The Effect of Aging on the Stiffness of Ethylene Vinyl Acetate

Vi Le, Fernando Novoa, Professor Reinhold Dauskardt
Materials Science and Engineering, Stanford University

Introduction

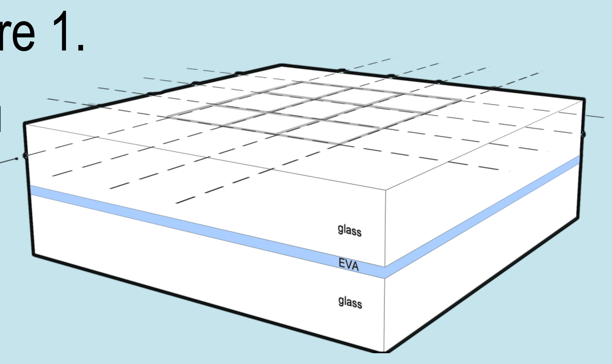
Preservation of the mechanical integrity of the encapsulation materials used in photovoltaic (PV) modules, such as Ethylene Vinyl Acetate (EVA), is essential to maintaining the long-term reliability of PV applications. The effects of short-term aging under aggressive laboratory environments (high temperature, high humidity) on the properties of EVA have been previously documented [1-3]. However, the influence of long-term aging on the mechanical properties of EVA have barely been explored.

In this study, we determine the change in the Young's Modulus of an EVA film after 1-year aging in a laboratory environment (25C, 40%RH). We also report the mechanical stress developed in the EVA film during cyclical strain. The encapsulation specimens were prepared by laminating a film of EVA between two glass substrates. The mechanical compliance of the testing apparatus was taken into consideration for the strain measurements.

Materials & Methods

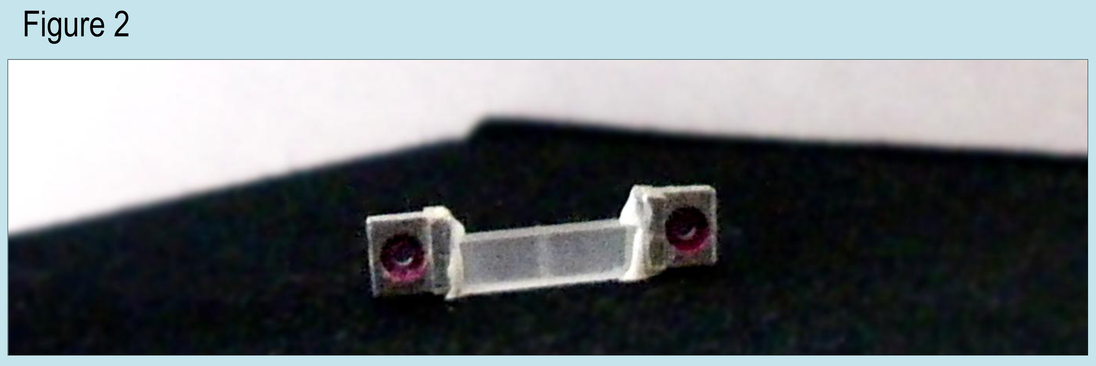
Encapsulation specimens were prepared by bonding a 500-micron film of EVA (Ethylene Vinyl Acetate) between two 0.006m glass substrates. One set of specimens was left to age for one year at room temperature while the other set was tested immediately after lamination. Small square specimens, 3.4 mm by 3.4 mm by 12.5 mm, were then cut from the center with a high-precision glass saw as shown in Figure 1.

Figure 1



Loading tabs were attached with a high-shear epoxy to both sides of each specimen (Figure 2). The loading tab was fixed to a mechanical testing system consisting of a displacement-controlled actuator and a mechanical load cell.

Figure 2

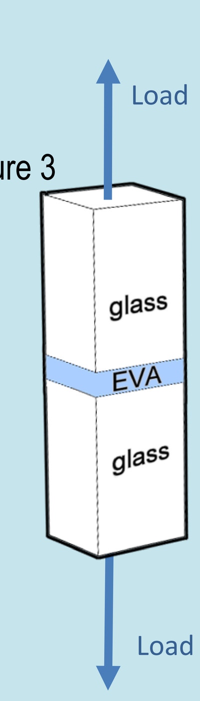


The experiments were conducted in an environmental chamber of controlled temperature and relative humidity (RH). The testing system and the specimen were stabilized for 30 minutes to reach thermal equilibrium before the mechanical test.

The developed mechanical load (Figure 3) was measured as the actuator position oscillated between 0.02 and 5.00 microns at 0.05 microns/sec in a triangle wave.

The experiment was conducted at five selected temperatures of 30˚C, 40˚C, 50˚C, 60˚C, and 80˚C. The relative Humidity was kept constant at 40%.

Figure 3



Materials & Methods

The mechanical compliance of the tensile specimens was measured:

$$C = \frac{\Delta x}{\Delta f}$$

where C is the compliance, Δx is the change in position, and Δf is the change in force

It is important to note, that during the experiment, not only did the EVA film was strained, but the rest of the specimen (the glass, epoxy, tabs) and the testing apparatus strained as well. To account for this artifact, a tensile specimen, consisting of a very stiff epoxy instead of the EVA film (otherwise identical to the previous specimens), was prepared to measure its mechanical compliance, defined as $C_{machine}$

The compliance of the EVA film, C_{EVA}, can be calculated with

$$C_{EVA} = C - C_{machine}$$

In order to compare the aged and new specimens, the Young's Modulus, which describes the stiffness of materials, was measured:

$$E_{EVA} = \frac{\sigma}{\varepsilon}$$

Where E is the Young's Modulus, and respectively, σ and ε is tensile stress and tensile strain, also defined by:

$$\sigma = \frac{\Delta f}{A}$$

$$\varepsilon = \frac{\Delta x}{L}$$

Where, Δf is the change in force, A is the cross-section of the tensile specimen, Δx is the change in thickness of the EVA film, and L is the original length of the film. The Young's Modulus can be finally expressed as:

$$E_{EVA} = \frac{\frac{\Delta f}{A}}{\frac{\Delta x}{L}}$$

$$E_{EVA} = \frac{\Delta f \cdot L}{\Delta x \cdot A}$$

$$E_{EVA} = \frac{L}{C_{EVA} \cdot A}$$

Results

Figure 4

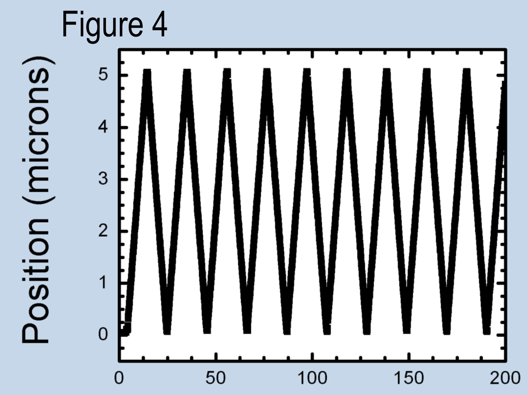


Figure 4: Position (microns) vs. time (sec) of a mechanical test of a new tensile specimen at 50˚C over 10 cycles

The change in position was set to 4.98 microns throughout.

Figure 5

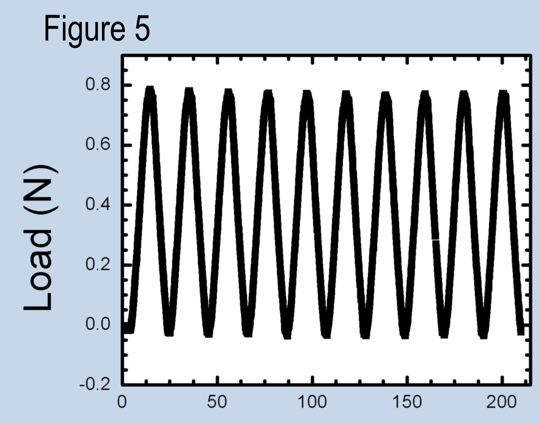


Figure 5: Load(N) vs. time (sec) of a mechanical test of a new tensile specimen at 50˚C over 10 cycles

The change in load remains at approximately 0.825 N.

Results

Figure 6

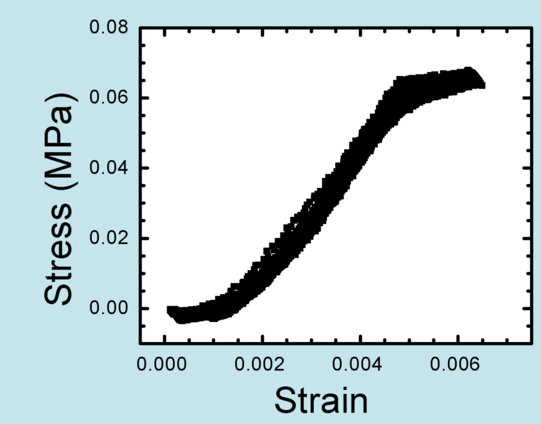


Figure 6: Stress (MPa) vs. strain of new tensile specimen at 50˚C and 40% RH. The slope of the graph represents the Young's modulus.

Figure 7

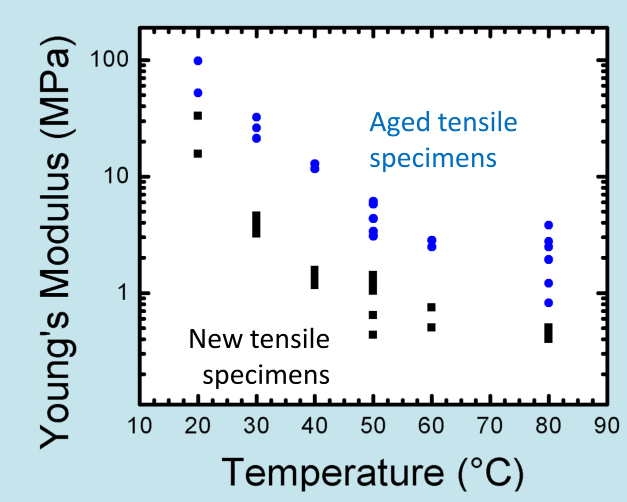


Figure 7: Young's Modulus (MPa) vs. temperature of aged and new tensile specimens. At lower temperatures, both specimens have a high Young's Modulus which then decreases exponentially with temperature. Both the Young's Modulus of the aged and new specimens have the same slope from 20˚C to approximately 50˚C. The plateau, the region where the graph is constant, begins at approximately 50˚C. Overall, aging of 1-year at 20C and 40% RH increased the stiffness of the EVA ~10 fold at every temperature.

Conclusion

- Tensile encapsulation specimens, prepared by laminating an EVA film between two glass substrates, were mechanically tested
- The mechanical stress developed in the EVA film was measured with the mechanical compliance of the testing apparatus considered.
- The Young's Modulus of the EVA was measured in aged (1-year) and new specimens. The modulus was higher in the new tensile specimens (~10 fold) for all the temperatures in range.
- The transition temperatures for aged and new EVA specimens were the same, showing that aging increases EVA stiffness but does not affect its the temperature dependence.

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References

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