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Material behaviour

Influence of typical stabilizers on the aging behavior of EVA foils for photovoltaic applications during artificial UV-weathering

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ABSTRACT

Ethylene vinyl acetate copolymer (EVA) is the most commonly used embedding material in crystalline silicon photovoltaics. It is responsible for fixing module components, electrical isolation and protecting cells against mechanical and environmental stresses. The degradation of EVA during weathering can cause adhesion loss, the so called delamination, and yellowing of the foil, resulting in a drop of module efficiency. In order to improve the long-term stability, several stabilizers including UV-absorber, hindered amine light stabilizer and phosphite are added to the polymer. However, the exact influence of the different stabilizers on failure mechanisms has not yet been identified in detail. Therefore, different EVA foils containing variable additive formulations were exposed to artificial UV-irradiation at 50 °C. As a result, delayed EVA degradation could be observed depending on stabilizers added. On the other hand, some of the tested additives were found to be involved in delamination and yellowing processes.

1. Introduction

Photovoltaic (PV) module failures such as adhesion loss and yellowing arising during field exposure are not only an optical deficit or a blemish. Discoloration as well as delamination leads to reduced electrical power due to decreased cell efficiency [1] and optical coupling loss [2]. Both failures are correlated to the degradation of the encapsulation material during weathering.

The most commonly used embedding material for crystalline silicon (c-Si) photovoltaic (PV) modules is the copolymer ethylene vinyl acetate (EVA). The embedding material fixes the module components together, ensures electrical insulation and protects the cells against mechanical and environmental stresses [3]. During operation, PV modules are exposed to environmental influences which promote aging of the encapsulation material. The exposure of EVA to UV-irradiation causes photo-degradation as well as Norrish type I and II reactions, resulting in decomposition with chain scissions and formation of volatile products [3–5].

Several stabilizers are added to the polymer in order to reduce degradation and enhance long-term stability. The most important candidates are light stabilizers, prohibiting initiation of the photo-degradation reaction, and antioxidants which can interrupt chain breaking.

Module failures related to the degradation of the embedding material are reduced to a minimum by optimizing the composition of the stabilizers. However, failures are not completely eliminated [3,6]. In order to avoid

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delamination and yellowing in the future, detailed understanding of the failure mechanisms is important. Therefore, intensive research was done in recent years, mainly focused on yellowing. For a long time it was assumed that the photo-degradation of EVA leads to the formation of conjugated C=C-bonds by acetic acid elimination. These double bonds are thought to be the responsible chromophores for discoloration [7]. However, the fact that the detected amount of degradation products could not be correlated with the degree of yellowing leads to the assumption that stabilizers are involved in the yellowing process [8,9]. Phenomenological investigations indicate a relation between discoloration under UV-exposure and the presence of some additive mixtures in the polymer [6]. However, accurate understanding of the action mechanisms has not yet been realised. Furthermore, in most studies the impact of stabilizers on delamination is not taken into account.

Therefore, we analyzed the influence of typical stabilizers including UV-absorber, hindered amine light stabilizer and arylphosphite on the delamination and yellowing of EVA foils. For that purpose, 8 different EVA formulations with varying additive mixtures have been prepared and exposed to artificial UV-irradiation.

2. Material and methods

2.1. Material

Custom-made EVA foils with a vinyl acetate content of 33% and varying additive mixtures have been prepared. The corresponding mixtures are listed in Table 1.

All formulations contain a silane-based adhesion promoter and an organic peroxide, which is indispensable for cross-linking during the lamination process. Furthermore, the impact of benzophenone type UV-absorber (UVAbs), hindered amine light stabilizer (HALS) and arylphosphite (phosphite) was investigated.

2.2. Test specimen preparation and UV-weathering conditions

Test specimens were prepared by laminating EVA foils between two low-iron solar glass plates (glass-glass-laminates) or between a glass plate and a commercial multilayer backsheet (glass-BS-laminate) in a Meier Solar Solutions vacuum laminator Icolam 18/11 at 145 °C for 13 min. In addition, EVA foils without encapsulation were laminated.

Artificial UV-weathering was done using a similar procedure to that in DIN 61215 at 50 °C [10] using a Hönle UV-preconditioning system. The light intensity (UVA + UVB) was 250 W/m^2. The maximum UV-dosage of 138 kWh/m^2 corresponds to approximately 2.5 years of field exposure in Germany.

2.3. ATR-FTIR-spectroscopy

Infrared spectra were recorded in order to study chemical changes during UV-weathering. Due to the low IR transmittance of the specimens, we used the attenuated total reflectance (ATR) method. The spectra were measured with a Thermo Scientific FTIR spectrometer Nicolet is10 in the range between 4000–400 cm^{-1} with a resolution of 4 cm^{-1}. Diamond was used as ATR crystal.

2.4. Adhesion measurement

For adhesion measurements, a 90° peel test was used with a similar procedure to that in DIN 28510 [11]. Test specimens were strips (10*100 mm) cut out from the glass-BS-laminates. The laminate was fixed in the tensile testing machine, Zwick Roell Z005, operated with a crosshead speed of 50 mm/min. Adhesion was calculated as the quotient of the average peel strength between 20–80% of path and the width of the strip.

2.5. Color measurement

Color measurements were made on the glass-BS-laminates before the adhesion measurement. A spectral photometer ColorLite sph900 with a 45°/0° measuring geometry was used and an observer angle of 10° was chosen. To quantify the color change, the yellowness index (YI) was calculated according to DIN 6167 [12].

2.6. Transmission measurement

Transmission measurements were performed on the glass-glass-laminates. The spectra were collected with a Perkin Elmer UV/VIS-spectrometer lambda 950 in the

Table 1
Summery of a) the used EVA formulations (✓: included; ✗: not included) and b) the basic structures of the involved additives peroxide, silane, UV-absorber (UVAbs), hindered amine light stabilizer (HALS) and phosphite.

		Peroxide	Silane	UVAbs	HALS	Phosphite
a)	EVA 1	✓	✓	✗	✗	✗
	EVA 2	✓	✓	✓	✗	✗
	EVA 3	✓	✓	✗	✓	✗
	EVA 4	✓	✓	✓	✓	✗
	EVA 5	✓	✓	✗	✗	✓
	EVA 6	✓	✓	✓	✗	✓
	EVA 7	✓	✓	✗	✓	✓
	EVA 8	✓	✓	✓	✓	✓
b)	basic structures of the additives