



BSI Standards Publication

Measurement procedures for materials used in photovoltaic modules

Part 2: Polymeric materials - Frontsheets and backsheets

National foreword

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TECHNICAL SPECIFICATION



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



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TECHNICAL SPECIFICATION



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**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

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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

backsheets

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 $\geq 85\%$ 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 perfluorinated 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:

- $d \leq 100 \mu\text{m}$ with accuracy $\pm 1 \mu\text{m}$;
- $100 \mu\text{m} < d \leq 250 \mu\text{m}$ with accuracy $\pm 2 \mu\text{m}$;
- $d > 250 \mu\text{m}$ with accuracy $\pm 3 \mu\text{m}$.

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 $23 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$ and $50 \% \pm 5 \% \text{ RH}$, 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 $23\text{ °C} \pm 2\text{ °C}$ and $50\% \pm 5\% \text{ RH}$, 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 frontsheets, 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. $10\text{ mm} \pm 1\text{ mm}$ bars, at least 150 mm long with initial grip of $100\text{ mm} \pm 0,5\text{ mm}$ for a 50 mm gauge.

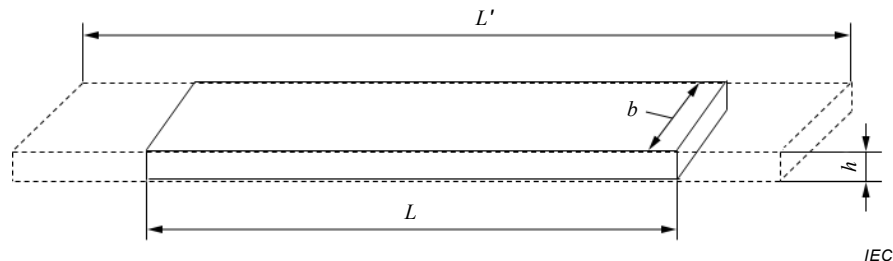
The following alternative strip lengths are allowed:

- 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 $> 100\text{ mm}$ is required.

Alternative strip widths are $12,5\text{ mm} \pm 1\text{ mm}$ and $15\text{ mm} \pm 1\text{ mm}$.

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. $23\text{ °C} \pm 3\text{ °C}$, $50\% \pm 3\% \text{ RH}$, 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 ($23\text{ °C} \pm 3\text{ °C}$, $50\% \pm 3\% \text{ RH}$).

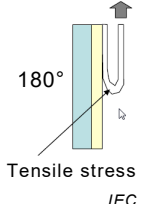
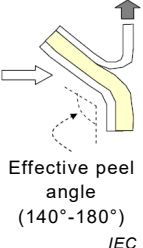
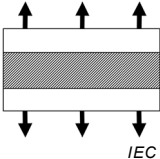
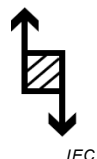
A total of at least five replicate specimens shall be tested and used for final calculations.

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	T-peel test	T-pluck test	lap shear test	cross-hatch tape test
	Clause B.1	Clause B.2	Clause B.3	Clause B.4	Clause B.5
	 180° Tensile stress IEC	 Effective peel angle (140°-180°) IEC	 IEC	 IEC	 IEC
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