APPLICATION NOTE

Differential Scanning Calorimetry

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Curing Determination of EVA for Solar Panel Application by DSC

Introduction

Renewable energy has attracted a lot of interest due to the limited supply of coal and oil and the environmental concern of carbon dioxide (CO_2) emission. There are many different forms of renewable (green) energy including: solar, wind, geothermal, biomass, and so on. Among them, solar energy is the fastest-growing segment. Increasing manufacturing capacity and decreasing product costs have led to significant growth in the solar industry over the past several years. For instance, solar photovoltaic (PV) production has been increasing by an average of 48% each year since 2002. By the end of 2008, the cumulative PV installation reached more than 15 giga-watts globally.

A solar cell is a device that can convert sunlight directly into electricity. Different solar-cell technologies including crystalline silicon, organic photovoltaics, and dye-sensitized solar cells have been developed for various solar-cell applications. Currently, the most widely commercially available solar cell is based on crystalline-silicon technology. This technology is mature compared with the other solar-cell technologies and its energy-conversion efficiency is high.

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A photovoltaic module or system consists of many jointly connected solar cells. The solar cells are packaged between a backsheet on the bottom and a tempered-glass window on the top. The cells are encapsulated by a polymer encapsulant (Figure 1). The polymer encapsulant serves many functions – it provides mechanical support, electrical isolation, and protection against outdoor environmental elements of moisture, UV radiation and temperature stress. Many different materials can be used for encapsulation, but one commonly used encapsulant for this purpose is EVA (ethylene-vinyl-acetate).

EVA, a thermal-set material, is a copolymer elastomer supplied in sheet form for use in the encapsulation of PV modules. It has many desirable properties which make it the material of choice for this application.

- It is not adhesive at room temperature for easy handling.
- It makes a permanent and adhesive tight seal in the solar-cell system through crosslinking and enhanced bonding when the film is heated and pressed.
- After crosslinking, the EVA has high optical transmittance, good adhesion to the different module materials – it provides good dielectric properties and great moisture-barrier properties with adequate mechanical compliance to accommodate system thermal stresses due to the different thermal-expansion coefficiencies.

During the PV-package process, the EVA sheet is placed between the solar cells and the backsheet/glass. It is heated, pressed into place, and cured at a certain high temperature for some time. Since the final cured material's properties are largely dependent on the curing degree, it is important to know the degree of curing of the EVA so that the encapsulation process is optimized. Differential scanning calorimetry (DSC) has been traditionally used for curing studies of thermoset resins. DSC can study the degree of cure and curing kinetics. In this note, different EVA materials with different curing times were investigated with PerkinElmer's high-end DSC 8000.

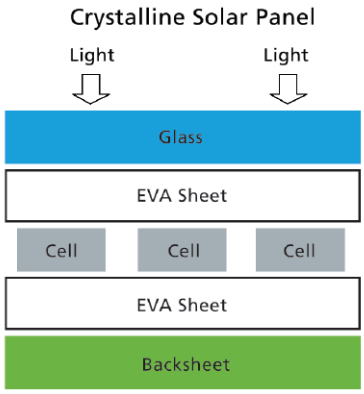

Figure 1. Scheme of a crystalline solar panel.

Experimental

The instrument used here is the PerkinElmer® double-furnace DSC 8000. It features power-controlled design for direct and accurate heat-flow measurements to and from the sample material. The cooling accessory is an Intracooler 2P mechanical refrigerator. Nitrogen is used as the sample purge gas at 20 mL/min. The instrument was calibrated with two metal reference materials: indium and zinc were used for temperature calibration, and indium was used for heat of fusion for heat-flow calibration. The EVA samples are from a solar PV manufacturer. They were cured at a high temperature and pressure for some time. Each EVA sample weighed approximately 10 mg. Each EVA sample cured at different times was encapsulated in the standard aluminum pans. The DSC program started from -50 °C and heated to 220 °C at 10 °C/min.

Results

The raw EVA material exhibits several transitions during heating, as shown in Figure 2 (Page 3). It was heated in the DSC from -50 °C to 220 °C at 10 °C/min, and after that it was cooled to the starting temperature quickly at 100 °C/min. It was heated for the second time at the same heating rate. The first heating curve shows an endothermic melting peak (26 J/g) followed by the exothermic curing peak with the curing enthalpy of 16.6 J/g. The second heating curve shows a glass transition (Tg) at -35.6 °C; the melting peak is smaller (12 J/g vs. 26 J/g) and there is no detectable curing exothermal peak. So by comparing the first heating curve with the second heating curve, it is clear that the EVA raw material is cured completely after first heating it up to 220 °C.

For a partially cured EVA sample, the residual curing peak during the first heating will be between the curing enthalpy of raw EVA material and zero for completely curing EVA. So the residual curing enthalpy can be used as an indicator of the curing degree of EVA material. A series of EVA samples with different curing time are studied by DSC and the results are shown in Figure 3 (Page 3). The calculated residual curing enthalpy is tabulated in Table 1 and fitted to a straight line in Figure 4 (Page 3). As can be seen, the residual curing enthalpy can be correlated to the curing time very nicely ($R^2 = 0.9893$).

Table 1. **Residual curing enthalpy of eight different EVA samples with different curing times.**

EVA samples	Curing Time (min)	ΔH (residual curing enthalpy J/g)
EVA-1	1	11.3572
EVA-2	2	10.7635
EVA-3	3	9.6878
EVA-4	4	7.9689
EVA-5	5	7.5885
EVA-6	6	6.7448
EVA-7	8	4.9335
EVA-8	9	3.9811

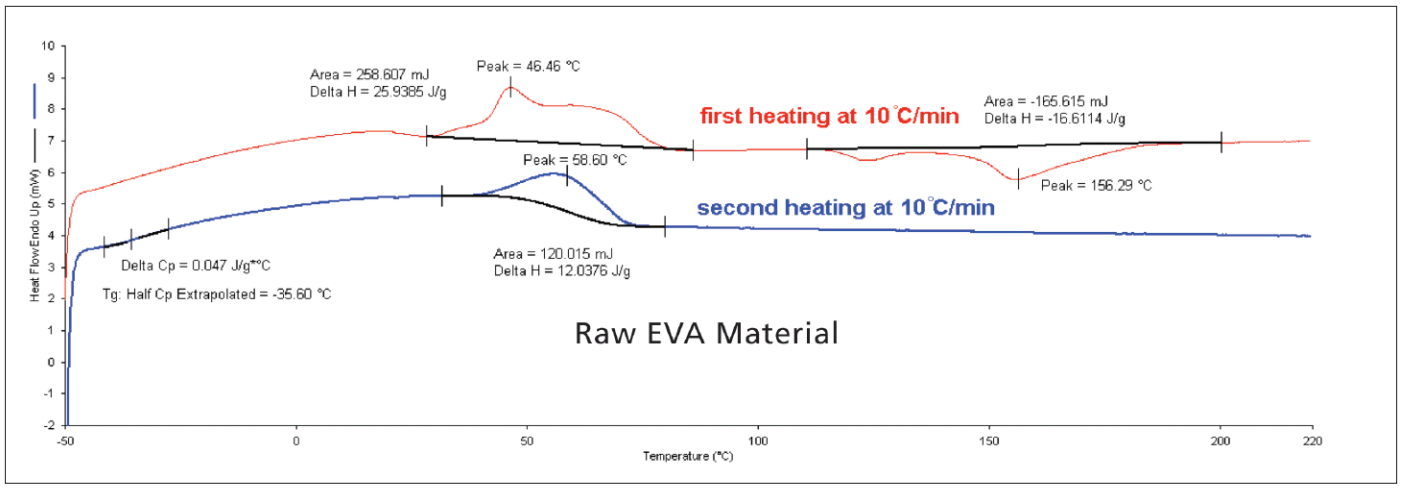

Figure 2. The first (red) and second (blue) heating curve of raw EVA material.

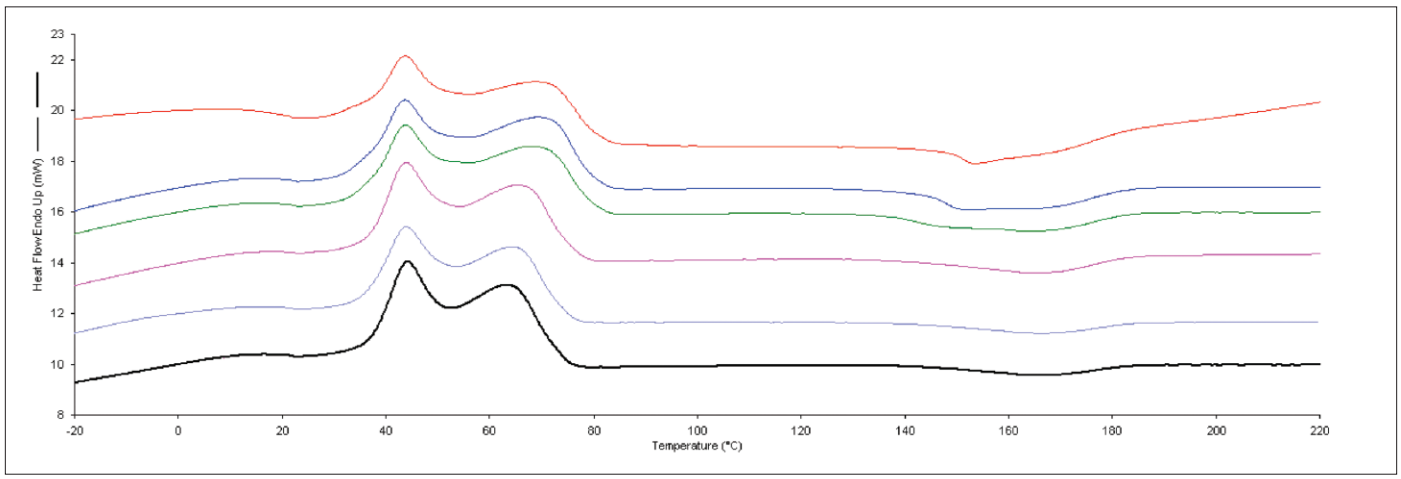

Figure 3. Partially cured EVA samples with different curing times.

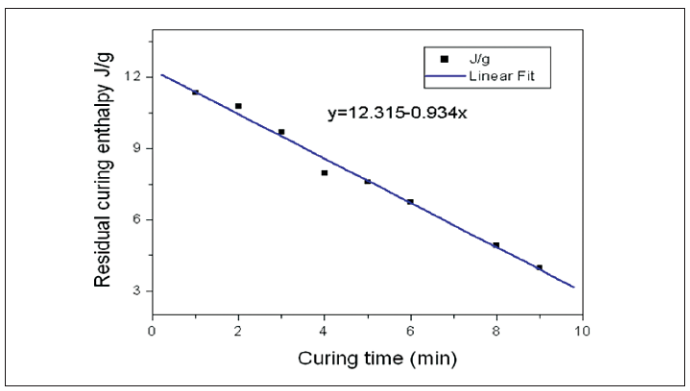

Figure 4. The relationship between residual-curing enthalpy and the curing time of the eight different EVA samples.

Conclusion

This study shows that DSC can be used to study the curing degree of the EVA resin by measuring the residual curing enthalpy. The data show that the residual curing enthalpy can be correlated to the curing time in a linear way. The DSC test is quick and easy. The double-furnace PerkinElmer DSC 8000 delivers accurate heat-flow data with great reproducibility. The power-controlled design ensures great accuracy and true isothermal measure so that it can be used for both scanning-curing and isothermal-curing studies of EVA resin.

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