

BAPVC Annual Project Report

Project Title: Photovoltaic Encapsulant and Backsheet Debonding

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Summary:

A metrology was developed to measure adhesion in solar module interfaces without the need for active crack monitoring. Coupled with previously developed fracture-mechanics metrologies, it was used to characterize interfacial debond as a function of temperature and relative humidity. Accelerated environmental testing of the backsheet structure revealed a dramatic drop in adhesion at the PVF/PET after exposure to damp heat. An investigation of the encapsulant lamination process identified a critical cure time and surface preparation procedures that improved the adhesion at the EVA/glass interface.

Key Accomplishments:

The Dauskardt group developed a simplified, mechanics-based adhesion metrology that is both crack-length independent and requires minimal data analysis and specimen preparation. To quantify encapsulation adhesion, Ti/glass/EVA/glass/Ti square adhesion coupons were fabricated as shown in Fig. 1. When loaded by a corner, the coupons debond at a constant mechanical force (P_c) and the energy of adhesion G_c (J/m^2) can be easily calculated with $G_c = P_c^2 / (4B)$, where B is the cross-section

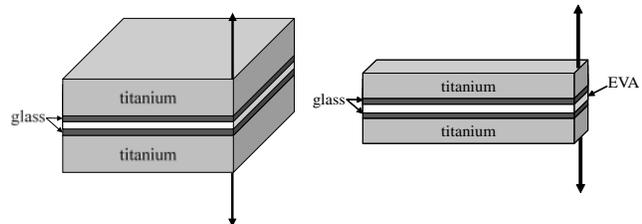


Fig.1. [left] Square corner coupon loaded in tension by a corner. A sheet of encapsulation (EVA, shown in white) was thermally bonded between two glass ($150\ \mu\text{m}$) square substrates bonded to secondary titanium ($830\ \mu\text{m}$) substrates as shown. [right] Double cantilever beam with bilayer (Ti/glass) substrates.

bending stiffness (per unit width) of the bilayer substrate (Ti/glass). A representative load-displacement curve for a square test coupon is shown in Fig. 2. The value of P increases upon initial loading, plateaus during steady-state debonding at P_c , and decreases abruptly when the debond line reaches the middle of the coupon. G_c measurements of EVA larger than $200\ \text{J}\cdot\text{m}^{-2}$ were common and were attributed to (1) cavitation ahead of the debonding-tip and (2) crazing and bridging behind the debonding-tip. It is important to note that the high energy deformation processes (cavitation and crazing) are not measurable in any of the currently-available peeling techniques.

This metrology was extended to quantify adhesion in other module laminates using both lab-made coupons and full-size solar modules, both with square and beam-shaped substrates. It was found that that adhesion of the backsheet structure decreased from 1000 to $30\ \text{J/m}^2$ as a consequence of exposure to an accelerated *damp-heat* treatment (80°C and $80\%\text{RH}$). As shown in Fig. 3, the debond energy decreased dramatically from 1000 to $27\ \text{J/m}^2$ (indicating increased propensity for failure) within the first 750 hrs and remained constant during the last 250 hrs of the damp-heat treatment. The loss in debond energy corresponded to a change in the backsheet

debond path, which was partially cohesive in the PVF in specimens aged for $t < 750$ hrs (remnants of the PVF film were left on the debonded PET surface) and was exclusively adhesive at the PVF/PET interface in specimens aged for 750 and 1000 hrs.

EVA/glass adhesion was characterized with respect to lamination cure time and substrate surface treatments. Concerning cure time, EVA/glass adhesion increased (0.48 to 1.5 kJ/m²) during the first 9 min of post-lamination treatment at 140°C, then decreased with further exposure, implying that there exists a critical time at temperature for

which adhesion is optimized. Regarding surface treatment, triple rinsing the glass substrate with acetone + IPA + UV ozone yielded a G_c of 1 kJ/m² whereas using a trichlorobenzene degreaser treatment yielded a G_c of 0.5 J/m². The triple rinse + UV yielded the largest G_c due to more efficient covalent bonding of the ionomer to glass; the residual thin film left by the trichlorobenzene lead to lower values of G_c . In both cleaning treatments, thicker encapsulations yielded larger values of G_c . All specimens exhibited cavitation, crazing and bridging, as expected when $G_c > 200$ J/m².

Future Work:

The Dauskardt group will characterize the effects of encapsulation material, (e.g. EVA, ionomer, polyolefin), on the debond energy and encapsulant debonding kinetics. The group will continue to develop multi-layer thin-film mechanics and degradation models for cell, interconnect, and encapsulant interfaces in PV module packaging technologies. Additionally, the group will refine the developed reliability testing capabilities for the broader BAPVC community, re-designing testing for field exposed samples and calibration/validation of kinetic degradation models and lifetime prediction procedures using in-service and field-exposed data.

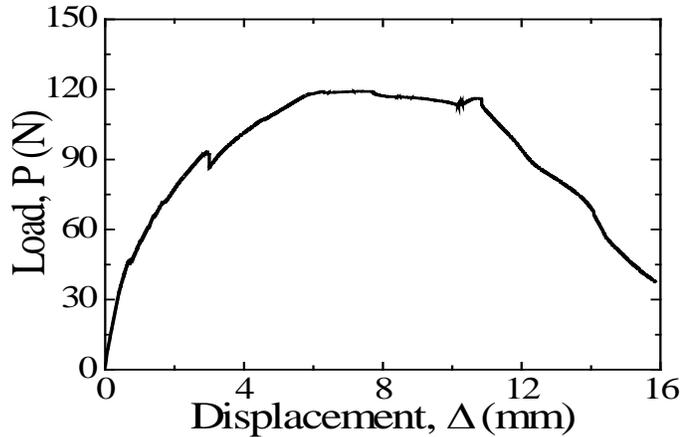


Fig.2. Load-displacement curve for EVA/glass debonding obtained by loading the square adhesion coupon by a corner. The value of P increased with initial loading, plateaued during steady-state debonding at P_c , and decreased abruptly when the

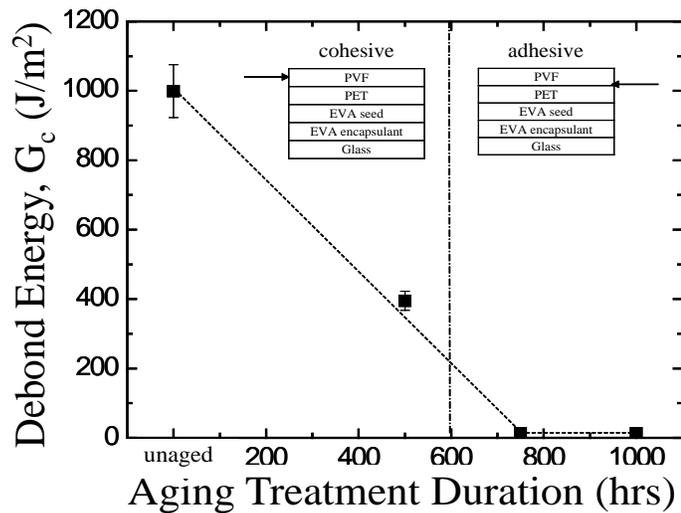


Fig.3. Backsheet adhesion vs. duration of aging treatment at 85°C and 85% RH. Arrow in stacking diagram indicates debond path location: partially cohesive in PVF after 0 and 500 hrs of treatment and strictly adhesive at the PVF-PET interface after 750 and 1000 hrs.