Trial-Run of a Junction-Box Attachment Test for Use in Photovoltaic Module Qualification

Preprint

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To be presented at the 40th IEEE Photovoltaic Specialists Conference (PVSC)
Denver, Colorado
June 8-13, 2014

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Conference Paper
NREL/CP-5200-61102
June 2014

Contract No. DE-AC36-08GO28308

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Trial-Run of a Junction-Box Attachment Test for Use in Photovoltaic Module Qualification

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***Abstract* — Engineering robust adhesion of the junction box (j-box) is a hurdle typically encountered by photovoltaic module manufacturers during product development and manufacturing process control. There are historical incidences of adverse effects (*e.g.*, fires) caused when the j-box/adhesive/module system has failed in the field. The addition of a weight to the j-box during the "damp-heat," "thermal-cycle," or "creep" tests within the IEC qualification protocol is proposed to verify the basic robustness of the adhesion system. The details of the proposed test are described, in addition to a trial-run of the test procedure. The described experiments examine four moisture-cured silicones, four foam tapes, and a hot-melt adhesive used in conjunction with glass, KPE, THV, and TPE substrates. For the purpose of validating the experiment, j-boxes were adhered to a substrate, loaded with a prescribed weight, and then subjected to aging. The replicate mock-modules were aged in an environmental chamber (at 85°C/85% relative humidity for 1000 hours; then 100°C/<10% relative humidity for 200 hours) or fielded in Golden (CO), Miami (FL), and Phoenix (AZ) for one year. Attachment strength tests, including pluck and shear test geometries, were also performed on smaller component specimens.**

***Index Terms* — photovoltaics, module qualification, polymer, junction-box attachment test.**

I. INTRODUCTION

Component adhesion relies on the system of attachment, which includes the component, adhesive(s), preparation of the adhered surfaces, and substrate. Historically, the system of adhesion for junction boxes (j-boxes) has proven an essential product detail for photovoltaic (PV) module manufacturers. The possible safety consequences of failure in the field for the j-box include electrical arcing and/or subsequent initiation of fire [1]. The detachment of the j-box also risks ingress of liquid water, subsequent corrosion, and the corresponding loss of performance. Possible failure mechanisms include: phase transformation, viscoelastic flow (creep), cohesive failure, and delamination [2]. Detachment of the j-box may also result from the degradation of the substrate (*e.g.*, delamination [3] or hydrolysis [4] of the backsheet).

We have recently proposed the addition of a weight to the j-box during the "damp-heat" [5],[6], "thermal-cycle" [5],[6], or "creep" [7] tests within the International Electrotechnical Commission (IEC) qualification protocols to verify the basic robustness of the adhesion system [8],[9]. The damp-heat test is performed at 85°C/85%RH for 1000 hours; thermal-cycle test is performed between -40°C and 85°C for 200 cycles; and the creep test is performed at 105°C for 200 hours. The weighted junction-box test is intended to query worst-case application conditions, which can approach 85°C and 105°C for rack- and roof-mounted modules, respectively, deployed in desert locations [8].

The attachment test is intended to emulate prolonged but intermittent wind, snow, or external (*e.g.*, animal) loads in installations with limited cable management (routing trays and cable ties). The typical combined weight of the cable and connector components is ~0.2 kg. A 4x margin of safety might be applied for the test to account for combined adverse loads in addition to the relatively short duration of the test. In the proposed test, [8],[9], a weight is attached to the sealed j-box, using wires, clips, or similar methods, to achieve attachment. The proposed attachment test would be performed with modules oriented upright to facilitate the maximum packing density in an environmental chamber. In this configuration, the test typically renders an applied shear load, with possible minor out-of-plane strain (depending on the attachment scheme).

Previous module-level experiments focused on the choice of weight for the test [8],[9]. A 0.5- or 0.9-kg weight was recommended for further study, based on the results and the application requirements. Previous material-level characterizations—including thermo-gravimetric analysis, differential scanning calorimetry (DSC), and dynamic mechanical analysis—were used to interpret the results (failure modes) for the

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representative materials examined in Refs. [8],[9]. The merits of each type of adhesive, as well as known-durable and known-incompatible attachment systems (substrate/adhesive/j-box), were also examined in Refs. [8],[9].

The goal of the study here is to validate the proposed test, by comparing the results of indoor- and field-aging. Representative test specimens including nine adhesives were used in conjunction with four types of substrates. The replicate mock-module specimens were aged in an environmental chamber (including the damp-heat and creep tests) or fielded in Golden (CO), Miami (FL), and Phoenix (AZ). Attachment strength testing, including pluck and shear test geometries, was performed on smaller component specimens. Recommendations for the test, including the choice of a 1-kg weight as well as the use of multiple indoor aging conditions, follow from the results of the present study.

II. EXPERIMENTAL

As shown in Figure 1, a series of mock modules was constructed, similar to Refs. [8],[9]. Commercial j-boxes (including a four-rail component used in silicon modules or a two-rail component used in thin-film modules) were attached to a glass, KPE , THV, or TPE substrate.

KPE Multiguard (FLEXcon Company Inc.) consists of a laminate of: polyvinylidene fluoride (PVDF "Kynar" film, manufactured by Arkema Inc.); polyethylene terephthalate (PET); and ethylene-co-vinyl acetate (EVA). THV consists of a laminate of: tetrafluoroethylene, hexafluoropropylene, and vinylidene fluoride (THV); PET; and EVA. TPE consists of a laminate of: polyvinyl fluoride (PVF, "Tedlar"), polyester, and EVA. In the backsheet materials, the PVDF, THV, and PVF layers face the environment.

Each j-box was attached with a single adhesive, *i.e.*, one of: four silicones; four foam tapes; or a polyolefin (PO) hot-melt adhesive. The silicones all consisted of two-part moisture-cure schemes, including: acetoxy (Sn catalyzed), two types of alkoxy (Ti catalyzed), and oxime (Sn catalyzed) formulations. The alkoxy silicones include one recent, high green-strength formulation. The foam tapes included: polyethylene (PE), polyurethane (PU), and two acrylic formulations. The PE and PU tapes consisted of two thin adhesive layers on a thick core layer, whereas the acrylic tapes were monolithic. Regarding the acrylic tapes, the 2110 and 4110 Solar Acrylic Foam Tape (SAFT, 3M Company) products were examined, respecitvely. A 0-, 0.5-, or 0.9-kg weight was attached to each of the replicate j-boxes. A silicone rubber trim (P/N 4869A3, McMaster-Carr Supply Co.) was attached at the module periphery using one of the silicone adhesives to prevent fracture of the glass layer. Figure 1 shows one of the module specimens at the end of the damp-heat test. The figure includes the fiberglass channel (P/N 3261T, McMaster-Carr Supply Co.) frame that was used to hold the modules upright in the chamber. Additional channel was also used to construct a tray to deflect detached specimens.

Figure 1: Representative specimen, constructed for the trial-run, photographed after completing the "damp-heat" indoor aging. The deflector tray used to protect the second (lower) row of specimens is labeled.

Indoor aging was performed using a "WITR" test chamber [SPX Corp. (Thermal Product Solutions Division)], programmed for damp-heat followed by the creep test. Replicate modules were simultaneously fielded in Golden, Miami, and Phoenix for one year. All fielded modules were rack mounted at 45°. The front glass surface of the fielded modules was painted with a black primer (P/N 245198, Rust-Oleum Corp.), with a measured absorptance similar to that of a PV module [10]. The mock modules were not producing electricity, and therefore may reach a slightly greater temperature than rack mounted PV. The temperature of the modules in Miami and Phoenix (for one of each type of substrate) was monitored using a T-type thermocouple. Additional thermography was performed on the specimens fielded in Golden using an infrared camera (ThermaCAM SC640, FLIR Systems Inc.). The camera, which operates at wavelengths from 7.5 to 13 μm, is capable of resolving temperature to within 0.06°C.

Adhesion strength tests were performed using a 5500R loadframe (Instron Corp.) equipped with a 5-kN loadcell (P/N A217-17, Instron Corp). Similar to ISO 4587 [11] and ISO 6922 [12], respectively, shear and pluck tests were performed using an aluminum /adhesive/glass geometry. A 25-mm x 25-mm x 1-mm adhesive specimen size was examined for one of the tape and one of the silicone materials. Crosshead speeds of 0.1, 1, 10, 100, and 1000 mm·min^{-1} were used for sets of five replicate specimens. Elongation was

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taken as the crosshead extension, which was not compensated to account for machine or fixture compliance.

III. FIELD TEST CONDITIONS

Temperature conditions for the field experiments are summarized in Table I. Among the sites, Phoenix has the greatest maximum temperature, Miami the greatest relative humidity, and Golden the greatest range in temperature (including the lowest minimum temperature). None of the fielded mock modules achieved a temperature of 85°C (the record maximum anticipated for a rack-mounted module in Phoenix). None of the sites achieved the average ambient relative humidity of 85%. Furthermore, the humidity in a module (operating at an elevated temperature) would be significantly lower than the field ambient.

Table I: Summary of the ambient and module temperature conditions. The average, maximum, and minimum temperatures; average relative humidity; and average and maximum wind speed are provided for the 1-year deployment period (conditions including both day and night).

LOCATION	MEASURAND	T_{avg} {°C}	T_{max} {°C}	T_{min} {°C}	RH_{avg} {%}	w_{avg} {m·s^{-1}}	w_{max} {m·s^{-1}}
Golden	ambient	12.9	36.4	-18.1	42.0	2.0	17.2
Miami	ambient	23.8	36.8	4.2	74.8	2.4	15.0
Phoenix	ambient	22.7	45.8	-3.4	32.2	3.0	13.7
Miami	module	28.5	74.0	0.0	N/A	N/A	N/A
Phoenix	module	28.4	78.3	-6.5	N/A	N/A	N/A

In a recent study [10], temperature data were also obtained using a thin-film T-type thermocouple taped to the back of PV modules. In that study, an ~15°C range was found to exist across a module, from a center location to the frame. Furthermore, a T_{max} of 105°C was measured for roof-mounted modules in Phoenix. Models as in Ref. [13] allow the module temperature to be estimated from the meteorological conditions. The King model suggests that the T_{max} of 110°C may be briefly achieved for roof-mounted modules during record hot weather (55°C ambient) in Riyadh, Saudi Arabia. Roof-mounted modules are generally ~15°C warmer than rack-mounted modules [10],[13],[14].

The module temperature measurements in Table I were obtained near the center of the mock modules using thermocouples, attached to the backsheet surface in an open area between j-boxes. The temperature on the backsheet is typically 1°–2°C cooler than the cell temperature [15], *i.e.*, the temperature typically represented in models [10],[13],[14]. Thermography was performed on the specimens fielded in Golden on one of the hottest days in July, 2013. In the field, the j-box is typically hotter than the module interior. For the specimens in Golden, thermography identified that the j-box was ~5°C hotter than the module interior.

IV. RESULTS OF THE TRAIL-RUN

The results of the trial-run experiment are summarized in Table IV, Table V, Table VI, and Table VII for the indoor-aged and field-deployed (Miami, Phoenix, and Golden) specimens, respectively. In the event of failure (colored yellow), the failure mode, time at failure, and failure interface are identified in the tables. "N.F." (colored gray) indicates that no failure occurred during the experiment. 108 specimens were examined at each of the four locations. A total of 66 failures occur within the tables.

Regarding delamination of the PO melt, 46 failures occurred at melt/j-box interface, whereas 10 failures occurred at the substrate/melt interface (on either glass or TPE substrates). In the case of glass and TPE substrates, failure at the melt/j-box interface occurred indoors, whereas failure at the glass/melt was common outdoors. Delamination at the TPE/melt interface occurred for samples with no weight after an extended duration only in Phoenix and Golden. When a weight was used, failure always occurred at the melt/j-box interface. This may suggest that the glass and TPE substrates are weaker adhering to the PO melt or are adversely affected in the environment with age. Prior DSC characterization of the PO melt [8],[9] identified the melting temperature of 81°C, which also likely affects its attachment in the trial-run experiment.

Regarding delamination of the PE foam tape, all 17 failures occurred at the surface/core interface. This is consistent with the discovery experiments, where delamination was also observed for both the PE and PU tapes at the surface/core interface. DSC characterization of the PE tape [8],[9] identified the melting temperature of 51°C, which also likely affects its attachment in the trial-run experiment.

The PE and PU foam tapes each demonstrated one creep failure. These two failures, which included combined rotation and displacement, were observed for the indoor damp-heat test only. The melt temperature of 51°C and glass transition temperature of -26°C were observed for the PE and PU tapes, respectively. The results of the discovery experiments and trial-run may suggest that the lesser melt temperatures apply to the adhesive surface layer of the PE and PU tapes. One creep failure was observed for PO melt. In this case, the unweighted j-box was displaced to the bottom of the substrate during the indoor damp-heat test only.

Regarding the indoor chamber results, most failures in damp-heat occurred quickly, *i.e.*, <1 day. The sustained combination of high humidity and high temperature present in damp-heat motivates failure. Additional failures, corresponding to the field results, occurred during the subsequent creep test. This

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suggests that the weighted j-box test should be applied during the creep test, in addition to the damp-heat and/or thermal-cycle tests. Finally, there are several instances in Table IV, Table V, Table VI, and Table VII where the PE tape delaminated with weights present, but not always without a weight. This suggests that a weight is required to adequately assess the system during the test. Within PV installations, there will likely be conditions where additional mechanical stress is applied to a j-box.

Regarding the field results, the most failures occurred in Miami. The results for the damp-heat test, including the number of failures and time to failure for the PE tape, exceeded the field results in Miami. This is attributed to the sustained moisture present, which in Table I is greater in the damp-heat test condition than in the Miami climate.

The results in Table VI and Table VII may be used to compare between Phoenix and Golden. Failures were typically observed sooner for the PO melt in Phoenix. As might be expected, the creep test is therefore better correlated to the field results in Phoenix, the climate for which the creep test was prescribed [10]. One additional delamination is observed for the PE tape in Golden. This may suggest that the greater humidity and/or range of temperature present in Golden may query adhesion better than the climate in Phoenix.

Regarding a comparison of the field and indoor test results, the PO melt and PE tape were consistently identified as the weakest systems. A good correspondence between failures, including the mode types and the specific system of materials affected, was observed between the indoor- and field-test results. A few discrepancies, however, were observed, including the duration to failure (more rapid in the indoor tests), failure modes (creep failure for PE tape and PU tape, observed only in the indoor test), and interfaces of failure (delamination at the adhesive/j-box interface vs. adhesive/substrate interface for the PO melt). In the case of test duration, the indoor tests occur at a greater temperature (facilitating degradation) than the majority of field ambient conditions, summarized in Table I. The results for weaker attachment systems were often similar, but the 0.9-kg weight sometimes motivated detachment when the 0.5-kg weight did not. Therefore, regarding the weight used during the test, a 1-kg weight is recommended to more rigorously examine the attachment system.

V. Attachment Strength Results

The results of attachment strength characterization are summarized in Table II and Table III for an acrylic tape and an alkoxy silicone adhesive. Quantities in the table include: the force, F; elongation, δ; test duration, t; mechanical stress, σ; and mechanical strain, ε. The maximum value of each parameter is given in the tables, which often corresponds to the measurement at the instant of failure. The average and standard deviation (S.D.) (±1) are given for five replicates at each test rate.

Table II: Results of the adhesion strength characterization for the adhesion strength characterization (overlap-shear test) for acrylic foam tape (acrylic #2) and alkoxy silicone (with Ti catalyst) specimens.

MATERIAL	CROSSHEAD SPEED {mm·min^{-1}}	F_{max} {N}	δ_{max} {mm}	t_{max} {s}	σ_{max} {MPa}	ε_{max} {mm·mm^{-1}}
tape	1000	1373±48	9.3±0.2	0.6±0.0	2.20±0.08	8.4±0.2
tape	100	773±84	10.5±1.0	6.3±0.7	1.24±0.13	9.5±0.9
tape	10	569±42	11.0±0.4	65.9±2.5	0.91±0.07	10.0±0.4
tape	1	429±23	10.3±0.2	617.6±15.0	0.69±0.04	9.4±0.2
tape	0.1	340±36	11.0±0.9	6,575.5±569.2	0.54±0.06	10.0±0.9
silicone	1000	992±50	7.4±0.6	0.4±0.0	1.59±0.08	7.4±0.6
silicone	100	794±29	7.4±1.0	4.4±0.7	1.27±0.05	9.5±0.9
silicone	10	665±51	8.2±1.2	49.1±7.1	1.06±0.08	8.2±1.2
silicone	1	610±46	8.2±0.6	495.2±38.2	0.98±0.07	8.2±0.6
silicone	0.1	503±26	8.0±0.9	4,825.2±529.7	0.80±0.04	8.0±0.9

Table III: Results of the adhesion strength characterization for the adhesion strength characterization (butt joint test) for acrylic foam tape (acrylic #2) and alkoxy silicone (with Ti catalyst) specimens.

MATERIAL	CROSSHEAD SPEED {mm·min^{-1}}	F_{max} {N}	δ_{max} {mm}	t_{max} {s}	σ_{max} {MPa}	ε_{max} {mm·mm^{-1}}
tape	1000	816±129	6.9±2.6	0.4±0.2	1.31±0.21	6.3±2.3
tape	100	639±44	4.8±0.7	2.9±0.4	1.02±0.07	4.3±0.6
tape	10	381±15	7.7±1.9	45.9±11.8	0.61±0.02	7.0±1.8
tape	1	306±22	5.6±0.8	338.7±50.5	0.49±0.03	5.1±0.8
tape	0.1	233±7	5.6±0.3	3,371.1±178.1	0.37±0.01	5.1±0.3
silicone	1000	1021±89	5.0±1.0	0.3±0.1	1.63±0.14	4.5±0.9
silicone	100	1037±99	4.9±0.5	2.9±0.3	1.66±0.16	4.5±0.4
silicone	10	957±63	5.8±1.6	34.0±10.0	1.53±0.10	5.3±1.4
silicone	1	796±52	5.6±1.0	333.7±58.1	1.27±0.08	5.1±0.9
silicone	0.1	738±36	4.8±0.9	2,907.0±512.4	1.18±0.06	4.4±0.8

Both types of material demonstrated substantial elongation (>4% strain) at failure. The acrylic tape demonstrated a strong rate dependence for attachment strength in both the lap-shear and pluck tests. Although a similar overt trend with test rate was not observed for the silicone, the strength was generally greater with speed. The greatest strength and corresponding elongation is observed for the tape in shear or silicone in tension.

Regarding differences between the materials and tests, the tape more often remained attached to the Al substrate, whereas the silicone remained attached nearly equally to the Al or glass. The area of the remaining attached tape typically reduced during test: in shear, the area was reduced down to one edge; in pluck, the area reduced down to one corner. The tape and silicone would both typically elongate in shear before delamination. The tape and silicone were both more prone to sudden delamination in the pluck test.

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The lap-shear and pluck tests examine strength and do not incorporate principles of fracture mechanics, *i.e*., they do not account for the fundamental physics of adhesion or its thermodynamic favorability. Although strength tests can be subject to specimen preparation, the attachment strength in Table II and Table III greatly exceeds the corresponding stress for the 0.9 kg j-box weights, ~5 kPa. The σ vs. ε results in Table II and Table III, however, are more akin to the "robustness of termination" test in Refs. [5],[6],[7], than to a sustained load that might be encountered in the field. It is the condition of a sustained load, which can facilitate detachment by severing bonds over time (even at loads below the maximum attachment strength) that is examined in the weighted j-box test.

VI. CONCLUSIONS

To validate a recently proposed weighted junction-box test procedure for use in the PV module safety and qualification protocols, a trial-run was performed to compare indoor- and field-results. Although the temperature in the field can readily vary with the local climate, the j-box is often the hottest location (*e.g*., by ≥5°C) in the module. Good correspondence between indoor- and field-tests was observed for the trial-run, including correlation between the mode types and the specific material systems affected. A weight is required to adequately assess the system during the proposed j-box test. A weight of 1 kg is recommended for the test to more rigorously examine the attachment system, emulating a prolonged load condition. Multiple indoor test conditions (including damp-heat and creep) were required to emulate the results from the field. It is therefore proposed to apply the j-box test during the creep test in IEC 61730-2, as well as the damp-heat and thermal-cycle tests in the module qualification protocols. Attachment strength tests demonstrate that the sustained load condition emulated in the weighted j-box test is very different from the existing "robustness of termination" test.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory.

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Table IV: Results for the mock modules subjected to indoor aging. The results for the damp-heat test are indicated in green font (failures are shaded yellow, with indications including: failure mode; time to failure, in days; and the failure interface). The results for the subsequent creep test are similarly indicated in red font. "N.F." (gray) indicates that no failure occurred during the experiment.

		LOCATION: INDOOR, DAMP HEAT & CREEP											
		SUBSTRATE											
		Kynar/PET/EVA			Tedlar/PET/EVA			THV/PET/EVA			untempered glass		
MATERIAL	DESCRIPTION or CURING SCHEME	APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}		
		0	0.5	0.9	0	0.5	0.9	0	0.5	0.9	0	0.5	0.9
		observation/time/interface											
acrylic 1	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
acrylic 2	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PE	foam tape	delaminated t<1d at tape surface layer	delaminated t<1d at tape surface layer	delaminated t<1d at tape surface layer	N.F.	delaminated t<1d at tape surface layer	delaminated t<1d at tape surface layer	creep (rotation) t~20d	delaminated t<1d at tape surface layer	delaminated t<1d at tape surface layer	N.F.	delaminated t<1d at tape surface layer	delaminated t<1d at tape surface layer
PU	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	creep t~14d	N.F.	N.F.	N.F.	N.F.
PO	thermoplastic hot-melt	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<6d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	creep t<1d	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box
silicone	acetoxy (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti) GS	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	oxime (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.

Table V: Results for the mock-module specimens fielded for one year in Miami. As in Table IV, the results for the test are indicated, if applicable, including: failure mode; time to failure, in days; and the failure interface. "GS" indicates the high green-strength silicone.

		LOCATION: Miami, FL											
		SUBSTRATE											
		Kynar/PET/EVA			Tedlar/PET/EVA			THV/PET/EVA			untempered glass		
MATERIAL	DESCRIPTION or CURING SCHEME	APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}		
		0	0.5	0.9	0	0.5	0.9	0	0.5	0.9	0	0.5	0.9
		observation/time/interface											
acrylic 1	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
acrylic 2	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PE	foam tape	N.F.	delaminated t~268d at tape surface layer	delaminated t~25d at tape surface layer	N.F.	N.F.	N.F.	N.F.	N.F.	delaminated t~186d at tape surface layer	N.F.	delaminated t~21d at tape surface layer	delaminated t<4d at tape surface layer
PU	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PO	thermoplastic hot-melt	delaminated t~0d at melt/j-box	delaminated t~0d at melt/j-box	delaminated t~0d at melt/j-box	delaminated t~12d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~0d at melt/j-box	delaminated t~333d at glass/melt	delaminated t<4d at melt/j-box	delaminated t~0d at glass/melt
silicone	acetoxy (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti) GS	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	oxime (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.

Table VI: Results for the mock-module specimens fielded for 1 year in Phoenix. As in Table IV, the results for the test are indicated, if applicable, including: failure mode; time to failure, in days; and the failure interface.

		LOCATION: Phoenix, AZ											
		SUBSTRATE											
		Kynar/PET/EVA			Tedlar/PET/EVA			THV/PET/EVA			untempered glass		
MATERIAL	DESCRIPTION or CURING SCHEME	APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}		
		0	0.5	0.9	0	0.5	0.9	0	0.5	0.9	0	0.5	0.9
		observation/time/interface											
acrylic 1	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
acrylic 2	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PE	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	delaminated t<6d at tape surface layer
PU	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PO	thermoplastic hot-melt	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~157d at TPE/melt	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~0d at melt/j-box	delaminated t~0d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~60d at glass/melt	delaminated t<1d at glass/melt	delaminated t<1d at glass/melt
silicone	acetoxy (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti) GS	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	oxime (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.

Table VII: Results for the mock-module specimens fielded for one year in Golden. As in Table IV, the results for the test are indicated, if applicable, including: failure mode; time to failure, in days; and the failure interface.

		LOCATION: Golden, CO											
		SUBSTRATE											
		Kynar/PET/EVA			Tedlar/PET/EVA			THV/PET/EVA			untempered glass		
MATERIAL	DESCRIPTION or CURING SCHEME	APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}			APPLIED WEIGHT {kg}		
		0	0.5	0.9	0	0.5	0.9	0	0.5	0.9	0	0.5	0.9
		observation/time/interface											
acrylic 1	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
acrylic 2	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PE	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	delaminated t~54d at tape surface layer	delaminated t<4d at tape surface layer
PU	foam tape	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
PO	thermoplastic hot-melt	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~339d at TPE/melt	delaminated t<4d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t<1d at /melt/	delaminated t<1d at melt/j-box	delaminated t<1d at melt/j-box	delaminated t~285d at glass/melt	delaminated t<1d at glass/melt	delaminated t<1d at glass/melt
silicone	acetoxy (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	alkoxy (Ti) GS	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
silicone	oxime (Sn)	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.

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