.

Prepare a stack of materials for lamination (listed from top to bottom) with all sheet materials and PV glass having about the same dimensions as the backsheet or frontsheet:

- 1 backsheet or frontsheet (inner layer facing down)
- 1 layer of encapsulant with thickness of 450 µm ± 100 µm

NOTE 1 Due to its thermoplastic deformation during lamination cycle, the encapsulation layer reduces the pressure acting from the solder wire on the inner side of the sheet. Current encapsulant materials are (i) ethylvinylacetate (EVA) type encapsulants including fast and slow types, (ii) thermoplastic polyolephine (TPO) type encapsulant and (iii) silicone type encapsulants.

- A piece of solder wire 800 µm ± 50 µm (e.g. 96 % Sn / 4 % Ag) having a minimum length of 15 cm is placed across the sheet area. The melting temperature of the solder wire has to be at least 20 K higher than the envisaged maximum lamination temperature. To limit environmental concerns lead-free solder is recommended.
- Release material (e.g. fluoropolymer film) with a thickness of ≤ 50 µm.
- Surface-structured PV glass 3,2 mm ± 1 mm (bottom), structure facing down.

See also coupon H in Table F.1 of F.2.2.

NOTE 2 The diameter of 800 µm mimics the size of solder peaks in case of manual soldering and also represents protrusions introduced by twisted ribbons or bend on ribbon, for which similar sized defects that have been observed. The cylindrical wire geometry improves the reproducibility of the test in comparison to using a tip defect: i) a tip is hard to reproduce and ii) the position of a tip hard to match in a cross-section, which is required to detect the minimum remaining thickness after test.

NOTE 3 Both, solder wire with or without flux are suitable. It has been found in a Round Robin test including PET based backsheets and backsheets with a totally displacing E-layer as inner layer that dti results do not differ between using solder wires with flux or without, even though some plastic deformation of solder wire with flux was observed. There was also no difference found for solder wire with and without lead. dti results in tests using copper or steel wires were also the same as for solder wire.

Either, laminate the stack at conditions suitable for the encapsulant following recommendations of manufacturer in order to produce a coupon representative for production of a specific PV module, or purposefully define and apply more severe lamination conditions with maximum temperature, lamination duration and pressure at maximum temperature being equal or higher than for lamination conditions representative for intended use, considering various module designs and types of encapsulant.

The actual temperature vs. time profile that is effective at the interface between frontsheet or backsheet and the encapsulant depends on the laminator and therefore the nominal settings are only approximate. For a given lamination program, the actual temperature vs. time profile at the interface between frontsheet / backsheet and encapsulant shall therefore be measured with temperature sampling at least every 5 s, e.g. by insertion of a thermocouple. The maximum average temperature reached during a time span of at least 1 min shall be reported. Also measure the lamination pressure.

NOTE 4 Typical nominal lamination conditions for EVA type encapsulant may take ~15 min at 145 °C under atmospheric pressure (via low-pressure vacuum). Example data in Figure 3 was obtained using a laminator with the bed nominally set for temperatures between 135 °C and 165 °C. The sample consisted of a 30,5 cm x 30,5 cm x 3,18 mm glass piece with EVA, a 156 mm cell, EVA and a backsheet with a soft interlayer (E-layer) with the thermocouple placed on the back side of the PV cell. For all runs, there was an approximate 5 °K difference between the final temperature measured with the thermocouple and the nominal chamber bed temperature.

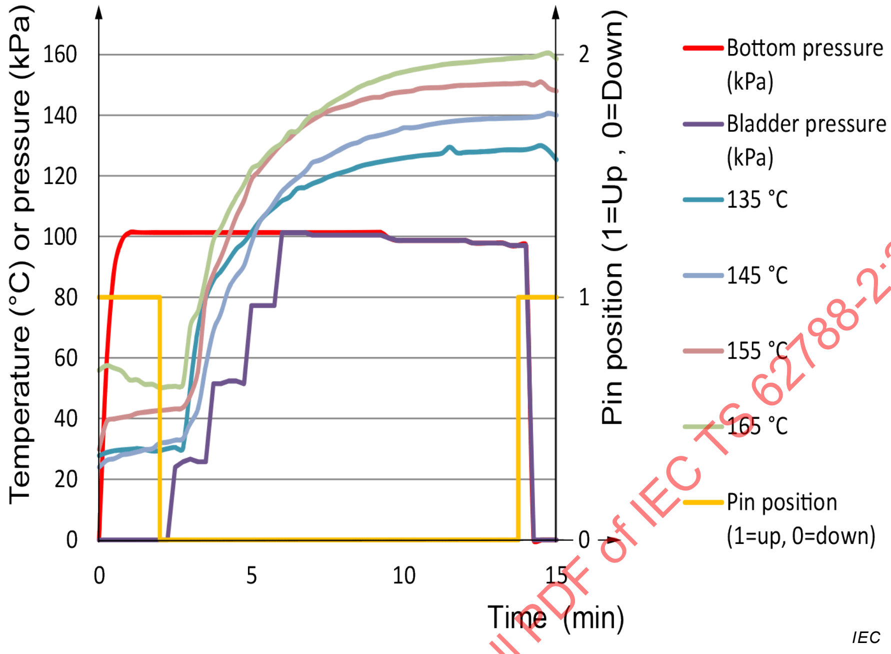


Figure 3 – Examples of lamination cycles

Remove the glass and release film from the stack after the lamination, see Figure 4.

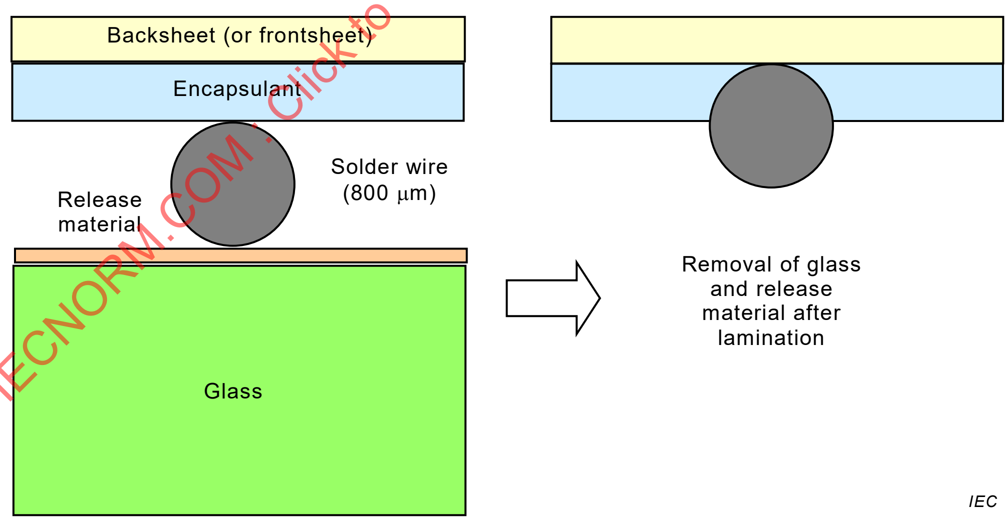


Figure 4 – Schematics of test specimen for distance for insulation before and after lamination

4.5.2.3 Apparatus

Cross-sectioning and layer thickness measurement should be performed according to ISO 2808. The tools shall allow a combined accuracy of ≤ 5 %.

Tools suitable for cross-sectioning include (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.

To verify the accuracy of the sectioning method, a comparison between measurement results with a calibrated calliper (gauge) and a cross-section assessment should be conducted on the same spot of a non-laminated part of a backsheet. This is to ensure that there are no deformations (like ridges) along the sectioned edge, which would increase the measured thickness. The level of accuracy may depend on the material construction, as artefacts introduced by cross-sectioning may depend on the mechanical properties of the individual layers in the stack. Therefore, accuracy shall be checked for the layer stack designs representative for the type of frontsheet or backsheet, for which dti shall be determined.

To determine the repeatability of the procedure the standard deviation of at least 3 measurements shall be measured, which shall be within the combined accuracy of ≤ 5 %. The 3 measurements shall be performed on cross-sections that are sampled at minimum 10 mm distance from each other along the wire. Sampling also requires a minimum distance of 10 mm from either any end of the wire (in case the wire ends within the laminated stack) or any edge of the laminated stack (in case wire extends the stack).

NOTE Due to the transient change of material thickness, effects of deformation may occur which are not intended by this method.

4.5.2.4 Procedure

The cross-section should be orthogonal to the wire and obtained with a suitable method. For some cross-sectioning methods it might be useful to remove the embedded solder wire prior to sectioning. Ensure not to damage the backsheet when removing the solder wire, see Figure 5.

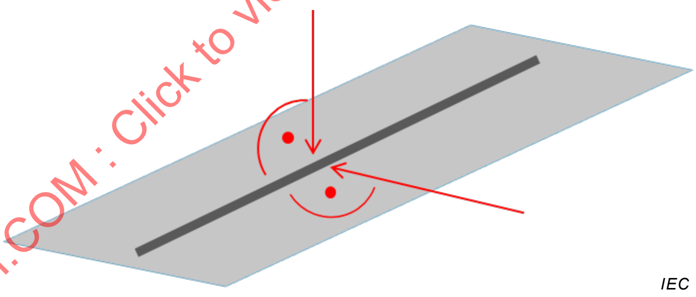


Figure 5 – Directions for sectioning (perpendicular to solder wire position)

The prepared cross-section should be mounted in the microscope in such a way that the obtained image is perpendicular to it. In the microscope picture or micrograph image, identify each individual layer, labelling each according to the layers given by the backsheet manufacturer.

In the cross-section measure the overall minimum thickness. This is typically found in a range of 150 µm or 300 µm related to the voltage class of the PV module, for which the frontsheet or backsheet has been designed, and is situated under the position of the wire, where the wire is closest to, touching or (partially) penetrating the frontsheet or backsheet. Measure at least at three positions within this range. Identify the position of the minimum thickness from these measurements. Also measure the thickness of each layer of the multilayer sheet at that minimum position. Save a copy of the cross-section image indicating the measurement position and the minimum thickness value.

Calculate the dti as the sum of the thicknesses of each layer, which satisfies the relied upon insulation requirements according to IEC 61730-1:2016, 5.6.4.2. Layers not qualified as relied upon insulation do not contribute to dti. If the whole backsheet stack fulfils the requirements, the overall minimum thickness can be reported as dti.

4.5.2.5 Reporting requirements

Report:

a) The dti value. This is the minimum thickness value of the cross-section measurement, from which the accuracy of the method rounded to 1 µm is subtracted to satisfy MST04 of IEC 61730-2.

b) The composition of the solder wire, its melting temperature and indicate, whether solder wire flux or without has been used.

c) Thickness and type of encapsulant (e.g. EVA including fast and slow cure type, TPO type, silicone type).

d) Lamination temperature, which is defined as average maximum temperature measured at interface of frontsheet/backsheet and encapsulant during at least 1 min of the lamination cycle.

NOTE 1 By calibration the actual lamination temperature can be related to the nominal lamination temperature.

e) Overall duration (time) of lamination cycle.

f) Average lamination pressure during period of time, when maximum temperature was reached.

g) The interface lamination temperature and pressure may be reported as function of time as shown in Figure 3.

h) An image of the cross-section at which the absolute minimum thickness has been measured and in which the measurement position is indicated.

NOTE 2 The following short nomenclature is proposed for datasheet reporting: dti (wire Ø [µm] and material [solder] / type of encapsulant / maximum lamination temperature [°C] / lamination pressure [Pa] / duration of lamination cycle [min]).

EXAMPLE In the example of Figure 6 a dti value of 164 µm is determined. Accuracy of the method has been determined as 4 %, resulting in 7 µm after rounding. Lamination is based on cycle “145 °C” of Figure 3 and a solder wire with the composition 96 % Sn / 4 % Ag and a diameter of 800 µm has been used.

Report: dti = 157 µm (800 µm solder wire 96Sn4Ag / 450 µm fast cure EVA / T_{max} 138 °C / p = 98 kPa / 13 min).

4.5.2.6 Pre-qualification

The reported dti qualifies for other PV designs with the same encapsulant type when all of the following pre-requisites are fulfilled:

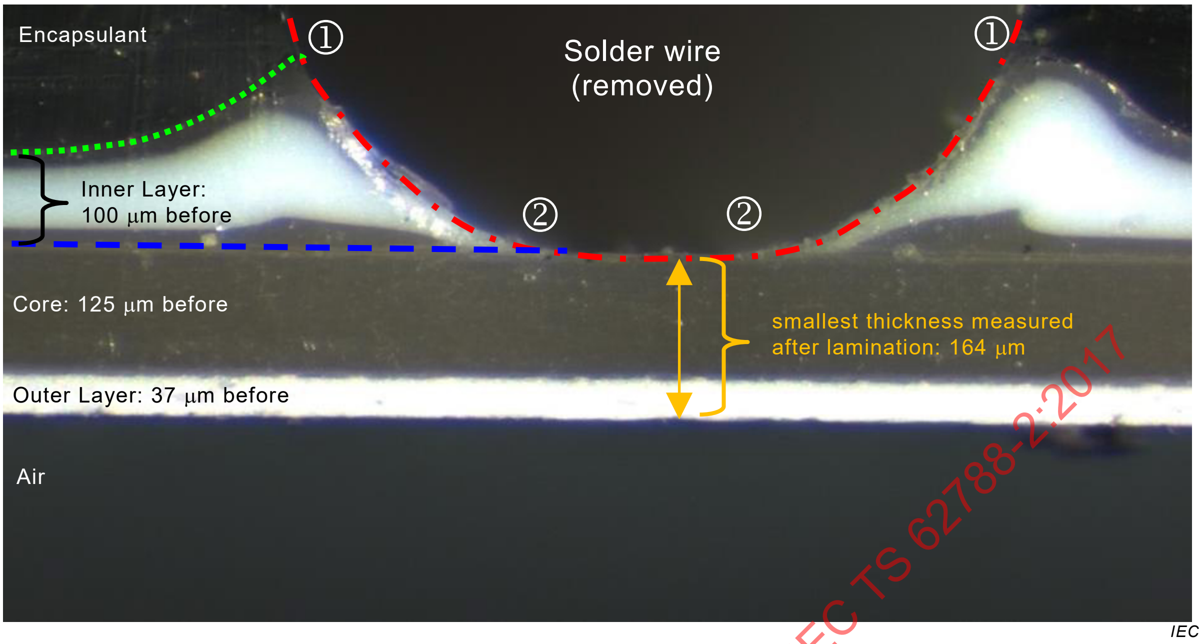
a) The encapsulant is of same thickness (within ± 100 µm) or thicker, of the same base resin type, with substantially similar cure chemistry.

b) The maximum measured (or calibrated-to-measured) lamination temperature is the same (within ± 1 °C) or lower.

c) The lamination duration is the same (within ± 5 %) or lower.

d) The lamination pressure at maximum temperature is same (within ± 5 %) or lower.

4.5.2.7 Example



NOTE The perimeter of the removed solder wire is indicated by the dash-dotted line. If the solder wire would be regarded as live part, 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 the figure 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 6 – Example of dti cross-section of a backsheet with an E-layer as inner side material

4.5.3 Comparative Tracking Index (CTI)

4.5.3.1 Purpose

To classify surfaces of frontsheet, backsheet or their components on which tracking may occur due to contact with conductive parts as defined in IEC 61370-1 and IEC 60112.

4.5.3.2 Method

Apply the test method given in IEC 61730-1:2016, B 2.2.4.

4.5.3.3 Sampling

Tracking between materials faces or interfaces potentially in contact with live parts needs to be considered because of horizontal standards. The dti test in 4.5.2 is used to identify those material layers in a multilayer sheet construction that may be in contact with live parts. See example in Figure 6.

Case 1: The most inner side material(s) of the frontsheet or backsheet facing towards the encapsulant is (are) not displaced and/or perforated in the dti test (4.5.2). In this case, tracking needs only to be tested on the surface of the most inner material of the sheet, facing the encapsulant.

NOTE The other material surface of the interface is the encapsulant material.

Case 2: The most inner side material(s) of the frontsheet or backsheet facing towards the encapsulant is (are) well displaced and/or perforated in the dti test (4.5.2) in such a way that live parts may come into contact with a potentially tracking material surface inside the multilayer sheet construction . Examples are an adhesive layer (see "x" in the multilayer sketches in Figure 4 of IEC 61730-1:2016) or a RUI-layer. In that case, the material surface of such layer needs to be tested for tracking in addition to those identified in case 1.

EXAMPLE In the example given in Figure 6, interface ① is between encapsulant and E-layer and Interface ② is between E-layer and the core material that is coated with an adhesive.

Interfaces between co-extruded layers of miscible polymer compositions (e.g. same base polymer resin) are not considered as potentially tracking interfaces. In the example of Figure 6, the E-layer is a three layers co-extruded film consisting of a white (pigment loaded) core layer sandwiched by thin transparent layer of the same polymeric material that are cohesively bond to the core in the process of co-extrusion (due to polymer entanglement on molecular level). The interfaces between the transparent layers and the pigment loaded core layer therefore do not need to be considered for tracking.

In this example the following sheets are to be sampled as specimens for CTI test:

a) The backsheet including the most inner E-layer that will be in contact with the encapsulant.

b) The backsheet without the displaced / perforated inner E-layer, but with a representative thickness of the adhesive layer.

According to IEC 60112, 3 mm stacks of foils of all aforementioned identified sheet materials (see case 1 and case 2) are prepared with the material surface, on which tracking shall be tested, facing upwards.

Alternatively one can choose to prepare 3 mm thick plates of the materials identified before, including the eventual presence of a representative amount of adhesive on the materials surface, and to determine the comparative tracking index on those.

4.5.3.4 Method

Comparative tracking index is determined according to IEC 60112:2003 (Clause 11) without determination of erosion depth.

4.5.3.5 Reporting requirements

Report according to IEC 60112:

a) the CTI value

b) sample stack preparation (stacked sheets or 3 mm plate like specimen) and

c) observations during test of

- the most inner interface and
- all additional material surfaces that – per dti test – may be in contact with live parts.

Also report the resulting material group as defined in B 2.1.4.1 of IEC 61370-1:2016 for aforementioned material(s).

4.5.4 Volume resistivity

4.5.4.1 Purpose

This test method provides the measurement of the volume resistivity of materials used as frontsheets and backsheets. The test is performed on separate dry and wet preconditioned samples. This test is designed for room temperature measurement, but 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 level of electrical insulation (or leakage currents) provided by a given material per se.

4.5.4.2 Sampling

Depending on the backsheet construction, obtain films consisting of a complete backsheet film, and as many of the other individual layers as is reasonably possible and relevant to the final backsheet laminate. Use film specimens of the thickness used in the backsheet product. Minimum sample sheet size shall be 100 mm x 100 mm. Test samples at 1 000 V d.c. using Method A according to IEC 62788-1-2 with both wet and dry preconditioning at 23 °C ± 2 °C. Each measurement will use the average and standard deviation 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 electrode 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 backsheet materials using common commercially available equipment, the resistivity will be so great that 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

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 5 measurements and the standard deviation are reported in [Ω·cm] following reporting 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 design to select suitable frontsheets and backsheets with respect to photon capture efficiency and thermal management.

- Optical transmittance of frontsheet directly effects PV module performance.
- Module performance following from the reflectance of the sun-facing side of backsheet depends on factors including: module design, the distance between cells, module temperature and type of mounting (roof or rack), etc. For c-Si modules with typical fill-factors of cells, the combined optical and thermal effects do typically introduce performance reductions of 3 % to 5 % when using a black backsheet in comparison to the same PV module constructed with a white backsheet. Variations of solar reflectance introduced by different shades of white backsheets are in the order of 10 % to 15 % of aforementioned effects, i.e. 0,3 % to 0,75 % of the module output power.
- Module performance following from the reflectance of the air side of a backsheet depends on factors including: module design, module installation (roof/rack and inclination angle), level of albedo, ventilation, and module temperature, etc. For typical c-Si PV module designs the resulting “indirect” effect is ca. ~1/10 of the effect estimated for direct exposure of the front side (see IEC TS 62788-7-2 and 4.10.3).

b) Appearance characteristics may be used to describe initial colour and gloss in addition to verbal classifiers, such as for example “white, grey, blue, black, etc.” or “glossy, matte, etc.” 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 frontsheet 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 [17]. 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. One shall assess this correlation 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.

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

NOTE The applicability of gloss measurements depends on the composition of the frontsheet 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 may 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 specimen

For optical characterization a number of 3 replicates is required, which are sampled according Annex E.

4.6.2.2 Conditioning of specimen

Before determination of the optical characteristics of the sheets, either fresh or after some ageing test, 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 function of any pre-treatment, such as a lamination step or an ageing test.

4.6.3.2 Procedure

An observer with normal or corrected-to-normal viewing shall inspect the specimens under an illumination of not less than 1 000 lx at 30 cm to 50 cm viewing distance for the following conditions:

a) bubbles,

b) de-lamination,

c) wrinkles,

d) cracks in the backsheet,

e) any other conspicuous conditions (inclusions, etc.).

4.6.3.3 Reporting requirements

Make note of and report presence or absence of any of aforementioned conditions (see 4.6.3.2) and their nature on 3 replicates of the sheet under investigation.

A photograph is recommended for documentation.

4.6.4 Optical transmittance of frontsheets and backsheets

4.6.4.1 Purpose

The optical transmittance of a frontsheet or backsheet is relevant to estimate its effect on PV module performance (see 4.6.1) in the case 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 needs to be characterized in addition, refer to 4.6.5.

NOTE Examples of clear backsheet 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 frontsheet or backsheet shall be provided. The solar 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 frontsheets and backsheets: In one part, BS 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 should therefore not be used for yield considerations. BS 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 photovoltaic cell.

4.6.4.2 Apparatus, procedure and sampling

The hemispherical spectral optical transmittance of the frontsheet 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, and 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.

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 x 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 calculation 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 AM1.5G 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 3 replicates) of the spectral optical transmittance data as graph or data table. Report the instrument geometry, e.g. 8°/d, and the side of the sheet that has been measured. The representative solar photon weighted transmittance as of IEC 62805-2 may also be reported (AM1.5G weighted average transmission in the range 300 nm to 1 250 nm).

4.6.5 Optical reflectance of backsheets

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 air side (e.g. via contribution to albedo in PV utility systems) are much smaller than those from the sun-facing side as indicated in 4.6.1, 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.

4.6.5.2 Apparatus, procedure and sampling

The hemispherical spectral optical reflectance of the reflective 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 may 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.

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 x 45 mm or 45 mm Ø circle. The inner side of the 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 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 AM1.5G spectrum shall be based on the 1 nm partition, for which linear interpolation of the reflectance spectrum may be required.

White encapsulant films may also be measured as in 4.6.4.2.

4.6.5.3 Reporting requirements

Report the average (of the 3 replicates) of 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, report the representative solar photon weighted reflectance as of IEC 62805-2 (AM1.5G weighted average transmission in the range 300 nm to 1 250 nm).

4.6.6 Yellowness index (YI)

4.6.6.1 Purpose

This procedure quantifies the degree of yellowness of a test sample, and serves as a means to compare changes to materials resulting from weathering exposure with a report of delta YI.

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 transmittive 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. Changes in YI may correlate to degradation of mechanical or electrical properties, depending on the composition of the material, but because the mechanisms for degradation modes may not be the same, correlation is not guaranteed.

The characterization of discoloration via ΔL*Δa*Δb* or ΔE_{ab} (1976) is a suitable alternative, with Δb* being directly associated with ΔYI.

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

For coloured backsheet, measurement of colour changes via CIE ΔE 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 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 tests, an instrument with a measurement range of 380 nm to 780 nm with a spectral resolution of 10 nm is also suitable.

NOTE 1 Details of instrument configuration may influence the ‘absolute’ YI values measured. Such effects cancel out to first order when changes in Yellowness Index (“Delta YI”) 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 x 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). YI shall be calculated according to ISO 17223.

NOTE 2 Additional details related to the YI may be found in ASTM E313-10 and ASTM E308-08.

4.6.6.3 Reporting requirements

Report the average (of the 3 replicates) of YI values according purpose (e.g. initial values or post weathering evaluation). In the context of post weathering evaluation, Delta 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 (L*, a*, b*)

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 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 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.

NOTE Details of instrument configuration may influence the absolute values of colour coordinates L*a*b* measured. Such effects cancel out to first order when changes in colour coordinates (“Delta E”) 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 transmittive 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 of 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 x 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). 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 vs. before an ageing treatment. From the latter the colour distance CIE ΔE_{ab} (1976) is determined following ISO 11664-4.

4.6.7.3 Reporting requirements

Report the average (of the 3 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, also colour changes ΔL*, Δa*, Δb* or ΔE_{ab} can 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 air side of the 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 gloss can be used as precursor of chalking; however, such assessment may not be easily resolved for materials that are matte on the outset.

4.6.8.2 Procedure

Measure gloss according to procedure and using instruments stipulated in ISO 2813 on 3 replicates.

The initial measurement result on 60° gloss determines whether gloss values at 20°, 60° or 85° shall be collected, as gloss scale is less sensitive below 10 gloss units (GU) or above 70 GU.

If change of gloss values shall be characterized, e.g. in the course of an ageing test, 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 of gloss values and the measurement angle 20°/60°/85°, depending on initial glossiness of material.

In the context of post weathering evaluation, also gloss changes can be reported, with 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 frontsheet or backsheet may be useful for the design of the PV module and is expressed as water vapour transmission rate (WVTR) [3].

The range of suitable WVTR rates for polymeric frontsheet and backsheet materials depend on PV module design. In some instances the polymeric sheet has the function to provide a barrier function for liquid water while still letting water vapour, and by-products such as acetic acid, pass. 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 backsheet materials. WVTR relevant to cells will also depend on the encapsulant.

NOTE A specific standard for measurement of WVTR of sheet material for use in PV context is in preparation (designated as future IEC 62788-6-2).

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 done according to 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 may 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 might be of interest for PV module design.

4.7.1.3 Reporting requirements

Report the following:

a) The method used, i.e. ISO 15106-1, ISO 15106-2 or ISO 15106-3.

b) The test conditions (temperature T / °C and relative humidity % RH).

c) The WVTR value in g / (m^2·d) 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 backsheet and frontsheet 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 on the module’s design and the materials utilized.

NOTE In a comparative study of various type of backsheet, 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 (OTR) 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 T in °C and relative humidity % RH);

c) the OTR value in g / (m^2·d).

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 frontsheet or backsheet. The final cleaning of PV modules may require solvent cleaning and by this method the manufacturer can qualify a cleaning solvent as his 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 to ASTM D5402-06, Method A (Standard Method).

b) If the testing is being performed in a laboratory setting, 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 will be considered as being 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 coating in the selected areas in accordance with the test method of ISO 4593. Mark a 150 mm by 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 approximately 1/s.

g) Continue rubbing the test area for a total of such 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, 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, stop testing (after completing a specimen) until fatigue is gone.

4.8.1.4 Final measurements

Examine the test area by visual inspection. Identify, if 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 cloth and solvent used. Report the number of double rubs as well as the visual quality before and after rubbing

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 component level, because test results obtained without the thermal mass of the module being present are likely to cause misleading results. Instead IEC 61730-1:2016 covers this issue with a full module or representative coupon test.

Therefore, a specific test for ignitability of backsheet or frontsheet on 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 component level, because test results obtained without the thermal mass of the module being present are likely to cause misleading results. Instead IEC 61730-1:2016 covers this issue with a full module or representative coupon test.

Therefore, a specific test for flammability of backsheet or frontsheet on 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 frontsheet 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 between material changes upon cumulative exposure dose of stress applied in the accelerated test and the same dose present in the field, is not known. 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 case of deviation from linear (1^{st} order) degradation, additional measurements as function of the important stress variables (temperature, humidity, UV) are needed 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 veteran 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 may affect solar reflectance, resulting in degradation of PV module power output performance.

Thermal endurance of backsheet and frontsheet film material is assessed by RTE/RTI/TI measurement, based on 50 % retained mechanical strength and breakdown voltage as recommended by IEC 60216-2:2005, Table 1 and 4.4.1.

NOTE The retention levels of 50 % in RTE/RTI/TI testing have solely been defined for the purpose of extrapolation of failure times in an Arrhenius analysis (relative to a reference material). However, these retention values do not predetermine any correlation with material failure representing service life time.

This subclause describes accelerated damp heat testing and UV weathering for polymeric frontsheets and backsheets for use in terrestrial PV modules.

4.10.2 Damp Heat (DH) testing at elevated heat and moisture

4.10.2.1 Purpose

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

In order to assess the endurance of their insulating function of backsheets or frontsheets, mechanical strength and d.c. breakdown voltage of films are assessed before and after DH testing.

4.10.2.2 Samples

Refer to Table F.1 for sample preparation. Choose coupon A or coupon B1 for DH incubation followed by tensile strength test or d.c. breakdown voltage test.

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

Number of specimen depends on 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 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. This is e.g. given when samples are placed free hanging in the chamber.

4.10.2.4 Requirements for 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 needs to be pre-conditioned according to requirements of the post evaluation test.

a) Required material characterization includes:

- samples shall be visually evaluated before and after DH 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 4.3.6.2) is measured on replicate specimens before and after DH.

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

b) Optional material characterization includes:

- d.c. breakdown voltage of replicate specimen shall be measured before and after DH (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: 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 4.3.6.3) is measured on replicate specimens before and after DH.

4.10.2.5 Reporting requirements

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 clause 4.10.2.4. b).

In b) and c) report absolute results from the material evaluation tests after DH in comparison to values before. Reporting of % retention together with the initial value is an alternate reporting option.

4.10.3 Weathering at elevated levels of temperature and moisture

4.10.3.1 Purpose

The purpose of the weathering test is to characterize the ability of frontsheets 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 d.c. 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 side of the backsheet that faces towards the sun, with flux and spectral distribution depending on the PV module design;

b) radiation may also reach the air-side 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 (roof, rack, etc.) [4] [5]. This test method therefore provides two orientations of testing backsheet, namely sun-facing side or air side oriented towards 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. For other types of backsheet films, typically sheets with a symmetric layer design, UV filtering provided by other module components may not be required. This test method therefore provides a choice for testing backsheet or 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

Backsheet and frontsheet films shall be sampled from a roll according to Annex E.

Sample preparation for weathering depends on size of specimen holders and the material test methods to be evaluated after weathering. Refer to Table F.1, for sample preparation. In addition, Table 2 gives an overview of sample preparation for exposure of sun-facing side of backsheet in view of intended post-evaluation.

Method A: Frontsheet shall be tested only with its sun-facing side oriented towards the light source.

Method B: The air side of backsheet films shall be exposed directly to the test light source.

Method C: The sun-facing side of backsheet film will be exposed consisting of one of the two options C1 or C2:

Method C1 (exposure with UV-filter): This method is 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 340 nm to 360 nm. See requirements in 4.10.3.3 for qualification of UV filters and transparent release material (trm). There are two possible realizations C1a and C1b:

- Method C1a: One realization of a representative UV filter is obtained by lamination of a design specific laminate containing a transparent release material (trm), so that films can be sampled after weathering for subsequent material tests. For optical measurement, mechanical strength testing and electrical strength testing, coupon type B1 as defined in Table F.1 is selected. For adhesion peel testing, coupon B2 is suited. For pluck test, lap shear test and fracture mechanics test, coupon type D applies.
- Method C1b: 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 type C as defined in Table F.1. This method can be selected for weathering of sheet material intended for optical characterization, mechanical strength testing and dielectric strength testing.

Method C2: (direct exposure without UV-filter): In this optional method, the sun facing side of backsheets is exposed without a UV-filter. See specimen A in Table F.1. This method can be selected for weathering of sheet material intended for optical characterization, mechanical strength testing and dielectric strength testing.

NOTE 1 In method C1a, 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, whereas in methods C1b and C2 it is not.

Table 2 – Overview of sample preparation for exposure of sun-facing side of backsheet depending on intended post evaluation (see Table F.1)

<table>
<tr><td colspan="2"></td><td colspan="3">Specimen construction using backsheet</td></tr>
<tr><td colspan="2">Post evaluation</td><td>Separate sheet (or laminated sheet with full release)</td><td>Laminated sheet with partial release</td><td>Laminated sheet without release</td></tr>
<tr><td colspan="2">Mechanical strength (see 4.2.4)
Electrical strength (see 4.5.1)
Optical characterization (see 4.6)</td><td>Coupon A
OR coupon B1
OR coupon C</td><td>Not applicable</td><td>Not applicable</td></tr>
<tr><td rowspan="2">Adhesion</td><td>180° peel (See Clause B.1)</td><td>Not applicable</td><td>Coupon B2</td><td>Not applicable</td></tr>
<tr><td>t-pluck (see Clause B.3)
Lap-shear (see Clause B.4)
Fracture mechanics (under development in [18])</td><td>Not applicable</td><td>Not applicable</td><td>Coupon D and E with specific handles (see Table F.1)</td></tr>
</table>

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

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

Number of specimen 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 fall within 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, the corresponding handles (see F1, F2 and F3, respectively as defined in Table F.1) shall be mounted to the sheets after ageing in order to avoid unintended ageing of the glue or interactions of glue 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 barely exposed to UV, neither direct through the PV module neither via albedo. Refer to IEC 62790 for 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, for which e.g. a laminated coupon “G / E / E / (trm)“ or optical filter glass are suitable examples, has to 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 has to 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 might therefore be required to replace UV filters by fresh filters of the same type. Stable filter material may be re-used in subsequent tests.

Transparent release material (trm, see Table F.1) shall have a solar photon weighted transmittance > 85 % transmittance in both ranges:

a) 280 nm to 2 500 nm, and
b) 300 nm to 400 nm based on the calculation defined in 8.2 of IEC 60904-3:2016 and a thickness between 50 µm to 125 µm.

Suitable materials include:

a) perfluoroinated ethylene propylene copolymer (FEP) film, and
b) ethylene tetrafluoroethylene (ETFE) film, as pure formulations without UV absorbers.

NOTE 1 Foils thinner than 50 µ may introduce wrinkling during lamination, whereas foils thicker than 125 µm may introduce an unnecessarily strong diffusion barrier, making the test less representative for actual use.

NOTE 2 Direct contact between trm foil and neighboring layers may get lost locally during weathering exposure. If the material at the sun-facing side of the backsheet is susceptible to oxygen induced degradation, this may introduce e.g. non-homogenous discoloration, even though on a level much smaller than 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 foils 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 IEC TS 62788-7-2 method A that provides a spectral power distribution that simulates natural daylight as defined in ASTM D7869.

NOTE At the time of writing this document, only UV filtered Xenon can provide this spectral power distribution. See 4.10.3.8 for UVA tests.

4.10.3.5 Procedure

For white and clear frontsheet and backsheet materials, the test shall be carried out according to condition A3 in Table 1 of IEC TS 62788-7-2:2017 without backing material. For white and clear backsheet these test conditions result in a specimen temperature of about 70 °C. For black or coloured backsheet having significant absorption in the VIS and IR spectral range, test cycles A2 or A1 are recommended to provide a sheet temperature of 70 °C ± 5 °C (see IEC TS 62788-7-2 for guidance). If cycle A3 is selected for black backsheets, a considerably higher sheet temperature is likely to result, which may be above the glass transition temperature T_g of the polymeric material under test and therefore not necessarily representative for use.

NOTE 1 Conditions A3 in IEC TS 62788-7-2 are as follows:

a) Irradiance of (0,8 ± 0,08) W/m^2/nm at 340 nm, which is equivalent to (81 ± 8) W/m^2 measured between 300 nm and 400 nm, using a xenon arc source with filters complying with the latest version of ASTM D7869 daylight filter.
b) Chamber controlled to the black panel (un-insulated) temperature of 90 °C ± 3 °C.
c) Chamber controlled to ambient temperature of 65 °C ± 3 °C.
d) Ambient air relative humidity of 20 % ± 5 %.
e) No water spray.
f) The exposure may be intermittently interrupted for system maintenance.

Standard test duration for uniform characterization form and datasheet reporting is 2 000 h. Optional test durations are 1 000 h and 4 000 h.

NOTE 2 IEC TS 62788-7-2 provides context for the choice of test cycles for clear, white and coloured backsheet and the choice of test duration of 1 000 h, 2 000 h and 4 000 h.

If optional sun-facing side exposure of backsheet film through UV filter has been chosen, the UV filter needs to be placed between backsheet and light source.

4.10.3.6 Requirements for testing retention of properties by post evaluation tests

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

a) Required material characterization includes:
   - visual evaluation of the exposed side of samples before and after weathering according to 4.6.3.
   - mechanical strength testing (tensile strength and elongation at break, MD only) of replicate specimen shall be measured before and after weathering (see 4.2.4).

b) Optional material characterization includes:
   - mechanical strength testing (tensile strength and elongation at break, TD only) of replicate specimen can be measured before and after weathering (see 4.2.4).
   - d.c. breakdown voltage of replicate specimen can be measured before and after 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 4.3.6.2).
     – adhesion to a matched material, such as encapsulant or edge seal (see 4.3.6.3).

NOTE Junction box adhesives in actual field use are in between backsheet and junction box and therefore barely exposed to UV, neither direct through the PV module neither via albedo. Refer to IEC 62790 for ageing tests of junction box adhesives.

4.10.3.7 Reporting requirements

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 F.1)
c) the UV filter configuration by reference to Method A, B, C1a, C1b or C2.
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).

In d) and e) report the absolute results from the evaluation tests after weathering in comparison to measured values before. Reporting of % retention of initial values together with the initial value is an alternate reporting option.

4.10.3.8 UVA testing

IEC TS 62788-7-2 method B also defines a UVA test using UVA-340 fluorescent sources for assessment of UV durability of frontsheet or backsheet materials. UVA-340 testing is however not regarded as 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.

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 Table 2 in IEC TS 62788-7-2:2017 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 in Table 2 (UVA) of IEC TS 62788-7-2:2017 instead of condition A3 of Table 1 (Xenon).

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

5 Uniform characterization form (UCF)

5.1 General

The uniform characterization form for backsheet and frontsheet provides an extensive overview of mechanical, electrical, optical and chemical characteristics, that are related to safety, performance and processing of the frontsheet 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 required results of material characterization tests, and may contain results of optional characterization tests in addition. Furthermore, an UCF shall include at least the following information:

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

5.2 Layer stack description

The UCF shall contain a drawing, which shows the construction (layer stack) of the front sheet or backsheet, in which the individual layers are labelled and named and their nominal thickness is 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 UCF shall be given as tabular overview of results according to Table 3. 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. Table 3 defines the uniform characterization form for required (✓) or optional (O) material evaluation and ageing tests for polymeric frontsheets and backsheets. Reported data shall include tolerances as given by reporting requirements of each test method indicated in column “reference”.

Table 3 – Uniform characterization form (UCF) for polymeric PV frontsheet or backsheet

Test						
UCF No.	test name	reference	fresh	1 000 h DH test (4.10.2)	2 000 h UV (Xenon) test (4.10.3) with exposure of	
					air side[a]	sun-facing side[b]
1	dimensions and tolerances [µm]	4.2.2	✓	–	–	–
2	area weight and tolerances [g/m²]	4.2.3	✓	–	–	–
3	a) tensile strength [MPa] (MD)	4.2.4	✓	✓	✓	✓
	b) tensile strength [MPa] (TD)	4.2.4	✓	✓	O	O
4	a) elongation at break [%] (MD)	4.2.4	✓	✓	✓	✓
	b) elongation at break [%] (TD)	4.2.4	✓	✓	O	O
5	bond strength between layers of composition – or weakest link [N/mm] (for peelable layers)	4.3.6.2	✓	✓	O	O
6	bond strength between coatings or thin layers and film [rating scale] (for layers too thin or brittle to peel)	4.3.6.2	✓	✓	O	–
7	bond strength between a specific encapsulant and sheet [N/mm]	4.3.6.3	O	O	O	O
8	bond strength between a specific junction box adhesive and sheet [N/mm]	4.3.6.4	O	see IEC 62790	–	–
9	RTE/RTI/TI [°C]	4.4.1	✓	–	–	–
10	dimensional stability in MD and TD [%]	4.4.2	✓	–	–	–
11	relative thermal expansion [K^{-1}]	4.4.3	O	–	–	–
12	d.c. breakdown voltage [kV]	4.5.1	✓	O	O	O
13	distance through insulation [µm]	4.5.2	✓	–	–	–
14	comparative tracking index (CTI)	4.5.3	✓	–	–	–
15	visual inspection	4.6.3	✓	✓	✓	✓
16	solar transmittance (for transmittive sheets only)	4.6.4	✓	O	O	O
17	solar reflectance[c] (for reflective sheets only)	4.6.5	✓ (sun-facing)	O (sun-facing)	–	O (sun-facing)
18	yellowness index DYI [c]	4.6.6	O	O	O (air side)	O (sun-facing)
19	CIE L*a*b* (D65/10°) [c]	4.6.7	O	O	O (air side)	O (sun-facing)
20	specular gloss [c]	4.6.8	O	O	O (air side)	O (sun-facing)
21	water vapour transmission rate [g/m²d]	4.7.1	O	–	–	–
22	resistance to recommended cleaning solvent	4.8.1	O	–	–	–

[a] Air-side exposure only for backsheet.

[b] Exposure of sun-facing side of backsheet with choice of UV filter: i) C1A: G/E/E/(trm), ii) C1b: Filter Glass or iii) C2: no UV filter.

[c] for optical characterization of backsheet (UCF No. 17 to 20) the side of the sheet for optical measurement is indicated: i) air side or ii) sun-facing side.

✓ : required material characterization

O : optional material characterization

– : material characterization not required

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 those information and measurement values from Table 3 shall be given in the datasheet, that are required by IEC 61730-1, as these data are needed for module qualification. Requirements of IEC 61730-1 and eventual amendments shall supersede reporting requirements given below.

UCF No. 01 thickness of multilayer sheet (fresh) and detailed layer structure (see 5.2)

UCF No. 03/04 tensile strength and elongation at break

- fresh
- after 1 000 h DH testing
- after 2 000 h xenon weathering*

UCF No. 09 RTE, RTI or TI

UCF No. 12 d.c. breakdown voltage (fresh)

UCF No. 13 dti (fresh)

UCF No. 14 CTI (fresh)

UCF No. 15 visual inspection

- fresh
- after 1 000 h DH testing
- after 2 000 h xenon weathering*

Reporting of UCF Nos marked with * is planned to be required by a future amendment to IEC 61730-1, which is currently in preparation at the time of writing this document.

NOTE Manufacturers are free to report additional data as defined in the UCF (see Table 3) also 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:

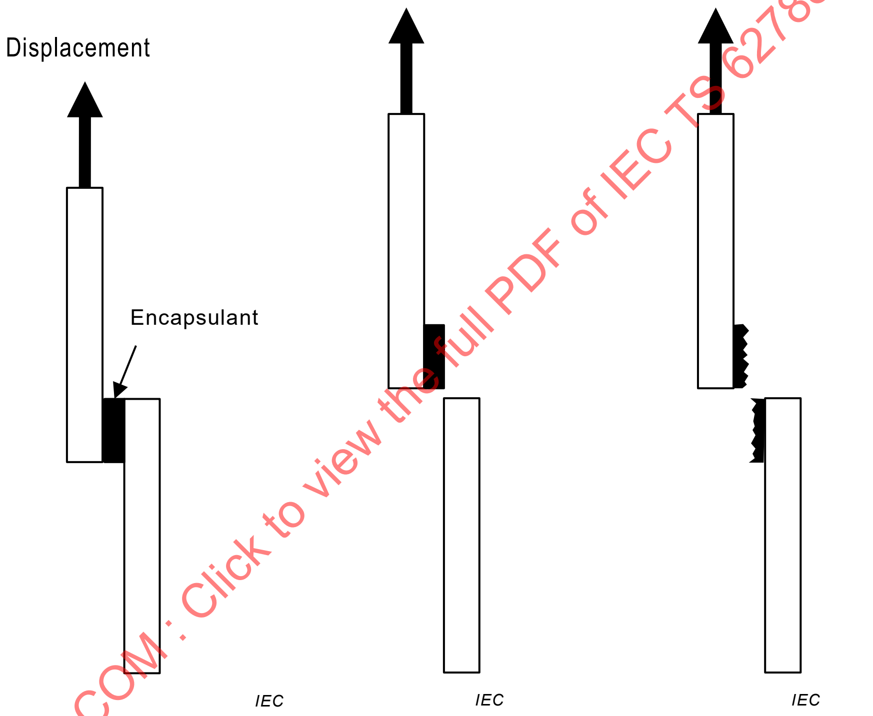
a) Type designation of frontsheet or backsheet
b) Name, address and contact information of the manufacturers or importers
c) Shelf age and storage conditions
d) Transport conditions and their maximum duration, if deviating from storage conditions
e) Identification of the inner side of the frontsheet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

Annex A
(informative)

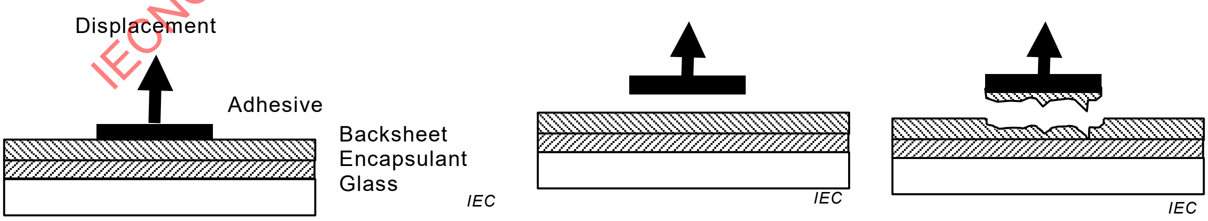
Overview of adhesion testing of frontsheet and backsheet

A.1 Type of adhesion failure

The geometry of the adhesion test determines how force is applied to the interfaces in a multilayer sample. Any of the interfaces involved in a multi-layered composition could be the weakest link in the stack. Cohesive failure within a layer may occur rather than failure at an interface. In case of adhesive failure, the corresponding interface(s) needs to be identified. The presence of compliant or brittle layers in the multilayer stack may actually prevent assessment of interfacial adhesion. See Figure A.1.



(A) initial setup (B) adhesive failure (C) cohesive failure



(A) initial setup (B) adhesive failure (C) cohesive failure

Figure A.1 – Adhesive and cohesive failure type schematics for lap-shear (top) and T-pluck (bottom)

A.2 Characteristics of adhesion peel tests

In adhesion peel tests, the peeled layer acts as a kind of lever by which the peel force is exerted to the interfaces of the stacks. Therefore, including other factors, the measured adhesion strength value depends on thickness, elasticity and the curvature of the peeled lever. The measured peel strength is also function of the test geometry such as 90° or 180° peel and – depending on the geometric border conditions – may vary through the test, limiting reproducibility and the ability to compare between different backsheet and frontsheet products.

In T-peel, two 90° peels are simultaneously performed in opposite directions, with angles 90° + α° and 90° – α°. In T-peel of an asymmetric specimen the deviating angle α° may become quite large (> 5°), whereas in case of symmetric layer stacks, the α° may approach 0° on average but varying during the test. In the latter case, T-peel is recommended to quantify changes of adhesion strength e.g. resulting from ageing, provided sufficient replicates are tested in view of required significance of results.

In 180° peel, the curvature of the handle layer is significant which may cause tensile failure of the layer, making assessment of interface adhesion impossible.

Aforementioned dependence of resulting adhesion strength on layer characteristics (thickness, elasticity, etc.) limits the comparability of peel tests to a quite narrow scope, such as comparing different adhesives within the same set of material layers (of the same thickness). Eventually, also the relative degradation of adhesion strength upon ageing can be evaluated, provided other layer characteristics have not changed during ageing, such as layer elasticity.

In order to assess a specific interface, the adhesive function is partially omitted or rendered inactive by insertion of suitable release materials at a specific position in the layer stack, thus dividing the layer stack into two sub-stacks and defining their interface as starting point of the peel test. However, this does not guarantee that failure will propagate along initial interface.

Also temperature and humidity during the peel test or the pre-conditioning phase, as well as peeling speed may affect the measured results [6] [7].

A.3 Characteristics of pluck and lap-shear tests

In pluck and lap-shear tests, the geometry of the applied force is defined as 90° pluck or shear, ideally being uniformly distributed through the test through use of rigid auxiliary materials as handles, e.g. suitable constructed aluminium bars, to which the loadframe applies a load. These handles, however shall be attached to the multilayer stack by another adhesive, often epoxy possibly in combination with some surface etching procedure. An adhesive with insufficient strength limits the maximum measurable adhesion strength in the multilayer stack under test. Regarding the handles, premature failure of the handle layers may compromise the test, whereas mechanical compliance of the handles may also affect the test.

Glue may affect results, if it penetrates the typically thin layers of backsheet or frontsheet constructions, eventually chemically influencing the adhesion. When assessing the adhesion strength after ageing, it is recommended to attach the glue to the material after samples have been aged, since elevated temperature, humidity or exposure to UV may introduce artificial interactions between glue and material under test. Identification of suitable glue, pre-cleaning or etching procedures of the interfaces and its curing condition may require a pre-study for a particular material under test.

NOTE Adhesion tests based on the principle of fracture mechanics [8] are presently being developed in future IEC TS 62788-6-3 [18]. These have the potential to overcome some of the limitations of the aforementioned methods. These methods also rely on the attachment (glue, epoxy resin) of a rigid auxiliary plate or bar that acts as a cantilever of pre-defined geometry.

A.4 Cross-hatch tape testing

The cross-hatch test differs from the other tests methods, in that it is a manual test with visual evaluation according to a pictorial ruler as opposed to an instrument based test in which load/displacement is measured and analysed. For cross-hatch, the adhesion test force depends on the operator skill and also on the adhesion strength of the tape, for which a minimum strength is required (see Clause B.5). However, differences in tape products are not differentiated, which may introduce variations that limit comparability of results between specimens.

A.5 Other caveats

The interface in the layer stack at which de-lamination occurs may jump between different interfaces during the test, via cohesive failures, even though adhesion test was intended to examine a specific interface. Releaser liners can also be purposefully introduced during sample preparation to test adhesion of a whole frontsheet or backsheet to another material. A lamination step (i.e. a standard time, temperature, pressure episode with or without actual lamination to an encapsulant) should be included in the sample preparation to mimic the processing conditions during production of PV module as close as possible.

Sample preparation by 3rd parties by cutting through to some more or less defined depth of the layer stack or manual peeling will most probably results in a weakest link approach. The same holds for the cross-cutting / tape test.

Reducing the number of different materials and corresponding interfaces may help to limit testing to specific interfaces, for R&D purposes and bilateral qualification testing, even though the test geometry may no longer mimic the PV application.

Adhesion test results may be limited to the adhesive force provided by the adhesion or cohesion of an auxiliary material (glass, aluminium, or tape handle) that is needed to perform the test.

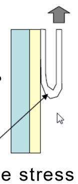
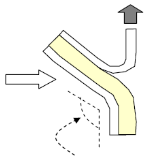
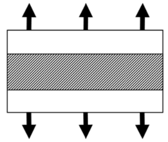
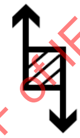
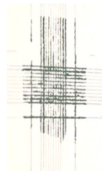
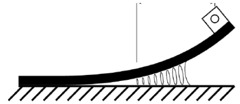
Adhesion tests at elevated temperature may be considered to investigate the effect of high temperature of a backsheet in an operating PV module. For this purpose, the loadframe machine should be equipped for operation at elevated temperatures through the use of an environmental chamber or by other means. If an environmental chamber is used, the samples shall be allowed to equilibrate to the test temperature before testing. At least 5 min should elapse between when the chamber door is closed (after the sample is mounted) and the start of the test.

A.6 Overview

Table A.1 gives an overview of adhesion test methods, described in this document that were adapted for testing component adhesion in the PV module context. All of the methods have their preferred application and corresponding inherent limitations, as described before. Test procedures are described in the corresponding clauses of normative Annex B.

A placeholder for a tapered beam adhesion test is listed in the table, which is based on principles of fracture mechanics and currently under development in future IEC 62788-6-3. The tapered beam method potentially overcomes shortcomings of conventional peel tests as both tapered form of the beam as well as choice of beam material result in reproducible definition of the lever in the adhesion test geometry.

Table A.1 – Overview of various adhesion tests and their general capability of testing polymeric frontsheet and backsheet

Context information	180° peel	T-peel	T-pluck	lap shear	cross-hatch tape	fracture mechanics
a) Reference	Clause B.1	Clause B.2	Clause B.3	Clause B.4	Clause B.5	Future IEC 62788-6-3 [18]
b) schematics	 180° Tensile stress *IEC*	 Effective peel angle (140°-180°) *IEC*	 *IEC*	 *IEC*	 *IEC*	 *IEC*
c) capability for test of adhesion between individual components of a FS/BS	suitable in general, but may be limited by tensile break due to curvature and material compliance	very limited reproducibility for asymmetric layer stacks	not applicable	not applicable	applicable for test of coatings or thin layers too thin or brittle to test via T-peel or 180°	quantitative measurement of all interlaminate interfaces is possible via sample preparation
d) capability for test of weakest (adhesion) link within a finished FS/BS	applicable if multi-layer sheet can be separated manually to mount free ends in grippers	not applicable	possible influence of epoxy on inner backsheet interfaces	possible influence of epoxy on inner backsheet material; geometry atypical for field failures	not applicable	quantitative measurement possible
e) capability for test of adhesion of a FS/BS to an encapsulant	suitable in general, but may be limited by tensile break due to curvature and material compliance	fair reproducibility	not applicable	not applicable	not applicable	quantitative measurement possible
f) capability for test of adhesion of FS/BS to a junction box adhesive or edge sealant	geometry atypical for field failure	fair reproducibility, even though geometry atypical for field failure	geometry atypical for field failure and possible influence of epoxy on interface	geometry atypical for field failure and possible influence of epoxy on interface	not applicable	quantitative measurement possible

Context information	**180° peel**	**T-peel**	**T-pluck**	**lap shear**	**cross-hatch tape**	**fracture mechanics**
g) test mode	specific interface	specific interface	weakest link		weakest link	test
h) auxiliary mounting	no	no	yes (epoxy)	yes (epoxy)	yes (tape)	yes (epoxy / cyanoacrylic)
i) sample preparation	prepare flaps for grippers, e.g. limit adhesive layer to 2/3 of length of sheets or insert release material	prepare flaps for grippers, e.g. limit adhesive layer to 2/3 of length of sheets or insert release material	mount (epoxy) T-pluck handle; mount sample on rigid support, if not self-supporting	mount (epoxy) lap shear handle on sample; mount sheet on rigid support (coupon D)	cut through thin layer or coating down into substrate of sheet	adhere appropriate elastic beam to surface and section through laminate around the beam

Annex B
(normative)

Adhesive bond strength test procedures in PV context

B.1 180°peel adhesion test

B.1.1 Specimens

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 frontsheet or backsheet. These may be prepared and bonded together with the same adhesive as used in serial production of frontsheet or backsheet. The samples may be created using the same vacuum lamination process used in the PV module fabrication.

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

c) Samples for the test of adhesion of backsheet or frontsheet to other material are produced by laminating frontsheet, encapsulant and a rigid substrate or backsheet, encapsulant to a rigid superstrate (glass) in 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.

The 100 mm long unbonded ends bent apart, perpendicular to the bond line, for clamping in the grips of the test machine. See Figure B.1.

Dimensions in millimetres

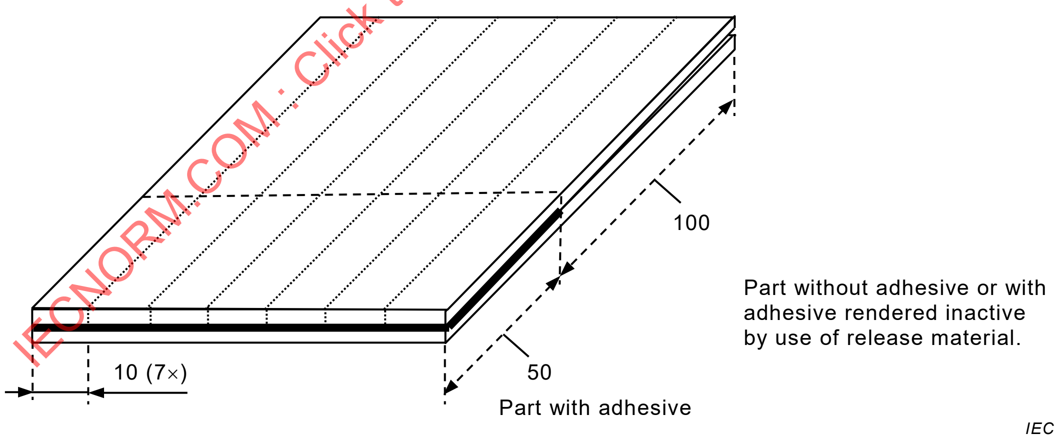


Figure B.1 – Example test panel (70 mm x 150 mm) and test specimen

B.1.2 Procedure

See 4.3.4 for pre-conditioning and 4.3.5 for general test procedure.

In addition:

a) For flexible/flexible samples, reinforce the side of the thicker film with a flat metal plate (see Figure B.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 glued 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. 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.

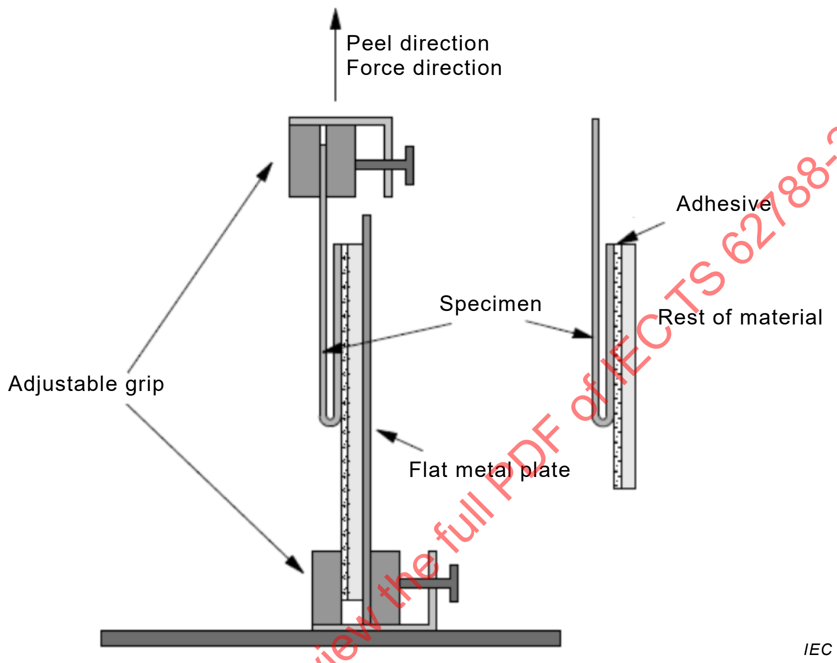


Figure B.2 – Fixation of the sample for 180° peel (for use with flexible/flexible samples) and cross-section of the sample

B.1.3 Measurement

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

If the mode of failure has not changed, a plateau like load versus displacement curve is recorded (see Figure B.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 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 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 B.3, right).

The average value and standard deviation for the adhesion between the peeled layers shall be calculated.

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

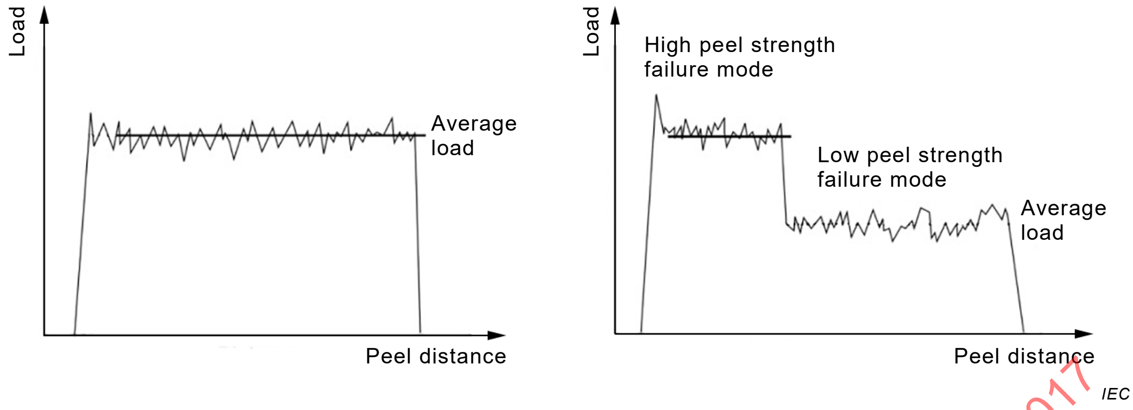


Figure B.3 – Single and multiple failure modes in a peel test

B.2 T-peel adhesion test

B.2.1 Sample preparation

See 4.3.3 for sampling of sheet material.

The laminated test specimen (see Figure B.4) shall be prepared from two flexible sheets of the same kind of frontsheet 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 ca. 2/3 of the length of the polymeric sheets;

b) two sheets of finished backsheet with their air side oriented inside and sandwiching an 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 ca. 2/3 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 stripe, with the dimensions of 10 mm width and 2 mm height. Flatten the stripe to a height of 1 mm by using distance plates in combination with the second sheet and cure it in accordance to 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 cuts (Figure B.4) 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 frontsheet or backsheet manufacturer.

Dimensions in millimetres

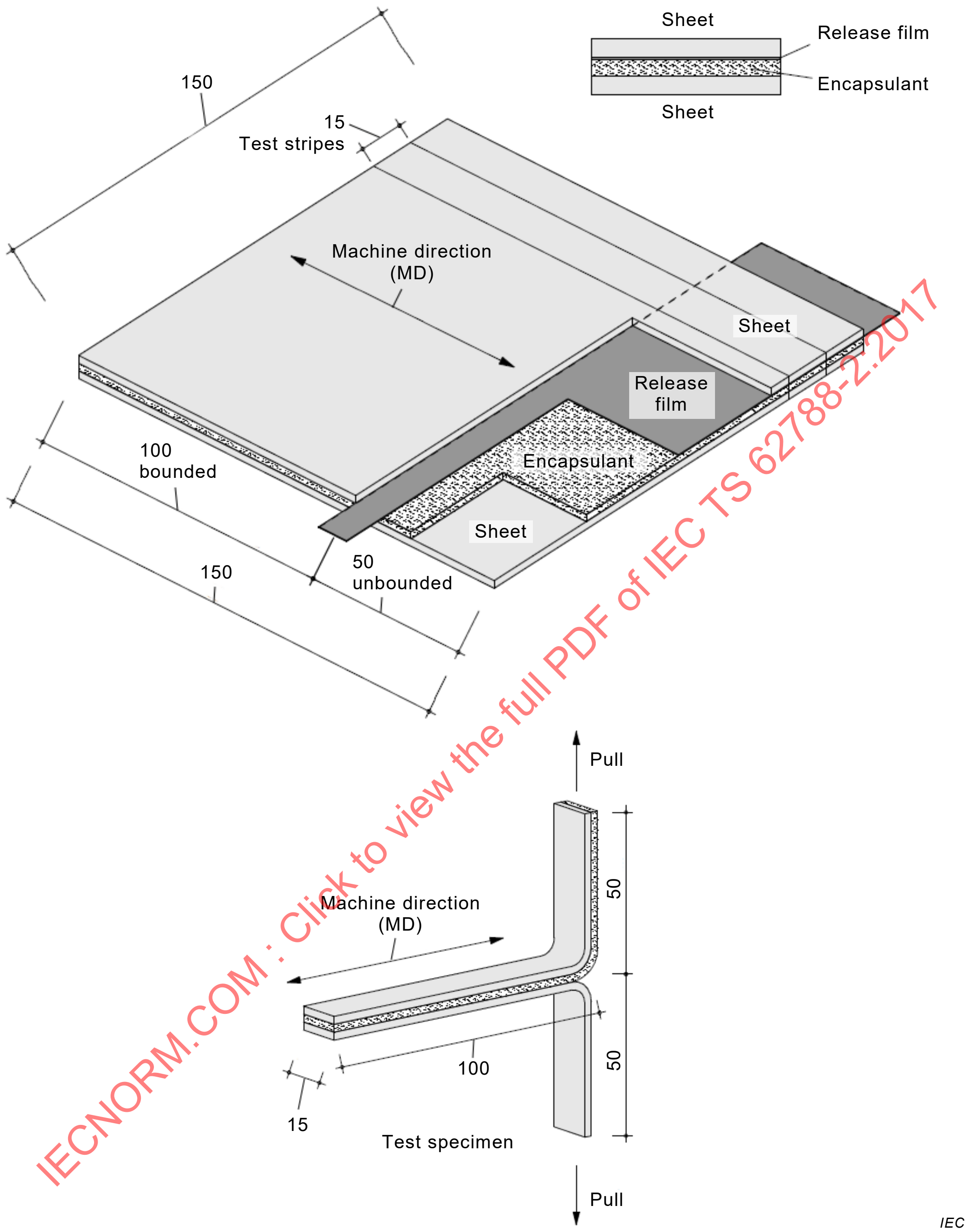


Figure B.4 – Sheet sandwich (above) from which test specimens for T-peel are prepared

B.2.2 Procedure

See 4.3.4 for pre-conditioning and 4.3.5 for general test procedure.

B.2.3 Measurement

See B.1.3.

B.3 Dynamic tensile (T-pluck)

B.3.1 Purpose

The purpose of this test is to evaluate the inherent resistance of a bonded interface (or set of interfaces) to tensile forces to quantify the strength of attachment for the weakest interface. Material, backsheet, and modules manufacturers may use the method to test coupon or module specimens. While the methods might be applied to material specimens, they are intended for use with finished backsheet product.

B.3.2 Principle

Tensile bond strength is determined by stressing a butt joint created between rigid adherents in tension by applying a displacement perpendicular to the bond area and to the major axis of the specimen as shown in Figure B.5. After suitable conditioning, the prepared assembly is tested in a displacement controlled mechanical loadframe apparatus at a defined crosshead displacement speed. An extensometer should be used to accurately determine the displacement at the specimen.

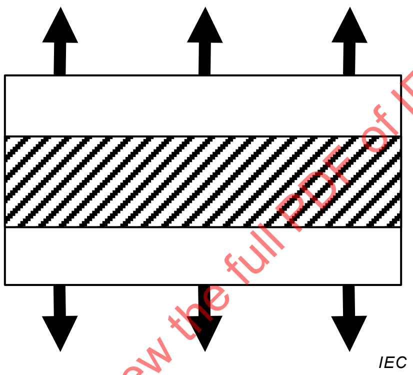


Figure B.5 – Dynamic tensile (pluck) schematic

B.3.3 Specimens

See 4.3.3 for sampling of sheet material.

Individual specimens shall be prepared according to Figure B.6. Coupons containing the backsheet will be constructed using 25 mm (or 38 mm) x 75 mm pieces of (5 ± 1) mm glass, encapsulant, and backsheet. This construction will be cured in a laminator.

Tensile pluck samples will be prepared using an aluminium t-block (handle) that is machined from a profile with at least 4 mm thickness, providing a plate base area of 25 mm x 25 mm within a tolerance of ± 0,5 mm for the linear dimensions, and a height of at least 12 mm. The handle shall have provisions for attaching it to the load frame, so that no torque is introduced during displacement. An example is a central hole in the vertical part of the handle.

Dimensions in millimetres

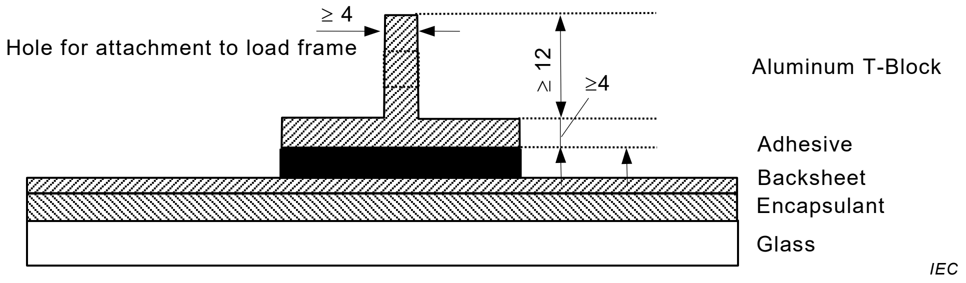


Figure B.6 – Schematic of pluck sample (in cross-section) for a laminated backsheet test

Bond the handle to the backsheet using a suitable adhesive - one that is strong enough to determine the weakest link in the backsheet or a junction box adhesive of interest. For liquid adhesives glass spacer beads may be used to create consistent bond thicknesses. Wipe the edges of the bond line to remove excess adhesive and maintain a bond area similar to the size of the t-block. Allow the adhesive to cure per manufacturer's recommendations to obtain the maximum bond strength.

B.3.4 Measurement procedure

See 4.3.4 for pre-conditioning and 4.3.5 for general test procedure.

Mount the laminated glass and the t-block to the grippers of the loadframe using suitable adapters.

B.3.5 Final measurements

Calculate strain and stress according to the following formulae, where the variables are described below and in Figure B.7:

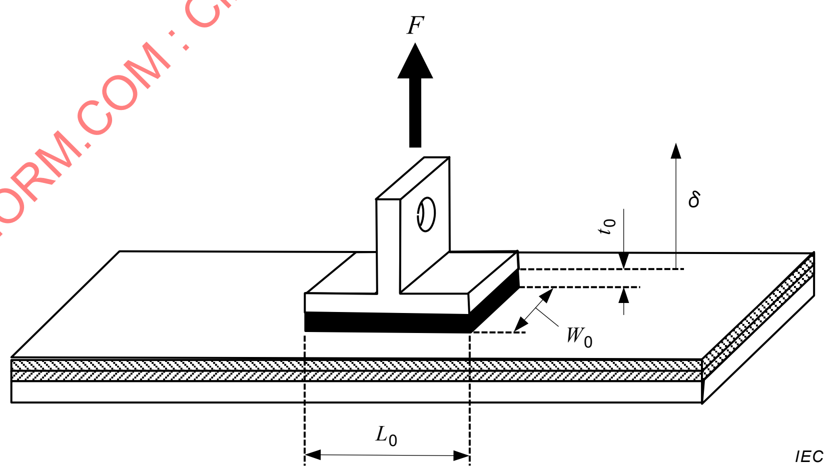


Figure B.7 – Dynamic tensile variables

The stress is calculated as

$$\sigma = \frac{F}{W_0 \cdot L_0},$$

where

ε is the tensile strain (%);

t_0 is the initial overlap adhesive thickness (mm);

δ is the specimen displacement (from strain gage or extensometer) (mm);

σ is the tensile stress (MPa);

L_0 is the initial overlap length (mm);

W_0 is the initial overlap width (mm);

F is the highest recorded force on the stress-strain curve (N).

B.4 Dynamic overlap shear

B.4.1 Purpose

The purpose of the shear test is to evaluate the inherent resistance of a bonded interface to shear forces to quantify the strength of attachment for the weakest interface. Material, backsheet, and modules manufacturers may use the method to test coupons or module specimens. While the methods might be applied to material specimens, they are intended for use with finished backsheet products.

B.4.2 Principle

Adhesive lap-shear bond strength is determined by stressing a single-overlap joint between rigid handles in shear by applying a force parallel to the bond area and to the major axis of the specimen, as shown in Figure B.8. After suitable conditioning, the prepared assembly is tested in a displacement controlled mechanical loadframe at a defined crosshead displacement speed. An extensometer should be used to accurately determine the displacement at the specimen.

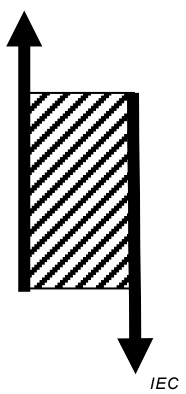


Figure B.8 – Overlap shear force schematics

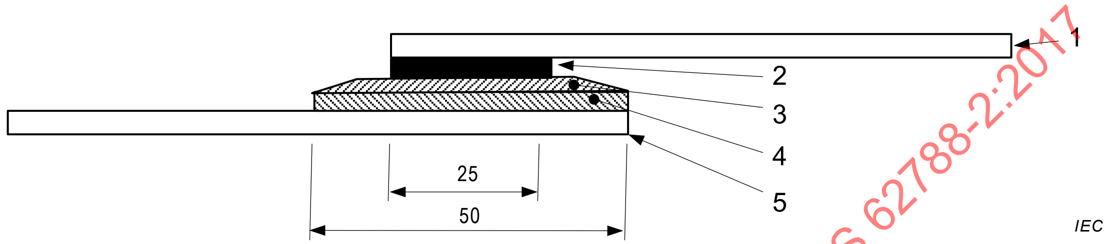
B.4.3 Specimens

A detailed description of the assembly of the specimens to be prepared is identified in Clause 5 of ISO 4587:2003. The specimens may be prepared either individually or from panels as described in of ISO 4587.

Individual specimens shall conform to Figure B.9 and Figure B.10, as in ISO 4587, where the overlap adhesive bond area is equal to 25 mm x 25 mm, and each aluminium substrate has a thickness of 1,6 mm, and an area of 25 mm x 100 mm. The laminated back sheet sample shall be made using a 25 mm x 50 mm piece of both the encapsulant and the backsheet. The sample should be run through a representative lamination cycle for the backsheet as recommended by the material manufacturer(s).

The backsheet sample is made slightly larger than the bond size to allow for the flow of excess encapsulant from the two ends of the sample. Small pieces of single-sided tape can be used to mask off the bond area. At least five replicate specimens shall be examined.

Dimensions in millimetres



Key

1 Metal coupon (25 mm x 100 mm)
2 Adhesive (25 mm x 25 mm)
3 Backsheet (25 mm x 50 mm)
4 Encapsulant (25 mm x 50 mm)
5 Metal coupon (25 mm x 100 mm)

Figure B.9 – Schematic of overlap shear specimen shown in cross-section, for a laminated backsheet coupon

Dimensions in millimetres

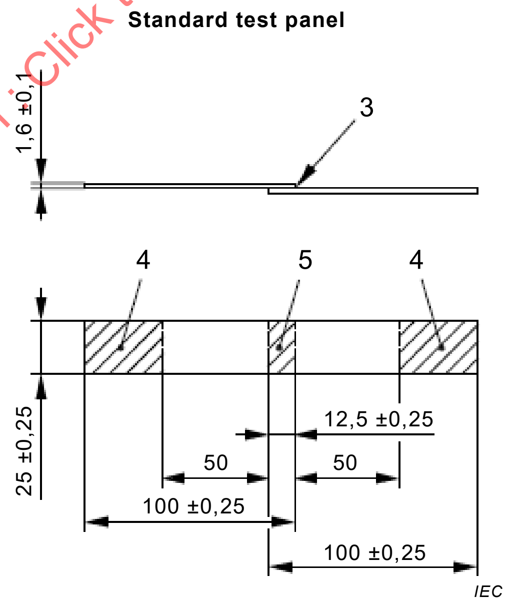


Figure B.10 – Details of overlap shear specimens (ISO 4587:2003, Figure 1)