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Priority 6.1.ii – Sustainable Energy Systems

D5.6.1

Methodology for service life prediction of polymeric materials in PV-applications based on accelerated testing

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (incl. the Commission Services)	
CO	Confidential, only for members of the consortium (incl. the Commission Services)	

Introduction

To effectively select, use and maintain a material in a given application, its degradation under service conditions must be predicted prior to use. Preferably, the durability of the material should be expressed quantitatively in terms of an expected service life. Durability in this case is the ability of a material to withstand deterioration caused by all external factors in the environment, which may influence the performance of the material under service conditions. Service life is defined as the period of time after installation during which specific material properties important for the performance of the material meet or exceed minimum acceptable values.

The service life of a material is, thus, not solely dependent on its physical and chemical properties, but also on its performance requirement in the application considered, and on the external environmental factors, which influence performance under service conditions. In design work, the important question is if a specific material can be expected to have a service life longer than a certain value, the so called design service life; the latter dictated by life cost considerations taking into account the total system. Service life assessment may be based on feedback data from practise or on results from so called qualification or acceptance durability tests.

The present recommended qualification procedures for polymeric materials in PV-applications are based on the conduct of a series of quite extensive constant load durability tests. During a test optical performance as well as mechanical properties of the material tested is determined by measuring its solar transmittance and mechanical properties such as strain at break. From the loss in optical and mechanical performance of the material, its failure time in the test performed is assessed and compared with the shortest acceptable failure time set by the design service life of the PV-module. Design service life, performance requirement defining failure time in terms of loss in optical and mechanical performance, classification of type and levels of environmental stress are set under the assumption, that the polymeric material tested will be used as encapsulation or as back sheet in PV-applications.

Recommended qualification test procedure for polymeric materials in PV-applications

1 Scope

This recommended procedure specifies durability tests to be used in the qualification of polymeric materials for the intended use as encapsulation or back sheet in PV-modules.

The polymeric material is considered qualified if it meets the requirement of design service life of 25 years. The maximum loss in the optical performance (light transmittance in the visible region of the solar spectrum) of encapsulation material, defining its service life, is fixed at a level corresponding to a reduction of 5%. The visible region is used because encapsulation materials in general contain UV-absorbers. Loss of UV-absorber must be regarded as a degradation process limiting the service life. However, loss of UV-absorber would increase the light transmittance if UV-radiation is included in the calculation of light transmittance. Concerning mechanical properties, a loss of strain at break of less than 50 % of initial value is required for qualification. A detectable loss of UV-absorbers as measured by UV-spectroscopy is not acceptable for qualification.

In the qualification procedure, the environmental factors considered the most important for the polymeric materials are limited to temperature in combination with high humidity and UV-radiation. The program of accelerated durability tests is accordingly restricted to the simulation of two types of processes: a) high temperature degradation in combination with high humidity, b) degradation by the action of UV-radiation at high temperature.

To quantify the expected environmental stress on the polymeric material determining its service life, climatic data from Miami during one year are utilized representing relatively harsh service conditions for PV-modules. For interpretation of the test results, modelling was used to relate intensities of the environmental factors under service conditions to that of the test conditions for the accelerated durability tests. The requirement on the service life of the polymeric material may then be converted into acceptable failure times in the accelerated tests.

2 Terms and definitions

For the purpose of this recommended qualification procedure, the following definitions apply.

2.1 Design service life

The time period of exposure under service conditions after installation during which the encapsulation or back sheet material are expected to meet the performance requirements.

2.2 Failure time

The time period of exposure in the accelerated test during which the encapsulation or back sheet material meets the performance requirements.

2.3 Visible solar transmittance, τ_s

Fraction of solar radiation in the visible region transmitted by the encapsulation material determined from measurement as is described in Annex A.

2.4 Elongation or strain at break □

Strain at break ε_B determined from measurement as is described in Annex A.

3 Requirements and classification

For classification of the durability of the encapsulation material, the following performance requirement shall apply:

$$\Delta\tau_s < 0.05$$

$$\Delta\varepsilon_B > 50 \% \text{ of initial } \varepsilon_B$$

For classification of the durability of the back sheet material, the following performance requirement shall apply:

$$\Delta\varepsilon_B > 50 \% \text{ of initial } \varepsilon_B$$

In general back sheet materials are not transparent and changes in optical properties do not affect the performance of PV-modules.

4 Test methods for assessing of polymeric materials performance in PV-applications

4.1 Sampling and preparation of test specimens

For durability testing, test specimens with a width of 15 mm and a length of 100 mm shall be prepared using a very sharp shear apparatus or razor blades. It is important that no fractural impressions are made in the samples. The test specimens should not be notched. Ten test specimens should be used for each exposure time. In total 50 specimens are needed.

4.2 Visible solar transmittance

Determine the value of the visible solar transmittance for a set of 10 test specimens after each exposure time from transmittance measurements as is described in Annex A. For the complete set of test specimens calculate also the mean value and standard deviation of visible solar transmittance.

4.3 Strain at break

Determine the value of the strain at break value for a set of 10 test specimens at each exposure time from tensile measurements as is described in Annex A. For a complete set of test specimens calculate also the mean value and standard deviation of strain at break value.

5 Test for assessing stability of polymeric materials with respect to high temperature and high relative humidity (Damp heat test) and UV-radiation

5.1 Principle

5.1.1 High temperature and high humidity induced accelerated ageing is frequently used in many technical application areas for the assessment of long term stability of materials. A high stress level accelerates all kinds of processes, normally leading to an increased rate of degradation of materials.

5.1.2 When used in a PV-module, a polymeric material is exposed to varying temperature, humidity and UV-radiation. The change of a performance property may be expressed by the following expression:

$$\Delta P(t) = \int_0^t (k_{UV} I_{UV}(t) \exp(-E_{UV} / RT(t)) + k_{aq} RH(t) \exp(-E_{aq} / RT(t))) dt \quad \text{eq. 1}$$

Where $P(t)$ is any important property like strain at break, k_{UV} and k_{aq} are reaction rate constants and E_{UV} and E_{aq} are activation energies. I_{UV} is the total UV irradiation reaching the samples. Total UV irradiation means here the integrated value between λ_{\min} and λ_{\max} . The change is controlled by four parameters (k_{UV} , E_{UV} , k_{aq} , and E_{aq}) that have to be determined in accelerated constant load exposure tests. This was done for a number of polymeric materials in the Performance project. Climatic data stored as 15 minutes mean value from Miami for a full year were used to calculate the total change of property P .

Of course, only the second term is applicable in a damp heat test.

6 High temperature and high humidity testing

6.1 Apparatus for damp heat testing

6.2.1 Testing chamber to be used for assessing the thermal stability of the polymeric material shall be constructed so that:

- 1) Constant temperature and humidity tests can be executed at a temperature of 85 °C and relative humidity of 85%.
- 2) The temperature and relative humidity of the test are monitored by sensing devices in the chamber so that it reflects the true temperature and humidity to which the test specimens are exposed.
- 3) The temperature is maintained at level of $\pm 1^\circ\text{C}$ and the relative humidity is maintained at a level of $\pm 1\%$ after stabilized conditions have been reached after start of test.

6.2.2 Instruments for measuring of optical and mechanical properties of the polymeric material are complying with the requirements as are specified in Annex A.

6.2.3 Tensile tester for measurement of strain at break in accordance with EN ISO 527-3.

6.3 Procedure for execution of high temperature and high humidity test

- 6.3.1 10 test specimens are examined with respect to visible transmittance and strain at break prior to the exposure test. Since tensile testing is destructive, transmittance measurements must, of course, be done first.
- 6.3.2 Expose 40 test specimens in a climatic chamber at 85 °C and 85% RH.
- 6.3.3 A set of 10 test specimens are taken out from the climatic chamber after 1000, 2000, 3000, and 4000 hours of exposure and the visible solar transmittance and strain at break are measured at each time. Since tensile testing is destructive, transmittance measurements must, of course, be done first.
- 6.3.4 Determine the visible solar transmittance and the strain at break of test specimens as is described in Annex A.
- 6.3.5 If the negative change in visible solar transmittance exceed 0.05 or the strain at break value is below 50% of the initial value at any time the material is not qualified with respect to thermal and humidity loads and the test can be interrupted.

6.4 Qualification

- 6.4.1 The polymeric material is qualified with respect to thermal and humidity loads if:

The negative change in visible solar transmittance is below 0.05 and the change in strain at break is below 50% of initial value after 4000 hours of exposure.

No detectable loss of UV-absorbers occur as measured in the UV-region

No deformation of the test specimens occur.

7 Tests for determining the resistance to UV-radiation

7.1 Principle

- 7.1.1 UV-radiation may cause severe degradation of polymeric materials. The situation in PV-applications is complicated by the fact that e.g. encapsulation materials are protected by glazing, which may more or less protect the encapsulation from UV-radiation. Back sheet material is not exposed to direct UV-radiation. However, as much as 50% of UV-radiation is diffuse radiation. Further, many polymeric materials for outdoor applications is protected by additives such as HALS (Hindered Amine Light Stabiliser) and UV-absorber.

The model described in 5:1.2 was used to model the in service performance of polymeric materials in PV-modules.

7.2 Apparatus

- 7.2.1 An Atlas Weather-ometer or similar devices shall be used to conduct constant load accelerated tests including UV-radiation according to the following conditions:

Black standard panel temperature: 85±1 °C

Relative humidity 25±1 %

UV-Irradiance (300-400 nm) 60±1 W/m²

Figure 1 shows the spectrum used in the weather-ometer and the natural UV spectrum represented by the solar spectrum from ISO 9845, Air Mass 1.5.

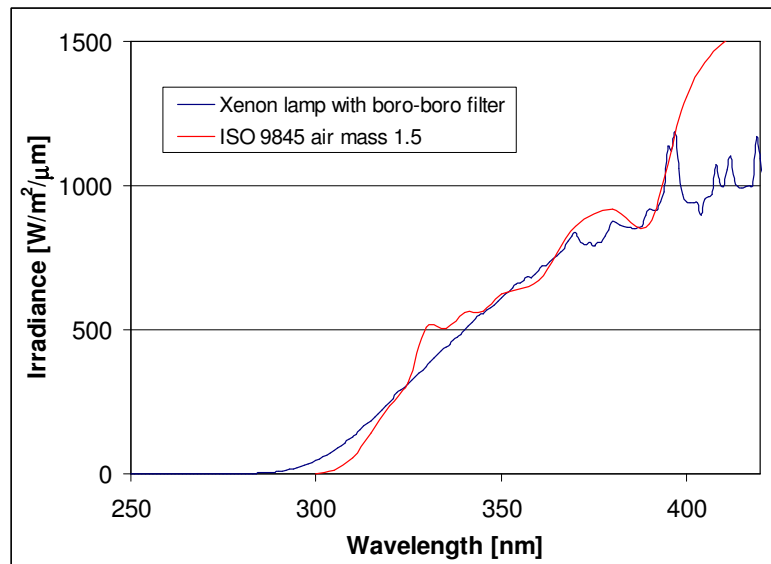


Figure 1. Spectral distribution of UV light from a Xenon lamp filtered by boro-boro filters and out-doors UV light according to ISO 9845 air mass 1.5.

7.3 Procedure for execution of Weather-ometer test

- 7.3.1 10 test specimens are examined with respect to visible transmittance and strain at break prior to the exposure test. Since tensile testing is destructive, transmittance measurements must, of course, be done first.
- 7.3.2 Expose 40 test specimens in a Weather-ometer or a similar device at 85 °C, 25% RH, and 60 W/m² UV-irradiance.
- 7.3.3 A set of 10 test specimens are taken out from the Weather-ometer after 1000, 2000, 3000, and 4000 hours of exposure and the visible solar transmittance and strain at break are measured at each time.
- 7.3.4 Determine the visible solar transmittance and the strain at break of test specimens as is described in Annex A.
- 7.3.5 If the negative change in visible solar transmittance exceed 0.05 or the strain at break value is below 50% of the initial value at any time the material is not qualified with respect to thermal and humidity loads and the test can be interrupted.

7.4 Qualification

- 7.4.1 The polymeric material is qualified with respect to UV-radiation at high temperature loads if:

The negative change in visible solar transmittance is below 0.05 and the change in strain at break is below 50% of initial value after 4000 hours of exposure.

No detectable loss of UV-absorbers occur as measured in the UV-region

No deformation of the test specimens occur.

Annex A

Procedure for determination of visible solar transmittance and tensile testing of polymeric materials for intended use in PV-applications

A.1 Assessment of visible solar transmittance and loss of UV-absorber

A.1.1 Scope

This procedure specifies a method for determination of the total visible solar transmittance τ_s for near-normal incidence, *i.e.* 8° to 10° to the surface normal, from total spectral transmittance $\tau(\lambda)$ values in the spectral range of 400 nm - 800 nm. However, the measurements should cover the spectral range from 250 – 800 nm. Preferably the near infrared region 800-2600 nm should be included in the measurements. The spectral total transmittance $\tau(\lambda)$ values are determined from spectral (near-normal) hemispherical transmittance $\tau(\lambda)$ values measured on transparent polymeric materials at room temperature.

A.1.2 Apparatus

Spectral (near-normal) hemispherical transmittance $\tau(\lambda)$ values shall be determined by photometric integration by use of a spectrophotometer equipped with an integrating sphere. The wall of sphere shall be coated with a highly and diffusely reflecting coating, e.g. BaSO₄. In the photometric integration the radiation transmitted in the normal direction as well as the diffusely scattered component of transmitted radiation have to be included.

The sphere shall be designed so that the sample is part of sphere wall during the measurement. The detector shall be positioned so that it is shielded against radiation received directly from the sample.

A.1.3 Evaluation of total visible solar transmittance

The visible solar transmittance, τ_s , is calculated from the following expression:

$$\tau_s = \frac{\int_{400nm}^{800nm} \tau(\lambda)S(\lambda)d\lambda}{\int_{400nm}^{800nm} S(\lambda)d\lambda} \quad (A.1)$$

where

λ is the wavelength

$\tau(\lambda)$ is the total transmission at wavelength λ

$S(\lambda)$ is the global spectral solar irradiance according to Table 1 of ISO 9845-1.

A.2 Assessment of mechanical properties

A.2.1 Scope

Tensile tests on unnotched samples shall be carried out according to EN ISO 527-3. Test specimens shall be cut prior to exposure using very sharp shear apparatus or a device with fixed razor blades and rotating sample.

A.2.2 Apparatus and testing conditions

Tensile tester fulfilling the requirements in EN ISO 527-3

Testing speed: 50mm/min

Specimen length: 100mm

Specimen width: 15mm

Gauge length: 50mm

Measurement of displacement via crosshead movement

A.2.3 Evaluation of mechanical properties

Ten measurements of each material (10 test specimens) at each state of ageing should be done. Strain at break (ϵ_b), tensile strength (σ_b), yield point (ϵ_y , σ_y) and elastic modulus (E) should be determined.