Technical Report

From: Dennis Booth

Subject: Adhesion Testing with HelioBond® PVA 900HM

Date: July 3, 2015

Executive Summary

As part of the Plug-and-Play project an adhesive capable of permanently bonding a semi-flexible PV module directly to asphalt shingles is sought. This application raises a number of questions concerning the adhesive used as well as the entire system and its interaction with the roof shingles.

This testing focuses on the capability of the adhesive to permanently bond the PV to the roof and to demonstrate the longevity of the adhesive under expected environmental conditions. The three basic questions to be answered are the durability of the adhesive under aging conditions, bond strength of the adhesive before and after aging, and compatibility of the adhesive with the shingles.

The test results confirm the long term durability of the PVA 900HM in this application. As the final bits of data becomes available over the next few weeks this will be supported. Much of the testing being conducted is from standards that are more stringent than those used in the roofing industry but are required for certification of the PV module.

The peel and shear results are as expected with results similar to other tests performed on similar materials. The adhesive strengths demonstrated after heat and water aging conditions are more than adequate to permanently bond a PV to asphalt shingles provided surface condition and preparation are proper for the application and adequate adhesive bond area is employed.

Testing of PV Backsheet bonded to asphalt shingles using PVA 900HM

The testing included both cleavage peel (ASTM D3807) and lap shear (ASTM D1002) testing of the PV backsheet to three different residential shingles provided by a major asphalt shingle manufacturer. The test values reported for cleavage peel include the peak value as required by ASTM D3807 but also include the average value over an extended range of the pull. The data was pulled directly from the Instron Bluehill software that is installed on the testing equipment. This equipment is calibrated by an independent outside company in accordance with Royal's metrology policy.

General Test Parameter Notes

All test methods used are industry accepted methods from accredited organizations such as ASTM, FM, and UL. Minor modifications are made to accommodate the particular superstrate/substrate sets being tested, to simulate temperatures and environmental conditions expected, or to meet the requirements of a particular standard. Some sample exposure conditions were chosen in consultation with the shingle manufacturer to answer specific questions regarding the direct attachment of PV modules to their asphalt shingles. All results are the average of at least 5 replicate samples.

The full set of aging conditions to be used to validate the adhesive performance and compatibility with asphalt shingles included:

- 24 Hours at room temperature, samples pulled at room temperature
- 7 Days at 85°C, samples pulled at room temperature

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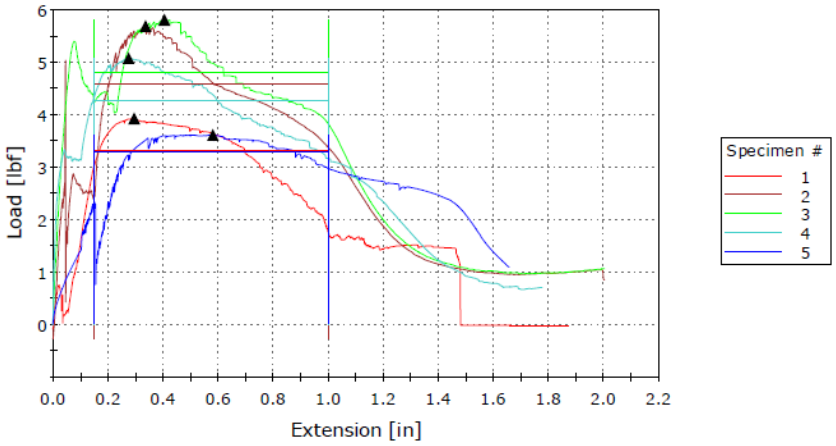
- 1000 Hours at 85°C/85% relative humidity (UL/IEC), samples pulled at room temperature
- 200 Thermal Cycles (UL/IEC), samples pulled at room temperature
- 10 Humidity Freeze Cycles (UL/IEC), samples pulled at room temperature
- 3725 Hours at 125°C, samples pulled at room temperature
- 7 Days water immersion at 85°C, samples pulled at room temperature
- 7 Days water immersion at 85°C, 72 Hours 70°C, samples pulled at room temperature
- 20 Water immersion/freeze cycles, samples pulled at room temperature

A typical output from the equipment is shown below. The failure mode is assessed by the operator and input into the software during testing. Mean and standard deviation is calculated by the equipment as part of the data output.



Results Table 1

	Maximum Load [lbf]	Average Load / Width at Average Value (Integral) [lbf/in]	Failure Mode
1	3.93427	3.3	
2	5.69158	4.6	CF
3	5.80770	4.8	CF
4	5.07620	4.3	CF
5	3.61873	3.3	CF
Mean	4.82570	> 4.1	
Standard deviation	1.00	0.71	

The PVA 900HM was placed on the PV backsheet which was adhered to test specimens cut from the shingle tabs. The assembled samples were tested after 24 hours at room temperature to establish the bond strength when fresh and un-aged. The cleavage peel specimens are attached to nominal 5/8" CDX plywood using a combination of roofing nails and/or adhesives developed by Royal and commercially sold for modified bitumen attachment in the commercial low slope market. When deemed necessary or prudent the samples were attached after the exposure such as after the seven day water immersion testing to prevent the degradation of the plywood and to allow both the front and back of the shingle to be exposed to the water.

Samples were then aged under the conditions noted below. These conditions are chosen based on industry accepted standards or by collaboration with the interested parties and are designed to discover any critical deficiencies or interactions within the system. They are designed to simulate the heat and environmental exposure that the installation may experience during normal operation.

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The tables and charts below show the test results of the testing.

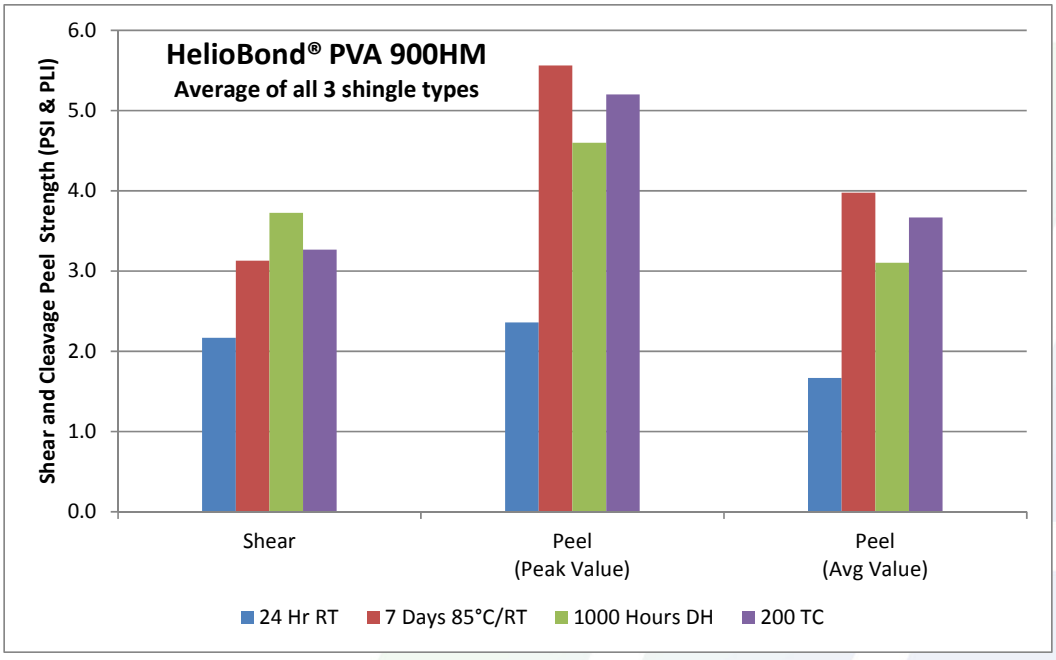
HelioBond® PVA 900 Adhesion to CertainTeed Shingles

Cleavage Peel and Shear Strength After Various Aging Conditions[8]

	Triple Tab			*Double Laminate*			*Triple Laminate*		
	Shear[3]	*Peel*[4] *(Peak Value)*	*Peel (Avg Value)*	*Shear*	*Peel (Peak Value)*	*Peel (Avg Value)*	*Shear*	*Peel (Peak Value)*	*Peel (Avg Value)*
24 Hr RT[1]	2.2	2.0	1.3	*2.0*	*2.8*	*2.0*	*2.3*	*2.3*	*1.7*
7 Days 85°C/RT[2]	3.3	6.2	4.0	2.8	5.6	3.8	3.2	4.8	4.1
% Increase in Value After Aging	52%	220%	206%	39%	99%	89%	42%	112%	145%
1000 Hours DH[5]	3.7	3.9	2.7	3.9	6.2	3.6	3.6	3.7	3.0
% Increase in Value After Aging	68%	99%	107%	68%	99%	107%	68%	99%	107%
200 Thermal Cycles[6]	3.3	4.2	2.9	3.4	5.4	3.4	3.1	6.0	4.7
% Increase in Value After Aging	50%	115%	120%	67%	91%	68%	37%	161%	183%
10 Humidity Freeze[7]	3.7	3.7	2.7						
% Increase in Value After Aging	69%	90%	105%						

1) Aged 24 hours at room temperature, samples pulled at room temperature
2) Aged 7 Days at 85°C, samples pulled at room temperature
3) Lap Shear testing (Royal T-307, ASTM D1002) pulled at 0.2"/minute, all values in pounds per square inch (PSI)
4) Cleavage Peel testing (ASTM D3807) pulled at 0.2"/minute, all values in pounds per lineal inch (PLI)
5) 1000 Hours at 85°C and 85% Relative Humidity (IEC 61215, IEC61646)
6) 200 thermal cycles (IEC 61215, IEC61646, UL1703)
7) 10 Humidity Freeze Cycles (IEC 61215, IEC61646, UL1703)
8) Value reported is the average of 5 sample replicates

Averaging the results from all three shingle types results in the chart below. In all cases the adhesive bond strength increases with exposure.



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Testing for UL Relative Thermal Index Rating

Underwriters Laboratories requires that any polymeric material used in an electrical device such as a PV module be proven to withstand the operating temperatures under which it will operate for an indefinite lifetime. The standard for this testing is UL746C. The testing consists of long term aging at elevated temperature well above that expected during its normal operation. A spreadsheet supplied by UL is used to establish the time and temperature needed to achieve a desired rating. The data below supports the ability of the PVA 900HM to operate indefinitely 95°C.

HelioBond® PVA 900HM Relative Thermal Index Testing (UL 746C)

Shear Strength After Extended Dry Heat Aging

	24 Hrs Room Temp (Initial Value)		1725 hrs at 125°C (85°C RTI Equivalent)		3725 hrs at 125°C (95°C RTI Equivalent)	
	PSI	Failure Mode	PSI	Failure Mode	PSI	Failure Mode
Average	**4.5**	Cohesive	**5.6**	Cohesive	**4.1**	Cohesive
Std Dev	0.20	Failure	0.17	Failure	0.19	Failure

Lap Shears Tested Using FRP to FRP
Royal Method T-307 Lap Shears pulled @ 0.2" min (ASTM D1002)
UL 746C requires that an adhesive maintain >50% of its initial value for compliance to the standard

Water Immersion Testing

To test the bonded system resistance to long term water immersion lap shear and cleavage peel, samples of asphalt shingles were bonded to the semi-rigid backsheet with PVA 900HM. These samples were then immersed in water at 85°C for 7 days. After 7 days immersion at 85°C the samples were placed into a 70°C oven for 72 hours before testing. After the dry heat exposure the peel and shear values were similar to the values after 1000 hours of damp heat (85°C/85% RH) exposure as seen below.

7 Day Water Immersion at 85°C Followed by 72 Hours at 70°C Dry Heat

	Shear	*Peel (Peak Value)*	*Peel (Avg Value)*
24 Hours at Room Temperature	2.2	2.0	1.3
7 Day Water Immersion	4.2	3.1	2.1
1000 Hours Damp Heat	3.7	3.9	2.7

Immersion/Freeze Testing

To test the possibility of permanent shingle damage being caused by repeated water soaking and freezing cycles samples were subjected to a thirty minute immersion in room temperature water followed by freezing at -40°C for 3.5 hours followed by 16 hours at room temperature in air. This was repeated 20 times. The shear and peel values are shown below. The amount of granules pulled from the shingles is similar to the amount detached after 7 days immersion at 85°C and 70°C oven exposure for 72 hours before testing as shown above.

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Freeze Thaw Cycling

30 min in RT water, 3.5 Hours @ -40°C, 20 Cycles

	Shear	*Peel (Peak Value)*	*Peel (Avg Value)*
24 Hours at Room Temperature	2.2	2.0	1.3
Freeze Thaw Cycling	4.0	2.3	1.9

Discussion of Results

The change in peel and shear values after 85°C dry heat and damp heat aging is a result of the adhesive wetting out the granules and flowing down to the asphalt base and is both expected and typical as a result of the material design. This is supported by the switch in failure mode from a combination of adhesive and cohesive failure in the samples pulled after 24 hours at room temperature to purely cohesive failure after aging seven days at 85°C, under damp heat conditions, or .

Factory Mutual has established a variety of wind categories to define the uplift requirements for different locations and local circumstances. Most of the country is now in the 1-90 category. The 1-90 category requires a minimum uplift resistance of 90 pounds per square foot (PSF) which is a built-in 2X safety factor. The lowest peak or initiation value tested, 24 hours at room temperature, is 2 PLI which would result in 288 PSF uplift required to initiate failure of the bond assuming 100% coverage of the module.

The adhesive strength values are typical of other tests performed on other substrate/superstrate combinations and are capable of holding a semi-flexible PV in place under any foreseeable environmental conditions.