IEC TS 62788-5-2

Edition 1.0 2020-06

TECHNICAL SPECIFICATION

colour inside

Measurement procedures for materials used in photovoltaic modules – Part 5-2: Edge seals – Durability evaluation guideline

IEC TS 62788-5-2:2020-06(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 27.160 ISBN 978-2-8322-8387-5

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FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

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

IEC TS 62788-5-2, 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:

DTS	Report on voting
82/1665/DTS	82/1712A/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.

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

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

The committee has decided that the contents of this 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- withdrawn,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.

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MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 5-2: Edge seals – Durability evaluation guideline

1 Scope

This part of IEC TS 62788 provides guidelines to assess the ability of an edge seal to prevent moisture ingress from the edges of PV modules. This document does not cover frame adhesives (sometimes colloquially referred to as edge seals) which by design do not serve to prevent moisture ingress to a meaningful degree. Edge seals should keep moisture out, remain adhered, and maintain electrically insulation from the environment. Much of the testing can be done on the material level, but given the fact that there are multiple surfaces, materials interactions, and mechanical stresses, testing on mini modules or modules is necessary. To accomplish this, this document contains three types of test sample types, materials, mini-modules, and full-size modules. It is intended that a quick evaluation and comparison can be made using materials only. This would be followed up by more rigorous tests using mini-modules where all the interfaces are correctly represented. And finally, full-size module tests are used to evaluate the actual construction process to allow unanticipated concerns to be addressed.

This document is structured to evaluate the ability of an edge seal and the overall packaging design to prevent moisture ingress and to provide sufficient electrical insulation according to accepted qualification standards. It seeks to uncover inadequacies in the permeation properties of the edge seal, electrical safety issues, or delamination resulting in moisture ingress. Here it is implied that mini-modules and full-size modules are constructed in accordance with IEC 61730 series This document does not attempt to evaluate the predicted service life of a module with respect to overall performance. It is designed to determine at the material level if the edge seal can keep moisture out, and then to uncover potential failure modes and/or evaluate the probable effect of manufacturing changes on the performance of edge seals. Test conditions focus on stresses likely to produce safety, moisture ingress, and debonding related failure modes.

For the purposes of this document, an edge seal is defined as a polymeric material designed to be placed between two impermeable (or extremely low permeability) frontsheet and backsheet materials to restrict moisture ingress from the sides. In some cases, an encapsulant with a diffusivity much lower than is found in polyethylene-co-vinyl acetate (EVA) may also serve the purpose of an edge seal and may be evaluated according to this document for comparison.

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 60904 (all parts), *Photovoltaic devices*

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

IEC TS 62782, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing*

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

IEC 62788-5-1, *Measurement procedures for materials used in photovoltaic modules – Part 5-1 Edge seals – Suggested test methods for use with edge seal materials*

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

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

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

ASTM D7869-13, *Standard practice for xenon arc exposure test with enhanced light and water exposure for transportation coatings*

ASTM G154 – 12a, *Standard practice for operating fluorescent ultraviolet (UV) lamp apparatus for exposure of nonmetallic materials*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 apply, as well as the following.

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
edge seal
polymeric material designed to be placed between two impermeable (or extremely low permeability) frontsheet and backsheet materials to restrict moisture ingress from the sides

3.2
backsheet
(combination of) outer layer(s) of the PV module, located on the back of PV module and providing protection of the inner components of the PV module from external stresses and weather elements, as well as electrical insulation

3.3
frontsheet
(combination of) outer layer(s) of the PV module, located on the front of PV module and providing protection of the inner components of the PV module from external stresses and weather elements, as well as electrical insulation

4 Testing

4.1 General

This document is separated into three different types of testing, materials, mini-modules, and full-size modules as outlined in Figure 1, Figure 2 and Figure 3 respectively. Material testing determines if the edge seal material is suitable for the application and provides some basic information for a gross comparison of materials. Here some longer-term durability is evaluated because of the ease with which this can be done on small material specimens.

Next, mini-module tests are designed to evaluate if the different materials can work together. These samples consist of most or all of the materials used in the module, but just in a smaller size consisting of a few cells or of one cell for crystalline Si modules, or a small number of small cells for monolithically integrated thin film cells. This includes some UV, thermal and humidity stress factors, but not mechanical stress. Because of its small size, significant UV exposure is still possible.

Finally, full-size modules are evaluated because this enables a more accurate evaluation of the response to mechanical stress factors, but because of the large size, there is a reduction in the amount of UV stress. The intent here is to determine if the design is adequate and if the design can be manufactured well.

4.2 Material level tests

4.2.1 Moisture ingress

Measure the permeation breakthrough time ($\tau_{F10\,\%}$) from the transient permeation through a film of material according to IEC 62788-6-2. Measure the transient water vapour transmission curve at (85 ± 2) °C and 100 % RH. An additional measurement at (60 ± 2) °C and 100 % RH may also be performed allowing the thermal acceleration to be determined, (see Annex A).

4.2.2 Adhesion

The adhesion of the edge seal material is critical in evaluating the ability of a PV package to prevent moisture ingress. If an edge seal delaminates, it will do nothing in that area to keep moisture out. This test attempts to allow qualitative comparison of different materials, but the viscoelastic properties of an adhesive material also affect its resistance to delamination limiting the accuracy in comparing the results of one material to another without a greater amount of data from other experiments. Furthermore, the mechanical stresses for a given module construction will affect the edge seal's resistance to delamination.

Measure adhesion strength according to IEC 62788-5-1 using the Butt Joint test with samples cut from the edge of a module or a module mock-up. Samples may be cut with a tile saw or water jet cutter. Measure a total of 30 samples, 10 unexposed replicates, 10 replicates after 1 000 h of 85 °C and 85 % RH, and 10 replicates after UV exposure (4.2.4) (Figure 1). For exposed samples, cut the test specimens out after exposure. Describe the failure mode using ISO 10365 for guidance. Report the average and standard deviation of all three sets of measurements. For the UV exposed samples report which side showed adhesive failure if any.

4.2.3 Dielectric strength

Measure the dielectric strength according to IEC 62788-5-1 using a total of 30 samples. Measure 10 unexposed replicates, 10 replicates after 1 000 h of 85 °C and 85 % RH, and 10 replicates after UV exposure (4.2.4) (Figure 1).

4.2.4 Material specimen UV exposure conditions

Expose specimens in a weathering chamber according to IEC TS 62788-7-2, condition A2 (Figure 1):

a) Ambient air temperature of (55 ± 2) °C.

b) Humidity at ambient air temperature of (20 ± 5) % relative.

c) Irradiance controlled at 340 nm to (0,80 ± 0,05) $W \cdot m^{-2} \cdot nm^{-1}$ or (81 ± 5) $W \cdot m^{-2}$ (300 nm to 400 nm).

d) Black panel temperature of (80 ± 5) °C.

e) Total UV exposure time of 4 000 h (or 324 $kWh \cdot m^{-2}$, 300 nm to 400 nm).

f) The UV light source shall be from a Xenon Arc lamp according to ASTM D7869-13, designed to duplicate outdoor spectral conditions.

g) Glass shall be chosen that will either duplicate the glass used in the module, or more generically a low-Fe soda-lime glass with at least 30 % transmittance at 300 nm.

NOTE Condition A2 was chosen because the materials are typically black and will run at a hotter temperature for better comparison to white or to transparent materials tested in the A3 condition.

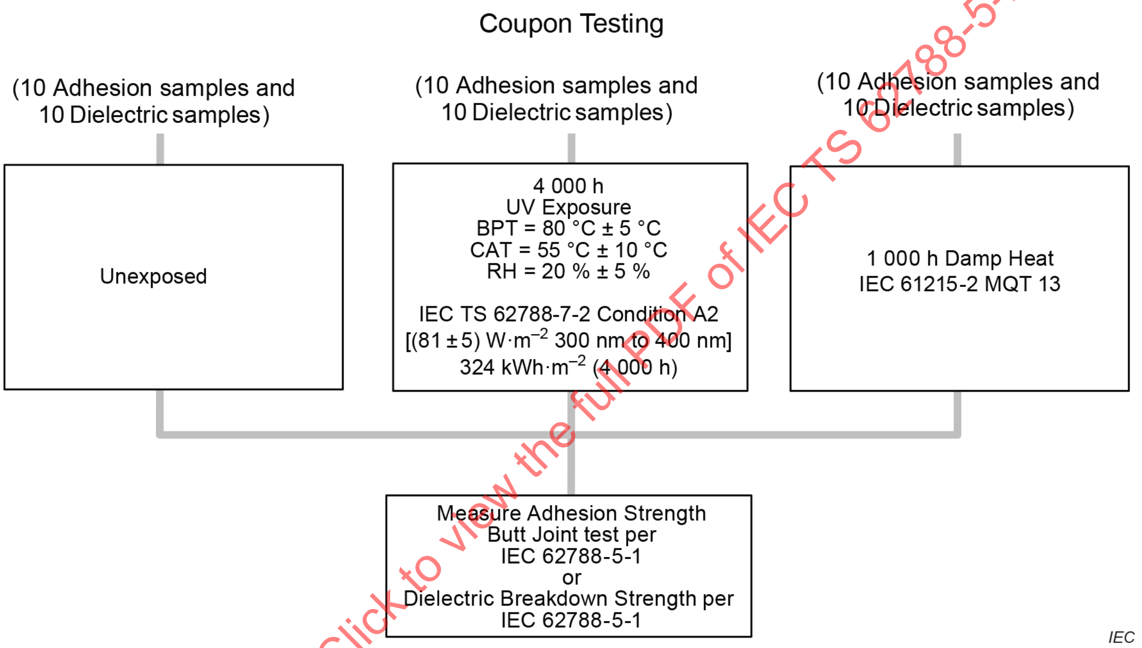

Figure 1 – Material specimen test flow diagram

4.2.5 Volume resistivity

Measure the volume resistivity according to IEC 62788-1-2. Test before and after saturation with water. Condition at room temperature in sealed package to prevent moisture exposure for “before exposure” condition. Precondition at (85 ± 2) °C and (85 ± 5) % RH prior to exposure. The amount of time shall be determined by the manufacturer to fully saturate the desiccant (if applicable) and fill the material with moisture such that the weight is no longer increasing in time. Test according to IEC 62788-1-2, Method A.

4.3 Mini-module testing

To capture the nuances of an actual application, but with a minimal and reasonable amount of effort, a mini-module test may be done. Mini-modules shall be prepared with the same bill of material as the full-sized modules in as much as is reasonably possible. For thin film monolithically integrated cells on glass, a mini-module sample shall be made similarly to a full-size module except that the number and size of cells is reduced. Cell dimensions shall only be shortened in the longer of the two dimensions. For modules made of discrete cells (*e.g.* CIGS cells on stainless steel foil), use a mini-module consisting of at least one cell. Any mini-module type shall have largest dimension of at least 150 mm. Dimensions of the edge delete (region where absorber is removed in a thin film on glass module) and/or perimeter construction of the module shall be maintained. If the full-size module design uses a frame, a frame shall be used on the mini-modules. Results obtained for framed mini-modules cannot be used to derive conclusions for unframed mini-modules.

The variation in module thickness from the sides shall be consistent with that of a full-size module. Thickness variation as measured at ~0 cm, 2 cm, 4 cm and 6 cm, when measured diagonally from the four corners and perpendicularly from the sides, shall be comparable to that achieved for a full-size module. For glass/glass modules this is especially important because the presence of edge flare or edge pinch will dramatically affect adhesion.

A junction box, or other method of termination the same as is used in a full-size module, shall be attached. If one does not want to consider humidity ingress through the junction box, it may be omitted and some other means for electrical connection may be devised.

a) Prior to exposure, perform according to IEC 61215-2:2016 a wet leakage current test (MQT 15), and initial stabilization (MQT 19.1), and determine the maximum power of the device (MQT 02) using I-V-characteristics measurement, according to the IEC 60904-1 series.

   As long term dark storage under elevated temperature, and (UV-)illumination may change metastable processes in TF and xSi cells, care shall be taken to choose proper stabilization measures.

b) Expose 10 samples to the environmental conditions of heat, humidity and UV irradiance using one of the following three conditions, (see Figure 2):

   1) Xenon Arc lamp according to ASTM D7869-13, designed to duplicate outdoor spectral conditions.

      i) Irradiance shall be controlled at 340 nm to 0,8 $W \cdot m^{-2} \cdot nm^{-1}$ or 81 $W \cdot m^{-2}$ (300 nm to 400 nm).

      ii) Expose samples for 4 000 h.

      iii) Ambient air temperature of (55 ± 10) °C.

      iv) Ambient air humidity of (20 ± 5) % RH.

      v) Black panel temperature of (80 ± 5) °C.

   2) Metal halide or other type of lamp consistent with IEC 61215-2:2016 MQT 10.

      i) Shall have a total irradiance of 81 $W \cdot m^{-2}$ between 300 nm and 400 nm.

      ii) Total exposure time shall be 4 000 h.

      iii) At least 3 % but not more than 10 % of the light energy between 280 nm and 400 nm shall be between 280 nm and 320 nm.

      iv) The sample temperature shall be controlled to (80 ± 5) °C.

      v) If humidity is controllable, control it to (10 ± 5) % RH at 80 °C.

   3) UV-A lamp (according to ASTM G154 – 12a, Daylight UV)

      i) If it can be shown that minimal attenuation of the UV light is obtained before the light reaches the first edge seal interface, then a UV-A lamp may be used. The transmittance to this interface shall be greater than 40 % at 300 nm.

  ii) Control the irradiance to 0,8 $W \cdot m^{-2} \cdot nm^{-1}$ at 340 nm.

  iii) Expose samples for 5 000 h.

  iv) Control sample temperature to (80 ± 5) °C.

  v) If humidity is controllable, control it to (10 ± 5) % RH at 80 °C.

c) Fifty thermal cycles as indicated in IEC 61215-2:2016 MQT 11.

d) Following UV exposure and thermal cycling, measure, after stabilization according to IEC 61215-2:2016 MQT 19.2, the I-V performance of the mini-modules according to IEC 61215-2:2016 MQT 19 and MQT 02, rank them in order from best to worst, then in order of rank alternatively assign them to one of two sets of mini-modules. Also take into consideration any failures of the wet leakage current test. This serves to create as much as possible two identical sets of modules. One set of 5 samples shall be exposed to 85 °C and 85 % RH for 1 000 h, and the other set of 5 samples shall be exposed to 85 °C and < 3 % RH for 1 000 h. Samples shall be tested before UV exposure, after UV exposure, and after 85 °C exposure using the wet leakage current test (IEC 61215-2:2016 MQT 15), and for performance. For PV devices with known transient performance behaviour, mini-modules should be preconditions prior to measurement to get optimally reproducible results.

For the performance test, the two sample sets should be indistinguishable if the edge seal is intact and performing its function of keeping moisture out. Evaluate statistical relevance of all performance parameters (P_{max}, FF, I_{sc}, and V_{oc}) using an analysis of variance (ANOVA) with a 95 % confidence interval (CI). Also inspect for visual signs of delamination or other failure.

NOTE If this test produces values greater than 40 $M\Omega \cdot m^2$ (the minimum requirement for IEC 61215-2:2016 MQT 15), then it is likely that a full-size module would pass the wet leakage current test.

Also perform a visual inspection according to IEC 61215-1:2016, Clause 8 and IEC 61215-2:2016 MQT 01.

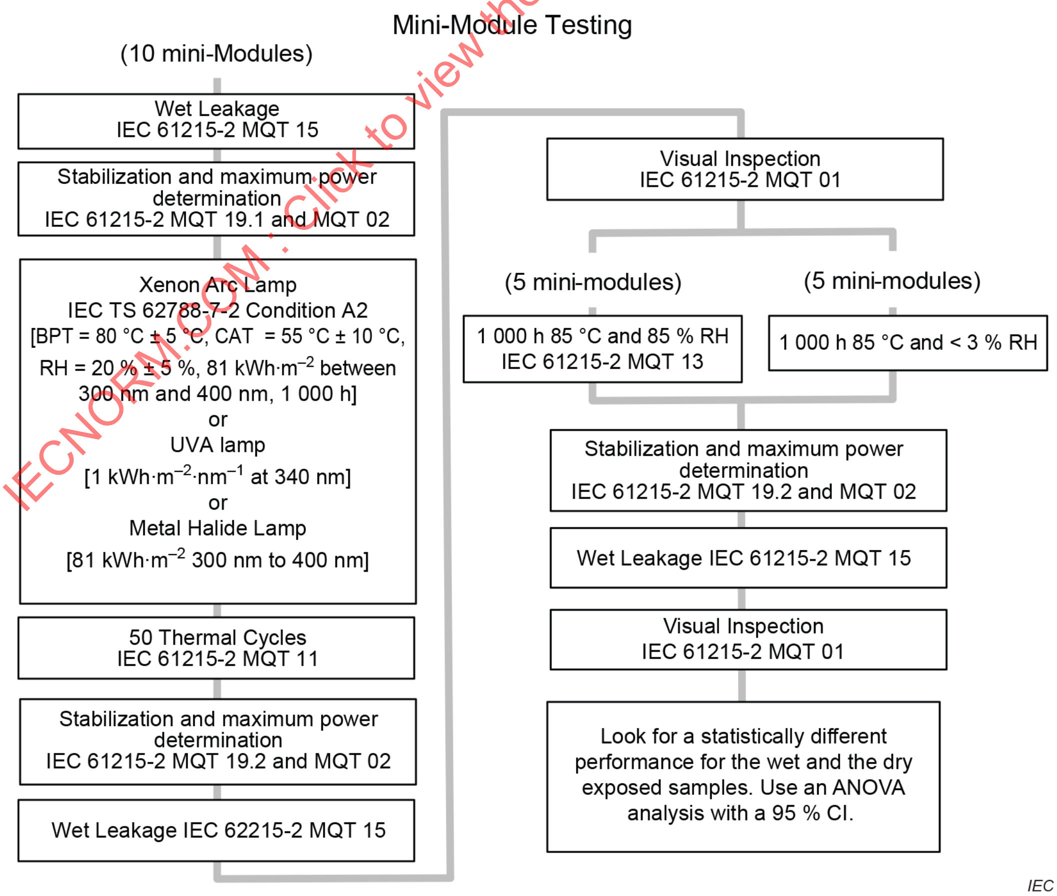

Figure 2 – Mini-module test flow diagram

4.4 Full-size module testing

Because there are some failure modes that can only be seen in a full-size module, and because mini-modules are typically hand-made and cannot fully represent a production module, testing of full-size modules is also recommended. Testing shall include exposure of two sets of 5 modules to the environmental conditions of (see Figure 3):

a) Total UV exposure time of approximately 1 000 h. One of three UV light sources may be used. Spatial uniformity shall be maintained to within ± 20 % of the average light intensity.
   1) Xenon Arc lamp according to ASTM D7869-13, designed to duplicate outdoor spectral conditions.
      i) Irradiance shall be controlled at 340 nm to 0,5 $W \cdot m^{-2} \cdot nm^{-1}$ to 1,1 $W \cdot m^{-2} \cdot nm^{-1}$ or 50 $W \cdot m^{-2}$ to 100 $W \cdot m^{-2}$ (300 nm to 400 nm).
      ii) The total dose, taking approximately 1000 h to implement, shall consist of 81 $kWh \cdot m^{-2}$ between 300 nm and 400 nm or 0,80 $kWh \cdot m^{-2} \cdot nm^{-1}$ at 340 nm.
      iii) Ambient air temperature of (55 ± 10) °C.
      iv) Ambient air humidity of (20 ± 5) % RH.
      v) Black panel temperature of (80 ± 5) °C.
   2) Metal halide or other type of lamp consistent with IEC 61215-2:2016 MQT 10.

      Shall have a total irradiance of up to 250 $W \cdot m^{-2}$ between 300 nm and 400 nm.

      The total UV exposure shall be 81 $kWh \cdot m^{-2}$ between 300 nm and 400 nm.

      At least 3 % but not more than 10 % of the light energy between 280 nm and 400 nm shall be between 280 nm and 320 nm.

      The sample temperature shall be controlled to (80 ± 5) °C.

      If humidity is controllable, control it to (10 ± 5) % RH at 80 °C.
   3) UV-A lamp (according to ASTM G154 – 12a, Daylight UV)

      If it can be shown that minimal attenuation of the UV light is obtained before the light reaches the first edge seal interface, then a UV-A lamp may be used. The transmittance to this interface shall be greater than 40 % at 300 nm.

      Control the irradiance to 0,8 $W \cdot m^{-2} \cdot nm^{-1}$ at 340 nm preferentially, but values between 0,5 $W \cdot m^{-2} \cdot nm^{-1}$ at 340 nm and 1,5 $W \cdot m^{-2} \cdot nm^{-1}$ at 340 nm are acceptable.

      Provide 1 $kWh \cdot m^{-2} \cdot nm^{-1}$ at 340 nm for an approximately 1 250 h UV exposure.

      Control sample temperature to (80 ± 5) °C.

      If humidity is controllable, control it to (10 ± 5) % RH at 80 °C.

The full environmental exposure sequence is as follows:

b) Approximately 1 000 h (or shorter for higher irradiance levels) of UV exposure as indicated above.
c) 1 000 dynamic mechanical cycles IEC TS 62782.
d) Static mechanical load test as indicated in IEC 61215-2:2016 MQT 16 for the desired module rating.
e) Fifty thermal cycles as indicated in IEC 61215-2:2016 MQT 11.
f) 10 humidity freeze cycles as indicated in IEC 61215-2:2016 MQT 12.
g) Split the samples into two sets matching them in similar performing pairs between the two sets similar to what was done with the mini-modules taking into consideration any failures of the wet leakage current test. Expose one set to 85 °C and 85 % RH, and the other to 85 °C and <3 % RH, both for 1 000 h.

The performance and wet insulation resistance of the modules will be evaluated before exposure, between the thermal cycling and 85 °C test, and after the 85 °C test. Modules shall pass the visual inspection in accordance with IEC 61215-2:2016 MQT 01. The wet leakage current test shall be evaluated in accordance with IEC 61215-2:2016 MQT 15. And the relative performance of the dry and wet sample sets at 85 °C shall be compared to determine if the package design was able to keep moisture out of the modules. Evaluate statistical relevance of all performance parameters (P_{max}, FF, I_{sc}, and V_{oc}) using an analysis of variance (ANOVA) with a 95 % confidence interval (CI). Samples should be stabilized to improve measurement reproducibility prior to I-V measurement.

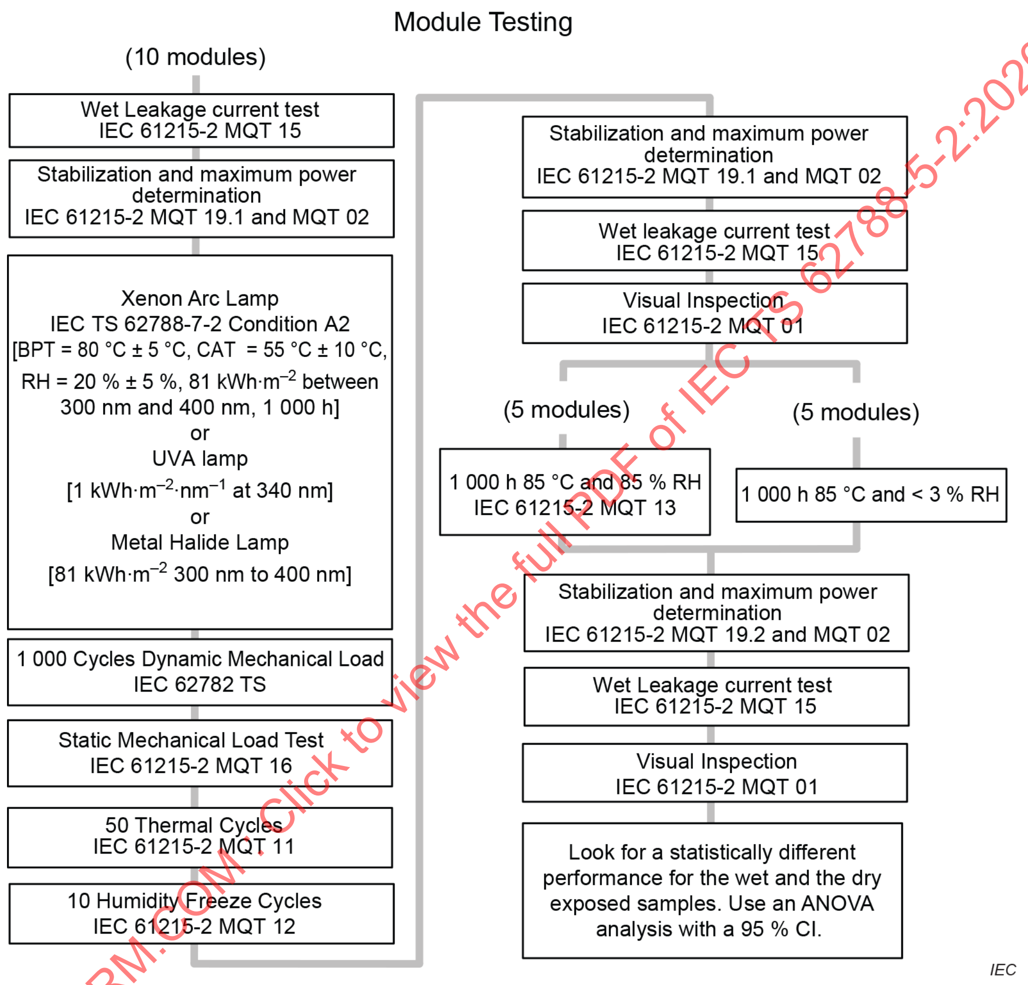

Figure 3 – Module test flow diagram

5 Test report

A report of the tests, with measured performance characteristics, shall be prepared by the test agency. Each test report 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 of each page.

d) Name and address of client, where appropriate.

e) Description of the specimen construction and identification of the item tested, including specimen thickness.

f) Characterization and condition of the test specimen; including the method and details of specimen preparation (including curing, lamination, or similar processing, if applicable) and preconditioning.

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) Description of any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific tests, such as environmental conditions.

k) $\tau_{F10\,\%}$, and $\tau_{M10\,\%}$ if multiple temperatures allow for extrapolation.

l) Adhesion strength [MPa] after exposure.

m) resistivity in the dry state before exposure, and after 1 000 h of exposure to 85 °C and 85 % RH.

n) A table containing mini-module results before exposure, before 85 °C exposure, and after 85 °C exposure. Include I-V traces, FF, V_{oc}, I_{sc}, P_{max}, and any other desired parameters. Report individual measurements and the corresponding averages and standard deviations. Also include the measured resistance, and the estimated specific resistance for a full-size module using both methods for estimation. Include the results of the visual inspection.

o) A table containing full-size module results before exposure, before 85 °C exposure, and after 85 °C exposure. Include I-V traces, FF, V_{oc}, I_{sc}, P_{max} and any other desired parameters. Report individual measurements and the corresponding averages and standard deviations. Include the specific resistance for a full-size module according to IEC 61215-2:2016 MQT 15. Include the results of the visual inspection.

p) A signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the report, and the date of issue;

q) Where relevant, a statement to the effect that the results relate only to the items tested.

r) A statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

Annex A
(informative)

Example of breakthrough time extrapolation

$\tau_{F10\ \%}$ is defined as the time at which permeation reaches 10 % of the steady state value, Figure A.1. Diffusion controlled processes are governed by the generalized formula for diffusion as:

$$\frac{\partial C}{\partial t} = \nabla(D\nabla C) \quad (A.1)$$

where

D is diffusivity,

C is the permeant concentration, and

t is time.

Inspection of Formula (A.1) indicates that the characteristic times should scale with the square of the characteristic length. Additionally, for scaling arguments, if the amount of moisture immobilized by desiccant is much greater than the moisture diffusing in the polymer matrix, then the C on the left-hand side is best described by the concentration in the desiccant and the C on the right hand side is best described by the moisture in the mobile phase. Thus, if solubility in the polymer matrix is assumed to be linear with relative humidity, then the breakthrough time would vary inversely with the relative humidity. With these scaling assumptions, the 10 % breakthrough time for a module in a very hot and humid environment ($\tau_{M10\ \%,45\ °C}$) can be estimated using data extrapolated to 45 °C data as:

$$\tau_{M10\%,45°C} = \tau_{F10\%,45°C}\left(\frac{x_M}{x_F}\right)^2\left(\frac{RH_F}{RH_M}\right) \quad (A.2)$$

where

X_F is the test film thickness,

X_M is the edge seal width,

RH_F is the relative humidity under the test conditions, and

$RH_M = 25\ \%$ represents the humidity level of a very hot and humid climate for an effective module temperature of 45 °C.

A value for $\tau_{F10\ \%,45\ °C}$ can be determined by extrapolating using measurements at two temperatures as:

$$\tau_{F10\%,45℃} = \tau_1 e^{\left[ln\left(\frac{\tau_2}{\tau_1}\right)\frac{\left(\frac{1}{T_3}-\frac{1}{T_1}\right)}{\left(\frac{1}{T_2}-\frac{1}{T_1}\right)}\right]} \quad (A.3)$$

Where the subscripts 1, 2, and 3 refer to measurements or extrapolation to 85 °C, 60 °C, and 45 °C respectively.