

Adhesion Durability of Encapsulant-Glass Interface in Photovoltaic Module

Abstract:

PV modules are expected to work under prolonged (25-30 years) outdoor exposure with consistent power output. One of the important component in the PV module is the encapsulant material that embeds the cells and binds with glass and backsheet. Under outdoor exposure, water ingresses inside the module through multiple cycles of water absorption and desorption that degrades the encapsulant-glass interface. These degraded interfaces further allow more water inside the module and ultimately reduce the cell layers efficiency. Therefore, study of the degradation in the encapsulant-glass adhesion under hygrothermal exposure becomes important to assess the long-term performance of PV modules.

A correlation is missing between indoor ageing and water diffusion behaviour of the PV module that will help to predict outdoor degradation of the encapsulant-glass interface adhesion. In order to fill this gap, water diffusion studies were correlated with the accelerated PV module ageing studies using an exposure dose based model. The exposure dose is a single parameter that combines the exposure temperature, humidity, and time using an exponential relation that is governed by degradation activation energy.

An *in-situ* gravimetric method was used to characterize the water diffusion behavior of ethylene-vinyl acetate (EVA) encapsulant. Both water absorption and desorption in the EVA showed a simple Fickian behavior. The water diffusion and solubility coefficients determined from *in-situ* gravimetric experiments in the test range of 24° to 50°C reasonably fitted the Arrhenius rate equations with activation energy of 30.64 kJ/mol and heat of solution of -16.86 kJ/mol.

The backsheet was characterized considering it as a two-layer laminate. An optimization technique was applied to determine the water diffusion and solubility coefficients that minimized the difference between the numerical and experimental water mass uptake. The optimized water diffusion and solubility coefficients in the test range of 24° to 50°C reasonably fitted the Arrhenius rate equations. Backsheet was also considered as a homogeneous configuration that was used to determine the effective water diffusion parameters. These effective parameters were found to be significantly different from the optimized parameters of the two-layer backsheets model.

Peel tests were used to measure degradation in EVA-glass adhesion in PV module laminates that are aged under various constant temperatures and humidity environments. The degradation activation energy of 59.4 kJ/mol was identified by applying an optimization technique that fits an exponential relation between the degraded adhesion strength and exposure dose.

The exposure dose based model was finally used to predict the EVA-glass adhesion degradation for glass-glass and glass-backsheet based PV modules exposed to 5 years outdoor (Delhi, India), 1000 h damp heat, 10 cycle humidity freeze, and 200 cycle thermal cycling environments. The spatial and temporal distribution of relative humidity at the EVA-glass interface inside the PV module was predicted. This predicted humidity is used to estimate the exposure dose, which is further used to predict adhesion degradation. The highest degradation in all exposures occurs at the edge for the glass-glass module, whereas near the gap between cells for the glass-backsheet module. At locations close to the exposed boundary, the loss of adhesion is higher under the damp heat exposure (~57%) and lower under the humidity freeze (~16%) and thermal cycling (~1.4%) exposures compared to the outdoor exposure (~26%). The integrity of the interface near the exposed boundary can be quickly assessed by the damp heat exposure, but the integrity away from the boundary cannot be assessed by any of the accelerated exposures.