

BAPVC Annual Project Report

Project Title: Photovoltaic Encapsulant and Backsheet Debonding

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Summary: A fracture-mechanics metrology was developed to measure the debond energy of photovoltaic encapsulation systems. The debond energies of encapsulants (EVA, PVB) and backsheets (TPT-PVF) were measured as a function of temperature. The kinetics of encapsulant and backsheet interfacial debonding were characterized as a function of mechanical stress, relative humidity, and environmental temperature. To elucidate the mechanisms of environmental debonding, a viscoelastic fracture-kinetics model, which provides the basis to assess long-term encapsulant and backsheet stability, was developed and validated.

Key Accomplishments:

The Dauskardt group developed scalable metrologies to characterize the coupled thermo-mechanical and photo-chemical degradation mechanisms of photovoltaic encapsulation systems. The effects of operating environments, including mechanical stress, flexing and bending, thermal cycling, temperature, moisture, and in-situ UV light were investigated.

A single cantilever beam (SCB) testing technique was developed to quantify debonding in backsheets and encapsulants. To measure the debond energy, the glass substrate of an encapsulation specimen (Fig 1) was fixed to a testing table using a spring clamp. An elastic beam (Poly-methyl-methacrylate, or Titanium), was then bonded to the specimen as shown in Fig. 1. An incision was made with a blade at the edges of the beam (through the full thickness of the backsheet and underlying encapsulant). A loading tab with a ruby bearing was then bonded to one end of the beam to facilitate mechanical loading. The loading tab was connected to an adhesion test system (Delaminator, DTS, Menlo Park, CA) consisting of a linear actuator (displacement-controlled) in series with a high-resolution mechanical load cell. To initiate backsheet debonding, a tensile force was applied on the loading tab until the debond length (distance from the loading tab to the debond front) was $\sim 15\text{mm}$.

Using the newly developed SCB technique, the Dauskardt group measured—for the first time—the debond energy, G_c , of the EVA-Glass interface, shown in Fig. 2, which decreased linearly with environment temperature, T , from $2.25 \text{ to } 1.8 \text{ kJ m}^{-2}$ in the $20 \text{ to } 50^\circ\text{C}$ range. At temperatures close to the T_m of EVA(60°C), the value of G_c decreased abruptly (six-fold) to 0.3 kJ m^{-2} . The values of G_c of the PVB-Ti interface ($0.6 \text{ to } 0.5 \text{ kJ m}^{-2}$) were much lower than those of EVA-Glass in the same temperature range, and only slightly higher than those of EVA-Glass at high temperature ($T > T_m$).

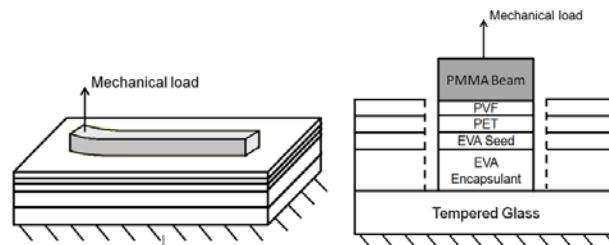


Fig.1. [right] Single Cantilever beam (SCB) specimen. Mechanical load is applied to one end of an elastic beam bonded to the encapsulation specimen [left] Side view of the SCB specimen. Dotted lines represent 1mm-wide cuts at the contour of the beam through the backsheet and encapsulant.

To characterize the effect of temperature and moisture on the kinetics of encapsulant debonding, the debond growth rates of EVA-Glass and PVB-Ti were measured as a function of debond driving force, G , environment temperature, and relative humidity, RH. The debond rates as a function of G and RH are shown in Fig. 3. The debond growth curves were shifted to lower values of G at higher values of RH. Debonding was, however, more sensitive to moisture changes in dryer environments: the value of G corresponding to $da/dt = 100 \mu\text{m/s}$ decreased 250 J m⁻² from 10 to 25% RH, but only 150 J m⁻² from 40 to 55%. The similarities between the effects of RH and temperature (shown elsewhere) on debond growth suggest a common debonding mechanism through the plasticization of the debond-tip of the polymer layer. To better understand the effect of T, G and RH on debond growth, a viscoelastic fracture-kinetics model was developed. The model, which includes the plasticizing effect of moisture on EVA, is shown in dashed lines in Fig. 3 to describe the debond rates as a function of RH. This model can be used to provide estimates of lifetimes and the evolution of pre-existing defects in the PV module. The debonding experiments were performed with the SCB load-relaxation technique in a chamber of controlled environment at 30°C.

Future Work:

The Dauskardt group will characterize the effects of encapsulant composition, (i.e. ratio of vinyl acetate in EVA), on the debond energy and encapsulant debonding kinetics. The group will also 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.

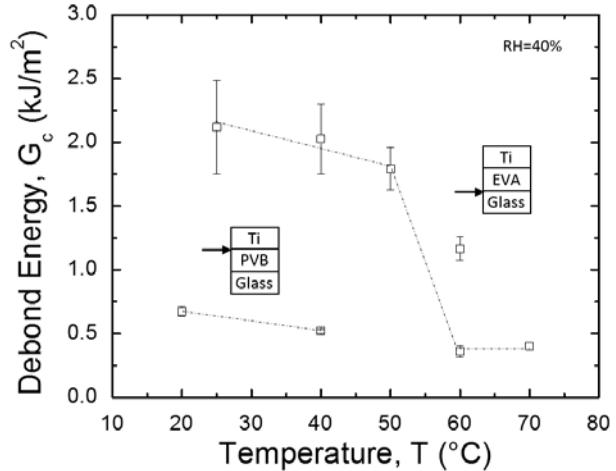


Fig. 2. Debond Energy of EVA-Glass and PVB-Ti interfaces as a function of temperature. The debond experiments were conducted using the single cantilever beam technique in a chamber of controlled environment at 40% relative humidity.

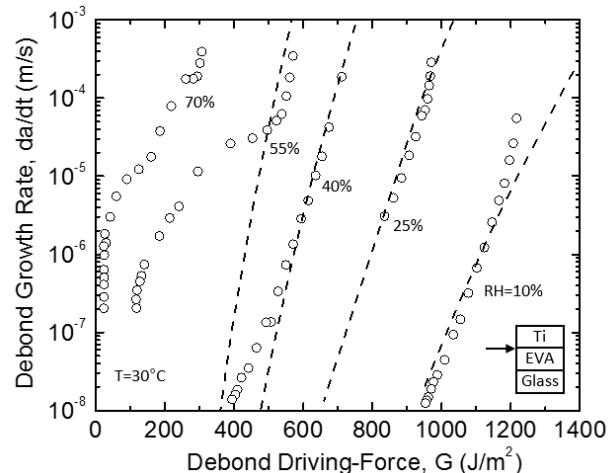


Fig.3. Interfacial debond growth rate of EVA-Ti as a function of debond driving-force, at five selected values of environment relative humidity, RH. The debond growth rates were shifted to lower values of G with increasing RH