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Adhesion Strength Study of EVA Encapsulants on Glass Substrates

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3.2.3. Effects of Glass Type, Surface Cleaning, Treatments, and Textures

Table 3 shows the effects of glass type, surface texture, cleaning method, and priming treatment on EVA adhesion. For borosilicate glass plates, cleaning methods by IPA, sulfuric chromic acid, 2.0 N NaOH soaking, and Liqui-Nox,™ followed by no priming or by 2% Z-6030 priming, did not appear to make a significant difference in the EVA/boro adhesion strengths, which were in the 7 ± ~1 N/mm range. Similar results were obtained (6~7 N/mm) for 1/16"-thick soda lime microslide plates.

Table 3. Effects of Glass Type, Cleaning Method, Surface Treatment, and Texture on the Adhesion Strength of Glass/15295P/ M-TPT Laminates Using 90-Degree-Pull

Glass Type (1/8" thick)	Plate Size (in.x in.)	Cleaning Method	Surface Priming	Max. Ad. Strength (N/mm)
Boro	1 x 3	IPA		6.44
Boro	1 x 3	IPA	Z-6030	6.74
Boro	1 x 3	IPA	PECMA	5.14
Boro	1 x 3	IPA/Chrom Acid	Primer C	6.21
Boro	1 x 3	Chromic Acid	Z-6030	6.88
Boro	1 x 3	2.0 N NaOH	Z-6030	6.51
Boro	2 x 3	Liqui-Nox		8.07, 6.02
Boro	2 x 3	Liqui-Nox	Primer-F	5.59, 5.67
Boro	2 x 3	Liqui-Nox	Primer-G	3.74, 5.04
Boro	2 x 3	Liqui-Nox	Primer-H	1.05, 0.88
AFG KK	2 x 3	Liqui-Nox		5.54
AFG KK	2 x 3	Liqui-Nox	Silq. A187	1.69
AFG KK	2 x 3	Liqui-Nox	Primer A	4.64
AFG KK	2 x 3	Liqui-Nox	Z-6030	5.54
AFG KK	1 x 3	Liqui-Nox		4.52
AFG Solatex	1 x 3	Liqui-Nox		4.88
AFG Solite	1 x 3	Liqui-Nox		4.61
Starphire	2 x 3	Liqui-Nox		7.00
Solarphire	2 x 3	Liqui-Nox		7.57
Microslide	1 x 3	IPA	(1/16"-thick)	6.30
Microslide	1 x 3	IPA	Z-6030	6.92
Microslide	1 x 3	IPA	Primer C	5.86

Surface priming of the borosilicate glass surfaces by dipping 2~3 min in custom-formulated solutions (PECMA, and Primers-C, F, G, and H), followed by IPA rinsing and oven heating at 85°C for ~15 min, could affect strongly the EVA adhesion, depending on the primer solution's formulation. Therefore, the surface affinity properties for EVA, which involve siloxane and hydrogen bonding and cross-linking through the Z-6030 silane, appear to be critical. Use of additional molecular mathacrylate-type cross-linkers in Primer G and H seems to "block" the typical siloxane and cross-linking between the glass and EVA. This was also observed for the AFG-KK glass that was directly primed with a Silquest A-187™ 3-glycidoxypropyltrimethoxysilane, whereas priming with Z-6030 or Primer A made no or little difference. The test results with AFG's cerium oxide-doped glasses–plain Krystal Klear™, mildly textured Solatex II™, and pyramid-textured Solite™–show that the EVA adhesion strength appears to be insensitive to the surface texture, which is likely a consequence of the soft, semi-elastic EVA film as discussed above. EVA adhesion to the PPG's Starphire™ and CeO_x-doped Solarphire™ was similar to the borosilicate glass, but stronger than AFG's soda-lime glasses.

3.3. Weak Adhesion of Fluoropolymer Thin Films

Adhesion of three fluoropolymer thin films to EVA and/or glass surfaces was also studied. Tefzel™ films have been used for years as superstrates for thin-film a-Si PV modules, and Dureflex™ and Dyneon's THV films (both based on Dyneon's THV220™ fluorinated terpolymer) have been tried recently as super- or substrates or even to replace entirely the EVA/Tefzel combination [6]. The results indicate all three films bonded weakly to the EVA at a level of ~1.3 N/mm for the Tezel and Dureflex, and ~2.6 N/mm for the 3-mil THV film. The adhesion of Dureflex film to a cleaned glass surface was very low at ~0.4 N/mm.

4. Conclusions

The extensive adhesion strength study has clearly demonstrated that the apparent adhesion strength of EVA/backfoil to glass substrates is affected by a number of factors, which include EVA type, formulation, backfoil type and manufacturing source, glass type, and surface priming treatment on the glass surface or on the backfoil. The results indicate that the adhesion test is critically dependent on the use of a mechanically "strong enough" backing foil on the EVA to achieve a meaningful peel test. The peel-test method with a 90-degree-pull yielded similar results to a 180-degree-pull. Effects of the glass-cleaning method and surface texture are not obvious. Fluoropolymer thin films show low adhesion to the EVA or glass. Based on our results and observations, we conclude that the adhesion strengths derived from the peel tests are comparative at best. In addition, it is recommended that all relevant conditions and materials information be clearly specified when an adhesion strength is cited or reported. More details will be presented in the Review Meeting.

5. Acknowledgement

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REFERENCES

[1] A. W. Czanderna and F. J. Pern, "Encapsulation of PV Modules using Ethylene Vinyl Acetate Copolymer as a Pottant: A Critical Review," *Solar Energy Materials and Solar Cells*, **43** (1996) 101-183.

[2] R.T. Tucker, "Primers and Adhesion," *Proc. of First Thin-Film Module Reliability National Team Meeting*, Sept. 4-5, 2002, at NREL, Golden, CO.

[3] G. Jorgensen, K. Terwilliger, G. Barber, S. Glick, and T. McMahon, *Proc. of First Thin-Film Module Reliability National Team Meeting*, Sept. 4-5, 2002, Golden, CO..

[4] S.H. Glick, F.J. Pern, G.L. Watson, D. Tomek, J. Raaff, "Performance Degradation Of Encapsulated Monocrystalline-Si Solar Cells Upon Accelerated Weathering Exposures," *Proc. of 2001 NCPV Program Review Meeting*, Oct. 2001, Lakewood, CO, pp. 307-308.

[5] F.J. Pern, unpublished results.

[6] Sample films were provided for testing by S.B. Levi of Clear Solutions, a representative of the respective companies.

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13. ABSTRACT *(Maximum 200 words)*

An extensive peel-test study was conducted to investigate the various factors that may affect the adhesion strength of photovoltaic module encapsulants, primarily ethylene-vinyl acetate (EVA), on glass substrates of various laminates based on a common configuration of glass/encapsulant/backfoil. The results show that "pure" or "absolute" adhesion strength of EVA-to-glass was very difficult to obtain because of tensile deformation of the soft, semi-elastic EVA layer upon pulling. A mechanically "strong enough" backing foil on the EVA was critical to achieving the "apparent" adhesion strength. Peel test method with a 90-degree-pull yielded similar results to a 180-degree-pull. The 90-degree-pull method better revealed the four stages of delamination failure of the EVA/backfoil layers. The adhesion strength is affected by a number of factors, which include EVA type, formulation, backfoil type and manufacturing source, glass type, and surface priming treatment on the glass surface or on the backfoil. Effects of the glass-cleaning method and surface texture are not obvious. Direct priming treatments used in the work did not improve, or even worsened, the adhesion. Aging of EVA by storage over ~5 years reduced notably the adhesion strength. Lower adhesion strengths were observed for the blank (unformulated) EVA and non-EVA copolymers, such as poly(ethylene-co-methacrylate) (PEMA) or poly(ethylene-co-butylacrylate) (PEBA). Their adhesion strengths increased if the copolymers were cross-linked. Transparent fluoropolymer superstrates such as TefzelTM and DureflexTM films used for thin-film PV modules showed low adhesion strengths to the EVA at a level of ~2 N/mm.

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