Characterization of the Adhesion Integrity in Photovoltaic Panels using Various Thermomechanical Blister Tests

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Introduction

Our group's focus is in characterizing the adhesion between the layers in photovoltaic (PV) solar panels, using the thermomechanical blister test. Characterization of the adhesion in PV panels is important because adhesive failure is a common mode of failure (see Fig. 1, below). Delamination of the layers can lead to reduced optical transparency, heat dissipation, and protection from outside elements [1]. We are interested in developing the blister test as an accelerated testing method for predicting the long-term adhesive reliability of PV modules.

There are several variations of the blister test, including the pressurized blister test, the shaft-loaded blister test [2], and the thermal blister test [3]. Our focus is currently on the thermal blister test and the shaft-loaded blister test (see Fig. 2, below).

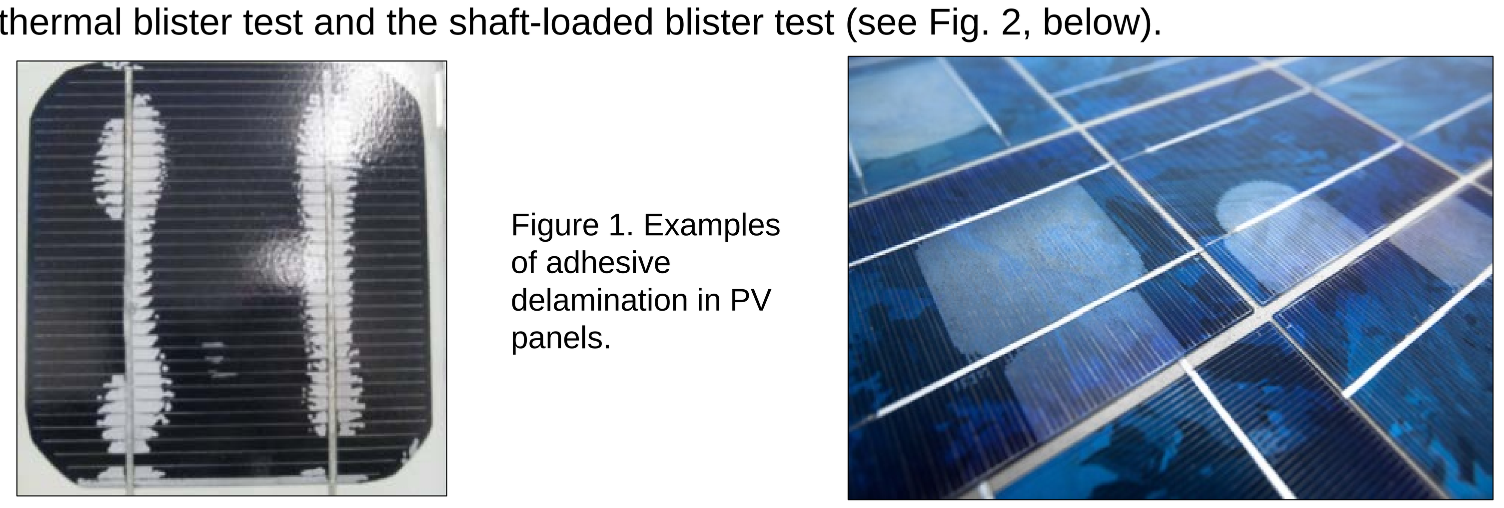
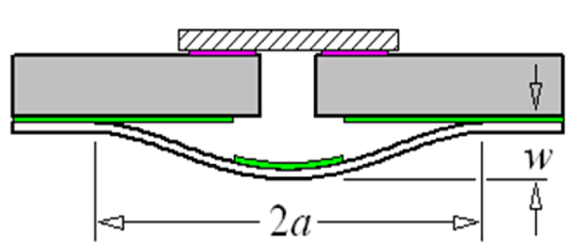
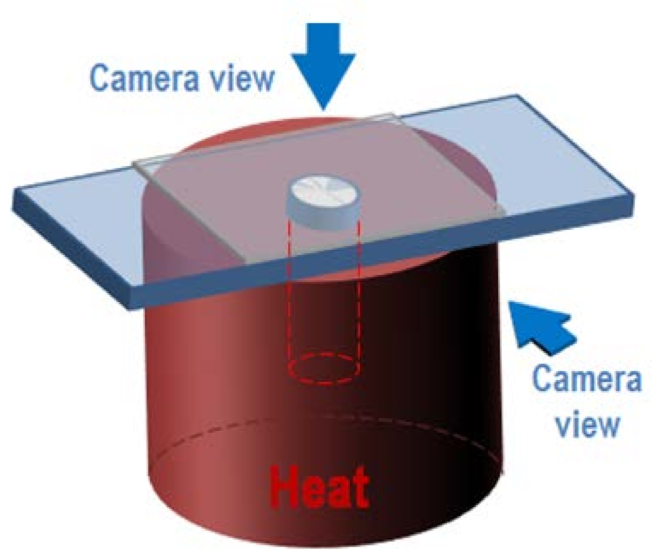


Figure 1. Examples of adhesive delamination in PV panels.

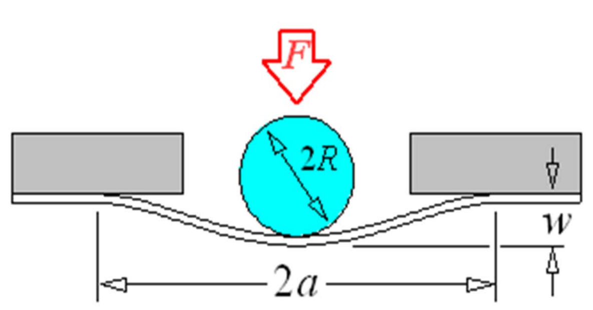
Method

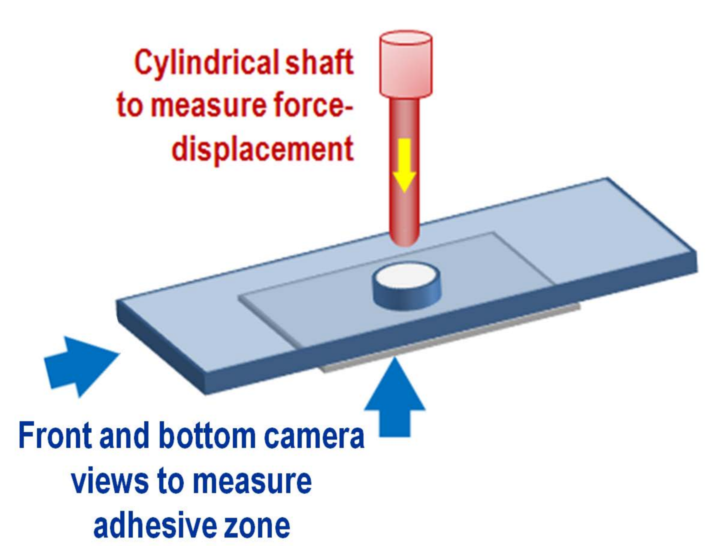
Figure 2. Variations of the blister test used in our study.





(a) Thermal blister test (TBT). At room temperature, the rear of the hole is covered with a plate, trapping the air in the blister cavity. Heat is then applied, causing the air to expand, and driving delamination. Side and top cameras are used to measure the blister radius, *a*, and blister height, *w*. These two parameters, along with the pressure of the entrapped air, *p*, are used to calculate the adhesion energy, *G*, of the film-substrate interface.





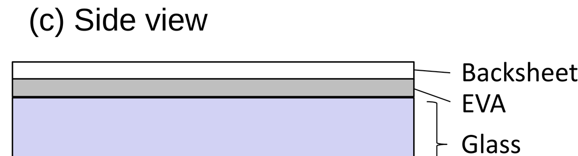
(b) Shaft-loaded blister test (SLBT). A shaft (either flat- or spherically-ended), is driven into the freestanding film, causing delamination. The applied force, *F*, punch radius, *R*, blister radius, *a*, and blister height, *w*, are used to calculated the interfacial adhesion energy, *G*.

Figure 3. Example of a blister test sample (here, a backsheet-thick glass sample).

(a) Glass-face view

(b) Backsheet-face view

(c) Side view



(d) Layering

Results

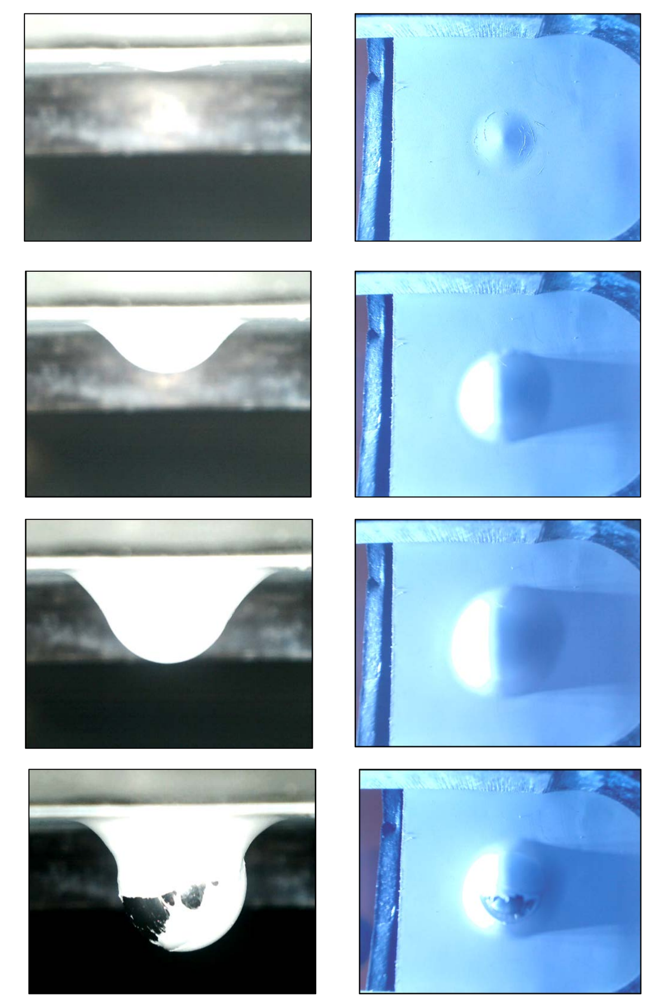


Figure 4. Sampling of sideview and bottom-view photographs from a spherical-ended shaft-loaded blister test on a backsheet-thick glass sample. The figures show, qualitatively, the evolution of the deformation/delamination process, from initial indentation to final rupture

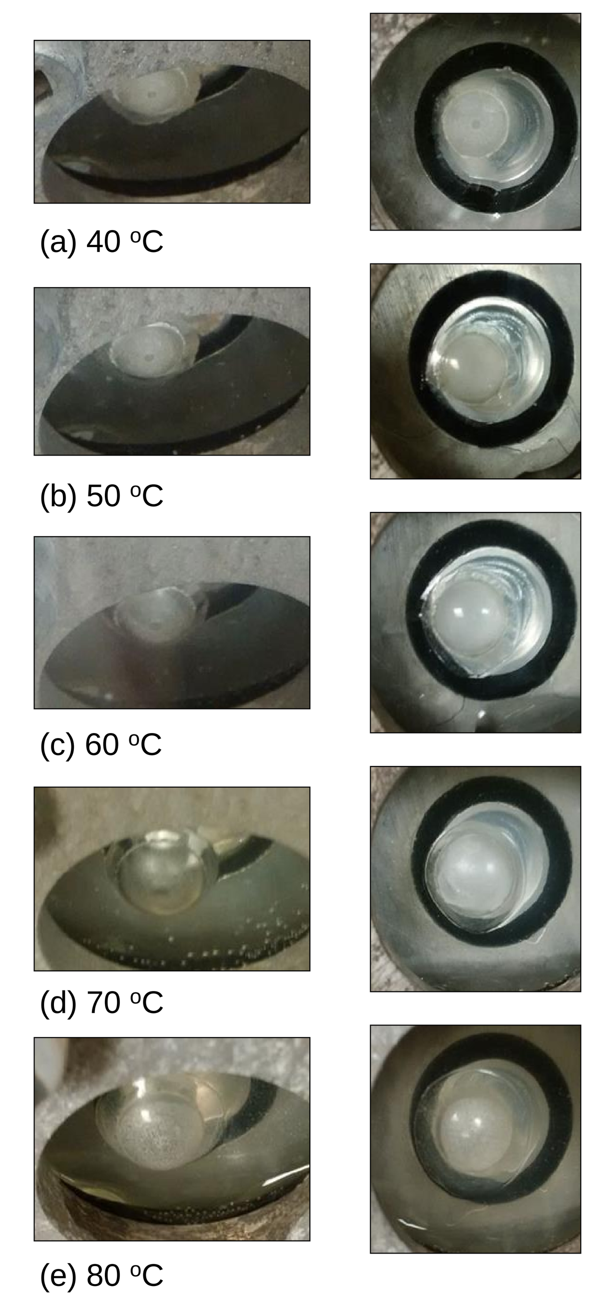
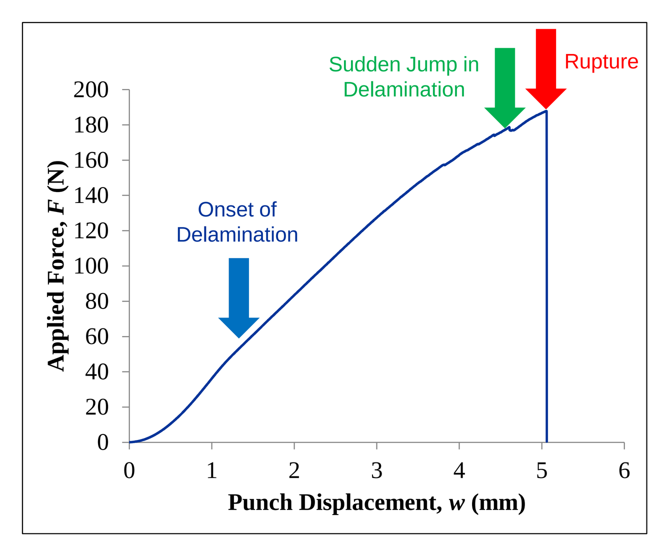
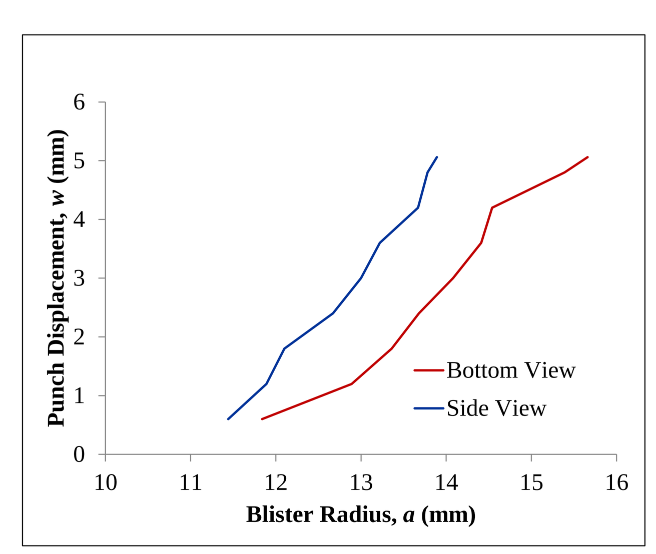


Figure 5. Results of a thermal blister test on an EVA-glass sample. The water was heated in intervals of 10 °C, starting at 40 °C. Between each increase, the sample was allowed to thermally equilibrate for 45 minutes. The photographs show the blister "ballooning"—i.e. deforming mechanically, significantly—while the blister grew slightly. This seems to indicate that the EVA-glass adhesion was strong, compared to the stiffness of the EVA.



(a) Punch applied force, *F*, vs. displacement, *w*. The blue arrow shows the approximate onset of delamination, prior to which the film simply stretched and deformed. The green arrow shows a sudden "jump" in delamination. The red arrow shows rupture, where the punch broke through the film.

Figure 6 (left and below). Example of quantitative data from a flat-ended shaft-loaded blister test. Note that, as we are still developing the testing method, the results are only preliminary and approximate. Only nine datapoints are shown in Figures (b) and (c)—explaining the non-linearity of the curves (the "bends" do not correlate with noteworthy events during the test).



(b) A plot of the punch displacement, *w*, vs. blister radius, *a*, shows that both increase, as the punch-driven delamination progresses.

(c) Punch applied force, *F*, vs. blister radius, *a*, showing the concomitant increase in both as delamination is driven.

Ongoing Work

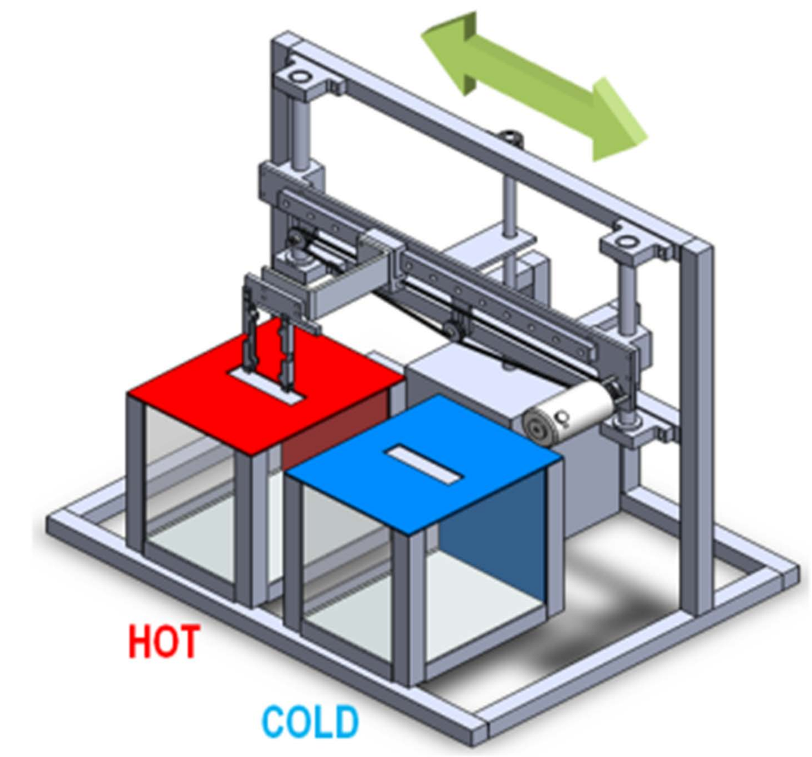
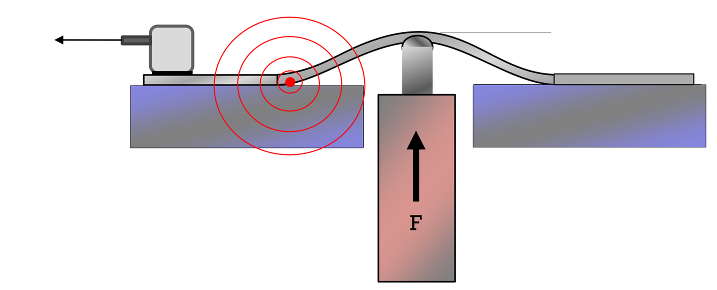
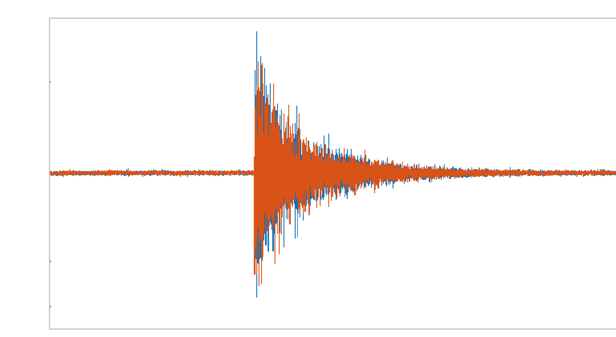


Figure 7 (above). Custom thermal-shock testing apparatus, currently being built. The device will interchange a set of thermal blister test samples between temperature-controlled hot- and cold-water baths, to simulate the thermal cycles experienced by PV materials in the field. Slated completion: Q1, 2016.

Figure 8 (below). Custom acoustic emissions blister test apparatus, currently being built. The apparatus will record high-frequency acoustic emissions, generated from sudden delamination events during a shaft-loaded blister test, to give further insight into the physics of the delamination process. Slated completion: QIV, 2015.





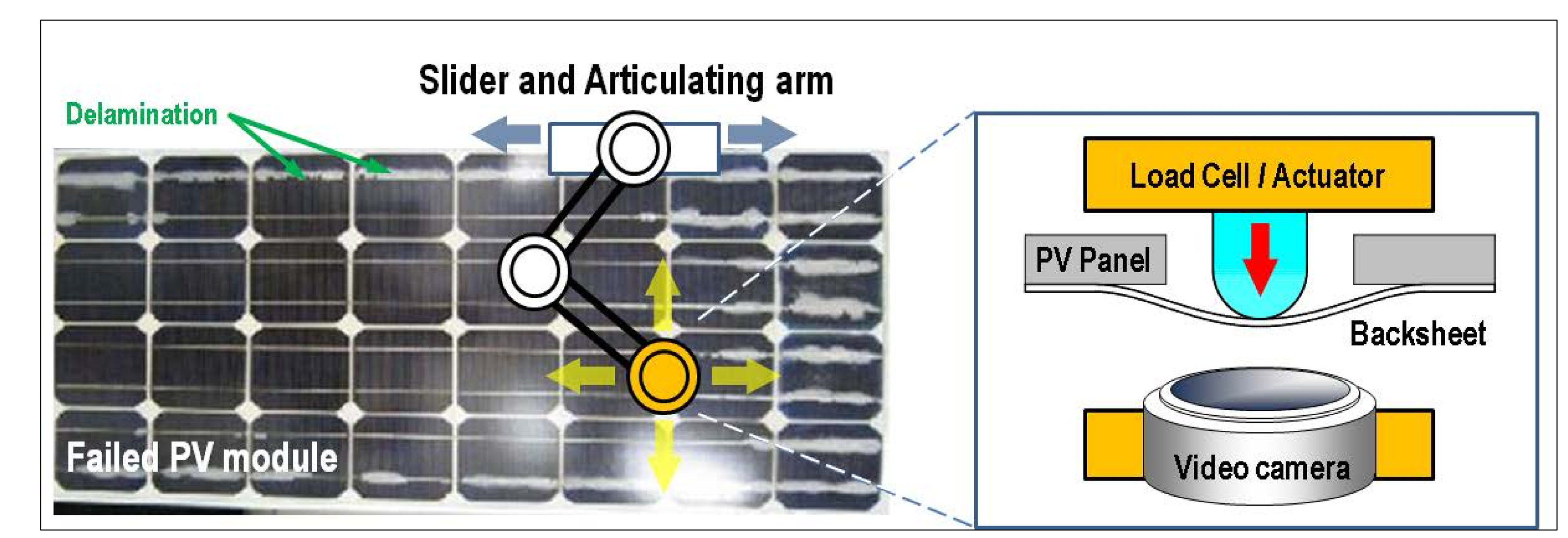


Figure 9. Custom apparatus for blister-testing real, field-weathered PV panel sections, currently being built. The device features an articulating arm that will position a probe for performing shaft-loaded blister tests, anywhere on the panel. Slated completion: QI, 2016.

$$G = \Phi(h, E, \nu, N_0, R, w_0) \cdot \frac{F \cdot w_0}{\pi a^2}$$

Equation 1. A new analytical model for the flat-ended shaft-loaded blister test, currently being developed. It will allow extraction of the interfacial adhesion energy, *G*, from our experimental results. The model will relate *G* to: (i) the properties of the film—the thickness, *h*, elastic modulus, *E*, Poisson's ratio, ν, and initial pre-stress, N_0— (ii) the size of the punch—the radius, *R* — and (iii) the experimentally measured variables—the applied force, *F*, blister height, w_0, and blister radius, *a*. Slated completion: QI, 2016.

References

1. M Quintana, et al, "Commonly Observed Degradation in Field-aged Photovoltaic Modules", *Photovoltaic Spec Conf, Conf Record 29th IEEE*, 2002 May: 1436–1439.
2. S Guo, KT Wan, and D Dillard, "A bending-to-stretching analysis of the blister test in the presence of tensile residual stress," *Int J Solids Struct*, 2005 May, 42 (9-10): 2771–2784.
3. KT Wan, "A novel blister test to investigate thin film delamination at elevated temperature," *Int J Adhes Adhes* 2001 Apr, 20 (2): 141-143.
4. S Julien, KT Wan, "An investigation of delamination in the shaft-loaded blister test." Future publication.

Acknowledgements

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