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Development of Damp-Heat Resistant Self-Primed EVA and Non-EVA Encapsulant Formulations at NREL

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ABSTRACT

Self-primed ethylene-vinyl acetate (EVA) and non-EVA (PMG) encapsulant formulations were developed that have greater resistance to damp heat exposure at 85°C and 85% relative humidity (RH) (in terms of adhesion strength to glass substrates) than a commonly used commercial EVA product. The self-primed EVA formulations were developed on the basis of high-performing glass priming formulations that have previously proven to significantly enhance the adhesion strength of unprimed and primed EVA films on glass substrates during damp heat exposure. The PMG encapsulant formulations were based on an ethylene-methylacrylate copolymer containing glycidyl methacrylate.

1. Objectives

A major emphasis of our task has been to mitigate the damaging effects of moisture ingress on PV modules. The primary objective of this work is to develop self-primed encapsulant formulations that possess increased reliability against prolonged damp heat exposure at 85°C and 85%RH relative to present commercial EVA. The long-term goal is to obtain high-performance, reliable encapsulants that facilitate 30-year service lifetimes of commercial PV modules as specified in the long-term (2020) goal of the Solar Program Multi-Year Technical Plan.

2. Technical Approach

The unprimed and self-primed EVA and PMG were formulated differently and extruded into films. Effectiveness of some high-performing glass priming formulations was further tested in a reproducibility study. All the laminates were constructed with a constant configuration of AFG's Krystal Klear® glass/ encapsulant/TPE. The TPE is a trilayer film of Tedlar®/ polyester/EVA manufactured by Madico. A leading brand commercial fast-cure EVA (refers to as "X-EVA" or "control" hereafter) was used as a control reference for comparison. Details of the glass plate cleaning by concentrated acids, priming, lamination, damp heat exposures, 90-degree peel test of the TPE/EVA adhesion strength to the glass, and the algorithm for the statistical analysis were described previously.[1]

3. Results and Accomplishments

Delamination of encapsulant from glass substrate was often caused by the hydrolytic dissociation of the siloxane bonds at the interface between the polymer and glass in the presence of saturating moisture. To mitigate or minimize the hydrolytic dissociation, we employed three key concepts in formulating the glass primers and encapsulants. By using mixed silanes we sought to increase (1) surface hydrophobicity to exclude water molecules from the interfacial regions, (2) siloxane bonding density at the glass/EVA interface, and/or (3) cross-linking extent between the interfacial silanes and the EVA.[1]

3.1 Glass-Priming Solution Formulations

The glass-priming solution formulations could be divided into two major categories: one based on a methacrylate silane (Z-6030®) and one based on a vinylbenzyl silane (Z-6032®). The statistical results indicated that the adhesion enhancements provided by both of these primer solutions on X-EVA, which is already self-primed with Z-6030, were comparable, although individual formulation details would dictate some differences in effectiveness. Storage aging of the X-EVA was found to substantially reduce the adhesion strength. The *time-averaged peel strength* (TAPS) after 500-h damp heat exposure decreased from 7.17 N/mm for 1-month-old X-EVA to 2.83 N/mm for a 13-month-old EVA film on unprimed AFG KK glass. With glass priming, the 500-h TAPS varied from 4.18 N/mm to 6.13 N/mm for 13-mo X-EVA, depending on primer formulation. For sandblasted AFG KK glass, priming did not offer significant adhesion enhancement.

The effectiveness of glass priming was more obviously manifested with unprimed encapsulants that contained no silanes. The statistical results given in Table 1 compare the performance of unprimed and self-primed EVA developed in this work on unprimed and primed AFG KK glass substrates. Without priming, the unprimed EVA (JP-0) lost its adhesion strength largely in the first 100 h of damp heat exposure. For the glass substrates primed with Z6030-J, Z6030-C, and Z6032-B (ranked #1, 2, 3, respectively), the unprimed EVAs (JP0-1P, -2P, -3P) performed either equal to or better than the 1-mo X-EVA on unprimed glass substrates. By modifying the unprimed EVA with a special additive, the JP-0M EVA performed equally well with or without priming the glass substrates with Z6030-J formulation.

3.2 Self-Primed EVA and PMG Encapsulants

Four highest-performing glass-priming formulations were chosen and incorporated with some

Table 1. Performance Ranking of Unprimed and Self-Primed EVA Formulations on Acids-Cleaned AFG KK Glass

Rank	Sample ID, Specimen #	EVA Priming	Glass Primer ID	TAPS (N/mm)	ΔTAPS (N/mm)	Cum ΔTAPS	Cum ΔTAPS	Cum ΔTAPS	Cum ΔTAPS
1	JP2A	Self	No	9.27	0.79	2.09	0.98		
2	JP4	Self	No	8.48	0.10	1.31	0.20		
3	JP0-3P	No	Z6032-B	8.38	0.10	1.21	0.10		
4	JP4N	Self	No	8.28	0.21	1.11			
5	JP2B	Self	No	8.08	0.29	0.90			
6	JP5, 23A	Self	No	7.79	0.27	0.61			
7	JP0-2P	No	Z6030-C	7.51	0.34	0.34			
8	Control-4N	Self (1-mo)	No	7.17					
9	JP3	Self	No	6.94	-0.23	-0.23			
10	JP0-1P	No	Z6030-J	6.92	-0.02	-0.25			
11	JP0M	No	No	6.34	-0.58	-0.84			
12	JP0M-1P	No	Z6030-J	6.33	-0.01	-0.84			
13	JP3N	Self	No	6.31	-0.02	-0.87			
14	JP1A	Self	No	5.87	-0.44	-1.31			
15	JP0	No	No	2.09	-3.78	-5.09	-3.78		
16	JP1C	Self	No	0.81	-1.28	-6.36	-5.06	-1.28	
17	JP1B	Self	No	0.55	-0.26	-6.63	-5.32	-1.54	-0.26
18	JP1D	Self	No	0.25	-0.30	-6.93	-5.62	-1.84	-0.56
Combined Control (13-month old X-EVA)				2.83					
Statistical Analysis			$w = q_{1-\alpha}\, s_e / n^{1/2}$ =	0.905					

modifications into EVA films. These self-primed EVA films were tested on AFG KK glass substrates without priming. The statistical results comparing the self-primed EVAs, samples of which were 6 months old before being tested, with new and old X-EVA, are shown in Table 1. When compared with 1-mo X-EVA, only two self-primed EVA formulations, JP2 and JP4 (that incorporated glass priming formulations Z6032-B and Z6032-A, ranked #3 and #4, respectively), performed better statistically. For EVA-JP1, which incorporated #1-ranked Z6030-J primer formulation containing a fluorosilane, all four variations in formulation performed poorly with low initial adhesion strength. A possible reason is that the fluorosilane might have segregated to the EVA film surface possibly because of low solubility, resulting in a "release coating" at the interface between the EVA and glass.

The self-primed PMG encapsulants were formulated differently from those of self-primed EVAs and performed very well during damp heat tests. A 2.5-month old PMG sample gave a highest TAPS of 9.62 N/mm. The PMG formulations also exhibited storage aging effects. For 13 month-old samples, the PMG's TAPS degraded by ~19% to 7.35 N/mm and 7.78 N/mm. The 19% adhesion loss in TAPS from storage aging is considerably less than the 60% loss for X-EVA (7.17 N/mm at 1-mo versus 2.83 N/mm at 13-mo), suggesting a greater storage stability of the self-primed PMG. At the same aging state of 13-months old for both, the TAPS for unprimed PMG is essentially identical to that for self-primed X-EVA (2.89 N/mm vs. 2.83 N/mm) when laminated to unprimed AFG KK glass substrates. The presence of a special additive in the unprimed PMG formulation, like EVA-JP0M, allowed a higher performance (TAPS = 8.01 N/mm) than without the additive (TAPS = 2.89). The unprimed PMG appeared little affected by 13-month storage. In general, PMG formulations performed much better than X-EVA in the damp heat tests.

4. Conclusions

High-performance damp heat-resistant, self-primed EVA and PMG encapsulant formulations have been developed at NREL and shown to perform better than a commercial self-primed EVA. More details of this work will be presented elsewhere. Optimization of the self-primed EVA and PMG encapsulant formulations are currently underway.

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[1] F. J. Pern, and G. J. Jorgensen, "Enhanced Adhesion of EVA Laminates to Primed Glass Substrates Subjected to Damp Heat Exposure," *Proc. 31st IEEE PVSC*, Lake Buena Vista, Florida, January 3–7, 2005, National Renewable Energy Laboratory, Golden, CO, 2003. NREL/CP-520-37391, 7 p. Web Link: http://www.nrel.gov/docs/fy05osti/37391.pdf

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