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Development of an Accelerated Weathering Protocol using Weatherometers for Reliability Study of Minimodules and Encapsulation Materials

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ABSTRACT

This paper is condensed from a full report [1] that describes the needs, reasoning, approaches, and technical details to establish a practical accelerated weathering test (AWT) protocol for indoor testing of the photothermal stability of encapsulation materials and encapsulated solar cells and minimodules. Essentially the AWT Protocol resembles ASTM methods and is designed solely to better utilize the capabilities of user-programmable systems such as the Atlas Model Ci4000 weatherometers (WOMs). The important part of the Protocol is on determining the parameters of the test cycles, total radiant exposure, and exposing duration.

1. The Need for an AWT Protocol

Strict requirements on the long-term weathering durability of all component materials and assembly integrity are necessary for PV modules to achieve a desired 30-year service life. Weathering-induced degradations of the ethylene-vinyl acetate (EVA) encapsulants, metallic components, and delamination have been observed for modules in the field and laboratories. The degradations resulted in performance loss and/or premature module failure [2,3]. Testing PV modules outdoors under natural weathering for 20-30 years is obviously impractical if one wants to determine and improve material stability in a span (life cycle) of 1-3 years. Thus, a practical and dependable test method that can *accelerate* the test conditions in a realistic manner over a reasonably short period of time is clearly needed. As shown in **Table 1**, only a few ASTM and one IEEE test standards are available for testing PV modules. AWT with exposure to (UV) light greater than 1 sun is clearly absent. A qualification test of PV modules in the IEEE 1262 specifying a 54 MJ/m^2 of UV exposure will most likely not qualify the modules and their comprising materials to be immune from long-term UV-induced degradation. The 54 MJ/m^2 can be accumulated in ~2 months outdoors or ~150 hours in a WOM using a Xe light intensity of 100 W/m^2 (300-400 nm broadband), which will hardly result in any observable physical or chemical changes on the presently existing module component (other than a-Si cells). Hence, the criterion of UV radiant exposure (e.g., total accumulated UV dose) is better established on the basis of actually known physical and/or chemical facts.

2. Weatherometer Systems and Capabilities

In this work we used two user-programmable Atlas Model Ci4000 WOMs. The systems use a water-cooled Xe arc lamp rated at 6500 W with a typical lamp life of 2000 h. Pre-aged type-S borosilicate inner and outer filters are selected for a light emission spectrum that best simulates the solar spectrum. The light intensity can be monitored and feedback-controlled by either a 340-nm narrow band filter or a 300-400 nm broad band filter. Development of the AWT Protocol involved determining the test conditions of variable parameters in light intensity, chamber dry bulb temperature (DBT), black panel temperature (BPT), relative humidity (RH), specimen spray (front side, to simulate rain), number of segments, and test duration control.

3. Samples, Sample Configurations, and Analytical Characterization

Encapsulated minimodules (and laminated encapsulation materials) are used as a miniaturized model of large-size PV modules. This allows the component materials in any type of PV module to be tested in an integrated, functional format. The sample configuration is designed in such a way that it permits independent spectroscopic characterization of the encapsulant and electrical characterization of the solar cell [3].

4. Development of the AWT Protocol

The following briefly summarizes the approaches and procedures to establish the AWT Protocol. Detailed reasonings and descriptions are given in ref. [1].

Step 1: Compiled 12 years of climatological data, provided by South Florida Test Center, for the hot-humid Miami, FL, and hot-dry Arizona areas. Derived the averaged values of radiant exposures and rain periods for each climate region.
Step 2: Compiled the most relevant test standards including the few existing for PV modules (Table 1), and compared the test conditions of those standards.
Step 3: Determined the WOM-deliverable operating parameters on light intensity, BPT, chamber DBT, RH%, light/dark cycles, specimen spray, segment time, etc. under different lamp operating wattage.
Step 4: Determined the physical/chemical reference from previous experiment results the approximate times required for EVA films to discolor, for example, by a net change of yellowness index of 4–4.5.
Step 5: Measured and determined the integrated UV intensity and the equivalent UV-suns in the 300-400 nm range of the Xe lamp emission spectra at different operating wattage.

Step 6: Determined from Steps 4 and 5 the approximate radiant exposures needed for A9918 and 15295 EVA discoloration. A total radiance of ~675 MJ/m^2 was obtained for a light yellow-brown EVA A9918 exposed to a solar simulator at a BPT of ~45°C.
Step 7: Compared the 675 MJ/m^2 in Step 6 to the UV-test set points described in test standards.
Step 8: Determined the daily radiant exposure and light cycle time comparable to the average daily UV radiance from the EMMAQUA systems operated in Arizona. Obtained an acceleration factor of ~5.7 for UV exposure alone. Calculated the total daily spray time and compared the result to the average daily rain time in Miami. Spray in the middle of a light cycle is to simulate rain and to induce a thermal shock. A 120-min "specimen spray time" was obtained versus a 72-min "rain time" per day.
Step 9: Determined the number of light/dark segments per cycle, specimen spray time, BPT, and chamber DBT for each light and dark segment. A BPT of 85°-90°C in the light cycle is about 20°-30°C higher than the typical operating temperatures of crystalline-Si PV modules on racks or on rooftops.
Step 10: Established and revised the AWT Protocol parameters per test results. After a number of test-runs and recent system hardware and software upgrades, the working AWT Protocol has been revised several times as following:

- Irradiance monitored and controlled at I(300-400 nm) = 125 W/m^2; corresponding I(340 nm) ~1.05 W/m2.
- Xe lamp operating power ~6.07 kW (safe under the nominal rating of 6.5 kW maximum).
- BPT Control: active (BST control inactive).
- Chamber DBT Control: active.
- Test Duration Control: by desired radiant exposure.
- Five Test Segment Parameters:
  1. Light, 125 W/m^2, 1.385 MJ/m^2 (~185 min), BPT = 85°C, DBT = 65°C, RH = 35%, Spray Off
  2. Light, 125 W/m^2, 150 KJ/m^2 (~20 min), BPT = 55°C, DBT = 60°C, RH = 50%, Spray On
  3. Light, 125 W/m^2, 1.385 MJ/m^2 (~185 min), BPT = 85°C, DBT = 65°C, RH = 35%, Spray Off
  4. Dark, 70 min, BPT = 40°C, DBT = 40°C, RH = 85%, Spray Off
  5. Dark, 20 min, BPT = 40°C, DBT = 40°C, RH = 95%, Spray On
  6. Three cycles per every 24 hours

5. Conclusions

A practical AWT Protocol has been established on the basis of numerous instrumental testing and observations. The radiant exposures for the overall test duration are established using the extent of actual EVA discoloration as a criterion rather than from an arbitrarily chosen number. The AWT Protocol is presently employed to test samples of a matrix experiment. The results will be compared with the previous tests using UV solar simulators. Test duration (of radiant exposures) may be adjusted because the AWT Protocol combines high BPT in the light cycle, low and high RH%, periodic specimen spray, and light/dark cycles. All of these were not available in previous AET experiments using solar simulators.

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REFERENCES

[1] F.J. Pern, "Accelerated Weathering Test (AWT) Protocol for PV Module Encapsulation Materials and Encapsulated Solar Cells," a task milestone report for Task PV80.6201, NREL, June 1998.

[2] A.W. Czanderna and F.J. Pern, "Encapsulation of PV Modules using Ethylene-Vinyl Acetate Copolymer as a Pottant: A Critical review," *Solar Energy Materials and Solar Cells*, 43 (1996) 101-183.

[3] F.J. Pern and S.H. Glick, "Photothermal Stability of Encapsulated Si Solar Cells and Encapsulation Materials upon Accelerated Exposures, *Solar Energy Materials and Solar Cells*, 61 (2000) 153-188.

Table 1. A List of Some Standard Test Methods and Practices for PV Cells and Modules

Standard No.	Title Description of Standard
ASTM E1038-93	Test method for determining resistance of PV modules to hail by impact with propelled ice balls
ASTM E1171-93	Test method for PV modules in cyclic temperature and humidity environments
ASTM E1462-95	Test method for insulation integrity and ground path continuity of PV modules
ASTM E1524-93	Test method for saltwater immersion and corrosion testing of PV modules for marine environments
ASTM E1596-94	Test methods for solar radiation weathering of PV modules
ASTM E1597-94	Test method for saltwater pressure immersion and temperature testing of PV modules for marine environments
ASTM E1799-96	Practice for visual inspection of PV modules
ASTM E1802-96	Test methods for wet insulation integrity testing of PV modules
IEEE 1262-95	Recommended practice for qualification of PV modules (with short UV conditioning; under revision)
NREL	Interim qualification test procedures for thin film PV modules (similar to ASTM E1171)