

Measurements of Backsheet Moisture Permeation and Encapsulant-Substrate Adhesion

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ABSTRACT

At the March 2001 NCPV workshop on “Moisture Ingress and High-Voltage Isolation”, industry participants identified several properties associated with PV module durability that are critical for commercial success. These include interface conductivity, adhesion of encapsulants to substrate materials as a function of in-service exposure conditions, and moisture permeation through backsheet materials as a function of temperature. Electrical data is discussed in a companion paper; adhesion and water vapor transmission rate (WVTR) measurements are presented herein.

1. Introduction

During service exposure, bonds between encapsulant and superstrate/substrate (E-S) materials of PV modules can weaken, leading to delamination failure and/or increased moisture ingress. We have adapted existing equipment to allow 180° peel strength to be measured on samples prepared in-house and by industry collaborators. Interface adhesion is being characterized for a number of types of glass and different substrate treatments; peel strength values of 7 N/mm are typical for unweathered better-quality samples. Adhesion will be measured for samples as prepared and after accelerated and real-world weathering.

Water transport can induce hydrolytic degradation of the PV device. A new instrument has been procured and activated to allow us to make WVTR measurements on a number of new backsheet materials of interest to industry as well as a number of other commercial and experimental backsheets. Samples prepared at NREL having the construction: oxide or nitride coating / polyester film have demonstrated very low WVTRs (~0.2 g/m²/d). Alternate deposition processes are being explored to produce economically feasible barrier coatings.

2. Adhesion Measurements

A practical and reliable measure of adhesion is needed that allows comparisons between different E-S combinations as a function of accelerated and in-use stress exposure. We have chosen 180° peel strength because it is straightforward to measure as a function of temperature, provides a measurable quantity that is related to the adhesive properties of the E-S bond, and is widely accepted by many industry partners. An Instron 5500R mechanical testing instrument is used to measure the peel strength between candidate E-S materials. For rigid substrate materials (such as glass), peel strength at 180° is measured as per a modified ASTM 903. To measure adhesion to flexible backsheet materials, two layers are bonded together and an 180° T-peel test is used as prescribed by ASTM

1876. Candidate samples have the construction: Superstrate / Encapsulant / Backsheet; samples are prepared using an Astropower, Inc. model LM-404 solar module vacuum laminator that replicates the procedure used by industry to manufacture commercial modules. Industry partners also provide samples.

In contrast to peel strength, measurement of the interfacial adhesion is complicated. For a given constant stress (σ) such as that experienced during mechanical peel tests, viscoelastic materials (e.g., polymer films) exhibit permanent deformation (time dependent strain, ϵ , or creep). Therefore, the peel shape (and consequent measured peel strength) will depend upon the time available for relaxation of the modulus ($Y=\sigma/\epsilon$), or equivalently, the pull rate. From energy balance considerations the measured peel strength (p) is a function of interfacial adhesion (γ) and viscoelastic dissipation of energy within the bulk of the polymeric layer (ψ_v) as [1]:

$$p = \frac{\gamma - \psi_v}{1 - \cos \phi} \quad (1)$$

where ϕ is the peel angle.

The viscoelastic effect is demonstrated in Fig 1 where the measured room temperature creep of a Tedlar/PET/EVA (TPE, where PET is polyethylene terephthalate) film is shown as a function of applied stress. The applied stress levels correspond to a range of peel strength values (5-7 N/mm) typical for unweathered TPE/EVA/Glass samples. Fig 2 presents measured peel strengths as a function of pull rate along the length of a test sample. Peel strength was measured at various pull rates over ~10-15 mm lengths ($\Delta\ell$)

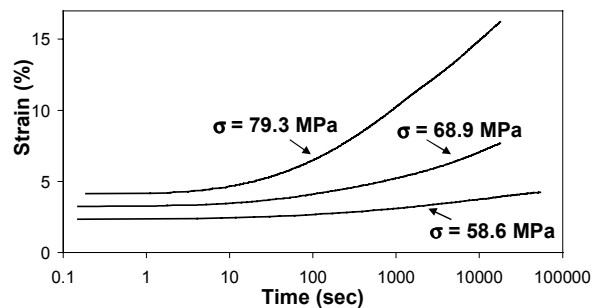


Fig 0. Room temperature creep of TPE film as a function of applied stress (σ).

along a test sample. As can be seen from Fig 1, there is little creep for times less than 10 seconds; this corresponds to pull rates greater than about 100 mm/min over $\Delta\ell$. From Fig 2, the measured peel strengths are fairly constant over this range. At values less than 100 mm/min the peel strengths generally decrease with pull rate as is expected from Eq 1.

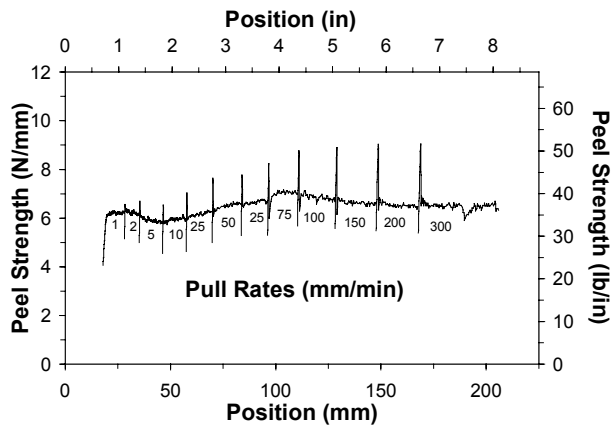


Figure 2. Peel strength as a function of pull rate along length of sample for TPE/EVA/Glass.

3. WVTR Measurements

Some thin-film PV devices have difficulty passing the damp heat qualification test (85% relative humidity at 85 °C for 1000 hours, as per IEEE 1262). Moisture ingress is the generally accepted mode of failure. As shown in Fig 3,

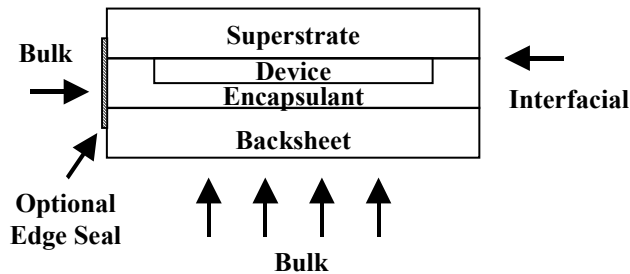


Fig 3. Possible paths of moisture ingress.

moisture ingress can occur along the edges (either along interfaces or through the edge seal/encapsulant) or through the backsheet material, typically a polymer laminate. For glass/EVA/polymer film constructions, initial experiments suggest that moisture ingress occurs primarily through the backsheet. WVTR is a measure of a barrier's capacity to restrict moisture ingress. It is important to determine the correlation between WVTR and the ability of a device to survive the damp heat test. NREL uses a Mocon Permatran-W 3/31 instrument to measure WVTR of candidate backsheet material constructions as per ASTM F1249. Measurements to date have been made at 20°C / 85% relative humidity (RH) and at 38.7°C / 85% RH. We are working to extend our capabilities to allow routine measurements to be made at 85°C / 85% RH.

Barrier-layer constructions have been extensively investigated by the food packaging industry [2]. For this application, such materials must have WVTR values ≤ 1 g/m²-d at ambient levels of temperature and RH. An additional requirement that the films be transparent can be relaxed for backsheet barriers, thus allowing a greater variety of candidate coating materials. In some situations, controlled breathable barrier constructions arise, but thin film devices will require backsheets that provide near hermetic seals.

WVTR measurements are very sensitive to temperature and RH conditions. For uncoated 0.1-mm thick PET film the measured WVTRs are 1.2 g/m²-d at 20°C/85% RH and 3.4 g/m²-d at 38.7°C/85% RH. However, at 85°C/100% RH the measured (at Mocon, Inc.) WVTR is 81.1 g/m²-d. This corresponds to an activation energy of 0.6 eV, which is quite high and must be significantly reduced to allow adequate performance at elevated temperatures.

To impede moisture ingress, we are focusing our efforts on low temperature deposition of inorganic thin films on polymeric substrates by sputtering and evaporation. Oxide thin films of aluminum, silicon, titanium, and boron have been deposited onto PET substrates using pulsed DC magnetron sputtering and/or electron beam evaporation with and without a pulsed bias assist. Nitride and/or oxynitride films of aluminum and silicon have also been prepared by these same techniques. Initial results show that films deposited by pulsed DC magnetron sputtering have a lower water vapor transmission rate at 37.8°C than films produced by electron beam evaporation by a factor of 2-30. Also, these films can have water vapor transmission rates lower than what is required by the food packaging industry by a factor of 8. Further improvements may be achieved by optimizing stoichiometry and surface treatments. We are investigating the possibility of alleviating problems encountered by the use of reactive pulsed DC magnetron sputtering (arc events that produce defects) through the use of either radio frequency sputtering or by the application of a radio frequency bias to the substrate. The UV stability of the adhesive bond between encapsulants and coated backsheets must also be explored.

4. Conclusions

We have established a protocol for characterizing the adhesion of E-S samples that is capable of measuring the initial peel strength of the best commercially available constructions. This procedure can also be used to track changes in adhesion with exposure. We have developed a capability to measure WVTR rate at elevated exposure conditions and have also shown promising early results in candidate backsheet material construction preparation.

5. Acknowledgements

Madico and DuPont Teijin have provided backsheet films, STR has provided encapsulant material, and AFG Glass has provided glass substrate materials. First Solar Inc. and BP Solar have provided E-S samples typical of those used in industry.

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