EVALUATION AND QUALIFICATION OF TAPE ADHESIVE FOR SPLICING EPDM MEMBRANE

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Tape adhesive is gaining widespread popularity in EPDM roof systems because of a number of benefits: ease of application, uniform thickness of adhesive, strength and integrity of finished tape seam, and reduced emissions of volatile organic compounds (VOCs) when compared to butyl-based liquid adhesive.

This paper examines the testing protocol conducted to evaluate and qualify a tape adhesive for splicing EPDM membrane. Seams made from butyl-based liquid adhesive were subjected to the same protocol for comparative purposes. Both small- and large-scale tests were performed. Small-scale tests included peels and shears of EPDM seams bonded with tape. Larger-scale tests included peel testing of 0.61-m (24-inch) base tie-ins, shear testing of 0.91-m (36-inch) base tie-ins and testing seams in conjunction with anchoring systems on a 3.7- by 7.3-m (12- by 24-foot) wind uplift apparatus. Samples were aged at temperatures from below -17.8°C (0°F) to about 115.6°C (240°F) for accelerated evaluation of tape performance.

Test data generated on selected tape seam samples are compared to those obtained with butyl-based liquid adhesives in similar applications. Evaluations of field trials and of tests to gain code agency acceptance are reported. This test protocol may be used for seam evaluation regardless of the membrane or adhesive used. The results provide information on tape seam performance.

KEYWORDS

Base tie-in, butyl-based liquid adhesives, cured tape, EPDM membrane, peel test, primer, reinforced EPDM membrane, rubber roofing systems, seams, seam tape.

INTRODUCTION

Background

Current cured tape adhesives for seaming ethylene-propylene-diene-terpolymer (EPDM) roof membrane have been in use since the mid-1980s.[1] They were preceded by uncured tape adhesives that lacked sufficient initial creep resistance in roof seaming applications. To ensure that the new tapes performed satisfactorily, it was necessary to subject them to extensive laboratory, field, and code testing before introducing them commercially. This paper examines the process of evaluating and qualifying a seam system using a selected tape for splicing EPDM roof membrane as the specific example.

Purpose of this Paper

In order to establish the confidence necessary to introduce a new membrane seaming process, the full range of performance issues must be identified and evaluated. The purpose of this paper is to relate how seam evaluation techniques can be selected to provide the data to support confident adoption by roofing contractors and specifiers. This paper presents the results of a progression of lab tests on tape seams, which led to full-scale field trials, and culminated with approval of this method of seaming through building code agency testing. Where appropriate, the results are compared to those obtained on EPDM seams prepared from a butyl-based liquid adhesive.

EVALUATION PROTOCOL

Field seams, regardless of their type, must perform similar functions on the roof. Based on years of membrane system investigation, it is possible to define the critical performance criteria. Detailed test procedures, including aging conditions, are described in the appendix. This section of the paper summarizes the objective and general methodology of each evaluation procedure.

Laboratory Small-Scale Testing

Peel Testing

T-peel testing of the completed seam systems are conducted after the test samples are aged at various time, temperature, and moisture conditions simulating rooftop exposure. Test samples are peeled at ambient, low, and high temperatures to determine the overall adhesion capabilities. Seam samples are also "cycled" (exposed to alternating high temperature, low temperature, and moisture) followed by T-peel testing to simulate, in a limited period of time, rooftop exposure. All of these T-peel tests are conducted on 25-mm- (1-inch-) wide samples in accordance with ASTM D 1876-93 "Standard Test Method for Peel Adhesion of Adhesives (T-Peel Test)."[2]

Seams Aged and Peel Tested at Room Temperature—A starting point in the evaluation process is to establish the tape seam's peel strength relative to that of a seam prepared from a butyl-based liquid adhesive, representing a proven seaming system in the industry. A set of five seam samples made from each adhesive was subjected to aging at room temperature for 24 hours and two other comparable sets for seven days at room temperature. This comparison was repeated several times. This comparison is intended to show if the tape seam system under consideration has sufficient room temperature peel strength to justify further testing.

Seams Aged at High Temperature and Tested at Low Temperature—Seam samples should be exposed to high and low temperatures that roofs experience, followed by peel adhesion testing at high and low temperatures to verify performance under these conditions. Samples prepared at ambient temperatures are aged at high temperatures, conditioned at low temperatures, and subjected to various environments typically used in the laboratory to evaluate butyl-based liquid adhesives:

- aged seven days at 70°C (158°F); peeled at 22.2°C (72°F)
- aged seven days at 70°C (158°F); peeled at 70°C (158°F)
- aged seven days at 70°C (158°F) in water; peeled at 22.2°C (72°F)
- aged seven days at 70°C (158°F) in water, followed by one hour at -40°C (-40°F); peeled at -40°C (-40°F)
- aged seven days at 115.6°C (240°F) in water in sealed vessel; peeled at 22.2°C (72°F)

The peel testing at high and low temperatures is performed in an environmental chamber fitted to the tensile test machine.

Seams Exposed to Cycled Temperature and Moisture and Peel Tested—A seam on the roof will be exposed to heat, moisture, drying, and cold. This sequencing, or variations thereof, will be repeated throughout the lifetime of the roof. Exposure to this cycling places stress on the interface between the membrane and the adhesive. This exposure may also lead to a chemical reaction within the adhesive and potential degradation of the seam. A procedure that simulates this cyclic rooftop condition is described in the Rubber Manufacturers Association's (RMA's) document RP-10, *Minimum Peel Strength Requirements for Adhesives Used in Seaming Black EPDM Sheets.*[3] The document specifies that seam samples be aged as follows:

- 24 hours in an air circulating oven at 80°C (176°F)
- 72 hours immersed in water at 80°C (176°F)
- 8 hours in a freezer at -18°C (-0.4°F)
- 64 hours immersed in water at 80°C (176°F)

Seams Creep Rupture/Dead Load Shear Tested

High Temperature Static Mode—In dead load shear testing, a 25- by 25-mm (1- by 1-inch) seam area is subjected to a 300-g (0.66-lb.) weight while hanging in a 70°C (158°F) oven. The sample should not separate within 24 hours.

Room Temperature Periodic Mode—Periodic dead load shear testing is a variation of the dead load shear testing. A 25- by 76-mm (1- by 3-inch) seam area is cyclically loaded and unloaded with 11.1 N (2.5 lbf) at approximately 30 cycles per minute. This simulates wind cyclical shear forces that roof membrane seams should endure. A counter tracks the number of cycles and regular visual observations bracket the failure point.

Laboratory Large-Scale Testing

Bond at Perimeter Securement Tensile Tested

A "base tie-in" is the attachment of roof membrane where the field of the roof intersects a vertical surface such as a wall, parapet, upstand, or curb. Secure base tie-ins are one criteria for the long-term success of low-slope roofs. On many installations, the field membrane is continuous through the perimeter angle change and up the vertical substrate without being penetrated by fasteners. A common base tie-in for this situation relies on the long-term integrity of a bond formed between the EPDM membrane and the underlying scrim reinforced EPDM strip, which has been mechanically fastened to the roof deck or wall.

Evaluation of base tie-ins using various lap configurations is performed by conducting tensile testing of a 0.61-m (24-inch) mock-up in accordance with the American National Standards Institute (ANSI) *Wind Design Guide for Ballasted Single Ply Roofing Systems* test for base tie-ins.[4] Base tie-ins that had been anchored both horizontally and vertically, utilizing tape or butyl-based liquid adhesive, were tested and compared. The base tie-in model is assembled and maintained at room temperature for seven days before testing. With the base tie-in model mounted to fit the tensile test machine, the secured membrane is pulled at 45 degrees from the horizontal.

Bond at Perimeter Securement Creep Rupture Tested

Creep results are known to be more sensitive than peel results in detecting differences in the performance of various seaming systems.[5] For this evaluation, 0.91-m (36-inch) models of the base tie-in, which were secured using screws and a batten strip attached to the vertical substrate, are evaluated under creep loading. The models are supported at each end and oriented so that a weight suspended from the secured membrane applies force parallel to the plane of the roof.

The models are initially loaded at 133.5 N (30 lbf), and after each week, an additional 133.5 N (30 lbf) load is applied until failure or 667.5 N (150 lbf) is reached. If failure does not occur after one week at the maximum loading, the evaluation continues until failure or suspension of the test. Regular observations bracket the failure point, and the force and time to failure are recorded.

Wind Uplift Test

A method of evaluating the strength of a seam in conjunction with a roof system is to conduct the wind uplift test, specified by Factory Mutual Research Corporation,[6] on the system including the seaming method. The seam under consideration is incorporated into a mechanically anchored system, which places the seam under a critical stress. The system is then subjected to positive air pressure from underneath the assembly, simulating the uplift produced on a rooftop from wind forces. The air pressure is increased periodically until failure occurs. Ideally, the seam should not fail before other components of the system.

Full-Scale Field Evaluation

A proposed seaming method must be field tested on actual roofs after successful small- and large-scale laboratory testing. This process establishes that the seam can be installed under the wide range of conditions to be encountered over the course of a year. A critical element is the feedback from roofing contractors who are asked to install the proposed new method along with the existing seaming method. The tape seam was field tested in many geographic regions of the United States and under hot and cold application conditions. Field testing includes verification of the feasibility of the prescribed installation technique in five areas: preparation; application; environmental factors; equipment requirements; and storage/handling. The performance of the seam in the field is followed as a function of time to confirm long-term durability.

Code Agency Evaluation

Roof systems must receive the appropriate building code agency acceptances before they can be fully marketable and gain widespread acceptance by contractors and specifiers. Furthermore, it is important that roof systems are designed and installed to meet the fire and wind uplift requirements for a specific building. Two of the major testing companies in the United States are Factory Mutual Research Corp. (FM) and Underwriters Laboratories Inc. (UL).

FM performed the following tests to determine if a roofing assembly incorporating tape seams meets Class I criteria:[6]

- Wind uplift resistance test—This test was performed on a 3.7- by 7.3-m (12- by 24-foot) apparatus. Roof systems, including field seams, are tested on this apparatus according to procedures found in appendix of the paper.
- Hail testing—The roof membrane and field seam withstood the impact of a 45-mm- (1.75-inch-) diameter steel ball dropped from a height of 5.4 m (213.5 inches) through a 51-mm- (2-inch-) diameter steel tube, with no signs of damage when viewed under 10 power magnification.
- Seam leakage test—A field seam that was weathered for 1,000 hours in the UV weathering apparatus withstood exposure to 152-mm (6-inch) deep water inside FM's leak apparatus [197-mm (7.75-inch) inside diameter] for seven days. The test is continued by pressurizing the assembly to 6.8 kPa (1 lbf/in^2) and cycled 25 times from 6.8 kPa to 0 kPa (1 lbf/in^2 to 0 lbf/in^2). There was no leakage of the sample at anytime during the test.

Although all FM tests listed above may not be required by local code agencies, they represent common roof design requirements.

UL conducts fire tests for various system requirements: UL 790 for external fire, UL 263 for "P" designs, UL 723 for surface burning and UL 1256 for deck constructions.[7] UL conducts external fire testing of roof systems to UL 790 (ASTM E 108), which can result in classifications of Class A, Class B, or Class C, depending on the slope, deck type, and specific components of the roof assembly. Seam areas have been tested as part of these assemblies. The lap slice constructed with either tape or butyl-based liquid adhesive does not adversely affect the outcome of the burn test.

RESULTS AND DISCUSSION

Laboratory Small-Scale Testing

Peel Testing

Seams Aged and Peel Tested at Room Temperature—The peel values for each sample set are averaged. The average peel value for each sample set is then divided by the average for all butyl-based liquid adhesive sample sets to get the index value reported. These index values are listed in Table I along with an average of the indices for each aging condition.

The tape average indices listed in Table 1 show that the peel strength of the tape seam is higher than that of the butyl-based liquid adhesive after 24-hour and 7-day room temperature aging. A similar relationship has been observed by others.[5] The locus of break (adhesive or cohesive) for each sample tested was a mixed cohesive/adhesive failure for both seaming systems. In view of this positive comparison with the butyl- based liquid adhesive, it was determined that the tape seam system was suitable for more stringent testing.

Seams Aged at High Temperature and Tested at Low Temperature—Rooftop seams can be subjected to above 80°C (176°F) and down to -40°C (-40°F), as well as moisture.[7] The testing protocol described previously simulates those conditions, with peel samples exposed to high temperatures up to 115.6°C (240°F), low temperatures down to -40°C (-40°F), with water included in some experiments. Peel results for sets of both tape and butyl-based liquid adhesive seams were processed as described in the previous section to derive the indices. None of the seams delaminated during any of the aging conditions. The indices in Table 2 show that the peel strength of the tape seams are higher than those of the butyl-based liquid adhesive.

Of special interest were Conditions 2 and 4 (data columns 2 and 4). They specify aging and testing the samples at extreme conditions encountered on a roof. Condition 2 ages the samples at 70°C (158°F) and tests it at that high temperature. Condition 4 ages the samples in hot water and drops the testing temperature to -40°C (-40°F). The results (Graph 1) for these two conditions show tape to be significantly stronger than butyl-based liquid adhesive seams.

Seams Exposed to Cycled Temperature and Moisture and Peel Tested—Seam samples were aged at room temperature for seven days. The samples were divided into two equal sets. One set was peeled at room temperature to establish an original value. The other set was exposed to the RMA RP-10 conditioning. One cycle of the RMA RP-10 testing sequence takes seven days to complete and is then repeated until the seams are exposed to a minimum of 28 days. After the samples were removed and cooled to room temperature, they were tested for T-peel strength. Tape and butyl-based liquid adhesive seams were exposed to the same procedures and tests.

Samples Aged 24 Hours and 7 Days at 22°C (72°F) and Tested at 22°C (72°F)		
Sample Set	24 Hour Indexed Test Value	7 Day Indexed Test Value
Tape 1	1.05	0.92
Tape 2	1.21	1.01
Tape 3	1.27	1.17
Tape 4	1.36	1.07
Tape 5	0.80	0.83
Tape 6	1.26	1.13
Tape 7	1.15	1.08
Tape 8	1.12	0.90
Tape 9	1.09	1.26
AVERAGE TAPE INDEX	1.15	1.03
Adhesive 1	1.17	1.00
Adhesive 2	1.14	1.13
Adhesive 3	0.94	1.00
Adhesive 4	1.11	0.90
Adhesive 5	0.96	0.94
Adhesive 6	1.04	0.85
Adhesive 7	1.07	0.98
Adhesive 8	0.52	1.22
AVERAGE LIQUID INDEX	1.00	1.00

Table 1. Room Temperature Peel Tests (indexed to liquid adhesive).

CONDITION:	#1	#2	#3	#4	#5
Aging Temperature Testing Temperature	70°C 22°C	70°C 70°C	70°C Water 22°C	70°C Water -40°C	116°C Water 22°C
Sample Sets	Indexed Test Value	Indexed Test Value	Indexed Test Value	Indexed Test Value	Indexed Test Value
Tape 1	1.19	1.44	0.89	1.46	1.00
Tape 2	1.16	1.65	1.17	0.86	1.28
Tape 3	1.29	1.89	1.16	1.96	1.31
Tape 4	1.25	1.52	1.02	1.99	1.19
Tape 5	1.23	1.71	1.04	2.17	1.43
Tape 6	0.96	1.93	1.18	0.36	1.08
Tape 7	1.27	1.71	1.02	2.03	1.27
Tape 8	1.43	1.71	1.04	1.69	1.14
Tape 9	1.00	1.36	0.73	1.45	0.96
Tape 10	1.45	1.62	0.95	1.28	1.32
AVERAGE TAPE INDEX	1.22	1.65	1.02	1.53	1.20
Adhesive 1	1.21	1.63	1.03	1.07	0.86
Adhesive 2	1.28	1.33	1.08	0.76	1.05
Adhesive 3	0.96	1.09	0.92	1.17	1.06
Adhesive 4	1.03	1.33	0.96	0.98	0.70
Adhesive 5	0.93	0.59	1.01	0.73	1.08
Adhesive 6	0.99	0.56	0.99	1.18	1.09
Adhesive 7	0.78	0.47	1.07	1.02	1.04
Adhesive 8	0.90	0.74	0.98	0.89	1.09
Adhesive 9	0.90	1.27	0.95	1.20	1.03
AVERAGE LIQUID INDEX	1.00	1.00	1.00	1.00	1.00

Table 2. Seven-day peel test results (indexed to liquid adhesive).

The tape and the butyl-based liquid adhesive seams start out relatively close in strength after room temperature aging (Graph 2, original). The difference between the strength of the tape seam system after the cycled aging, which simulates rooftop exposure, was double the peel strength of the butyl-based liquid adhesive system (Graph 2, aged).

Seams Creep Rupture/Dead Load Shear Tested

High Temperature Static Mode—The seam must resist the force of a 300-g (0.66-lb.) weight in 70°C (158°F) oven for 24 hours. Both the butyl-based liquid adhesive and tape adhesive seams pass this test. This is an indication of a seam's ability to resist creep during the critical early period after the seam is made.

Room Temperature Periodic Mode—In this test, seams made from butyl-based liquid adhesive have been shown from in-house testing to sustain about 400,000 cycles with nonreinforced EPDM membrane before beginning to show initial delamination at their edges. Tape seams show no sign of delamination after 1,000,000 cycles. This comparison shows that in situations where the membrane may experience fluttering, causing cyclical forces to be imparted to the seam, the tape seam will perform better than the butyl-based liquid adhesive seam.

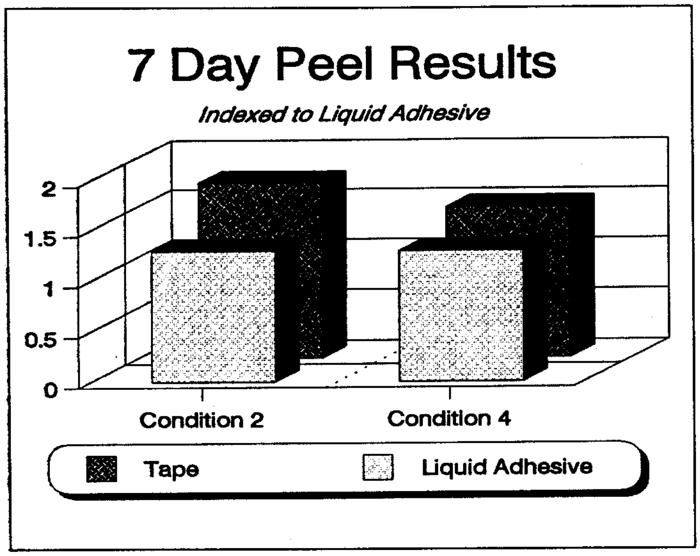
Laboratory Large-Scale Testing

Bond at Perimeter Securement Tensile Tested

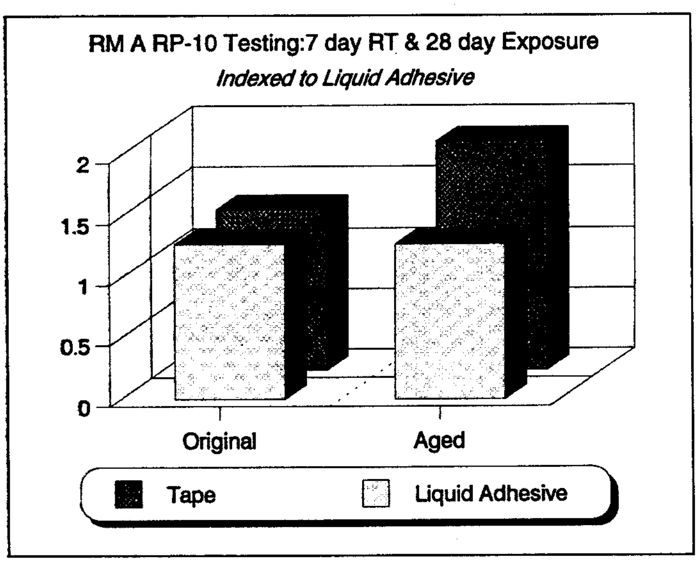
When the membrane changes angle from the horizontal to the vertical at the perimeter, penetration of the membrane can be avoided by adhering it to a reinforced perimeter fastening strip. The fastening strip is mechanically anchored to the horizontal or vertical surface in one of two different ways: 1) using seam plates [typically 50 mm (2 inches) in diameter] or 2) batten bars. Each securement method (seam plates or batten bar) can be anchored to the horizontal or vertical substrate.

The reinforced perimeter fastening strip can be supplied in two ways: 1) reinforced perimeter fastening strip without tape, using the butyl-based liquid adhesive to bond the strip to the field membrane and 2) reinforced perimeter fastening strip with tape laminated in the factory, using the tape as the adhesive to bond the laminate to field membrane.

The focus of this testing was the comparison of the butyl-based liquid adhesive with the tape for bonding the reinforced perimeter strip to the membrane. The bond strength of the reinforced perimeter fastening strip to the field membrane was evaluated by tensile testing. The membrane is pulled at a 45-degree angle from the reinforced perimeter fastening strip at the rate of 50 mm/minute (2 inches/minute).



Graph 1.

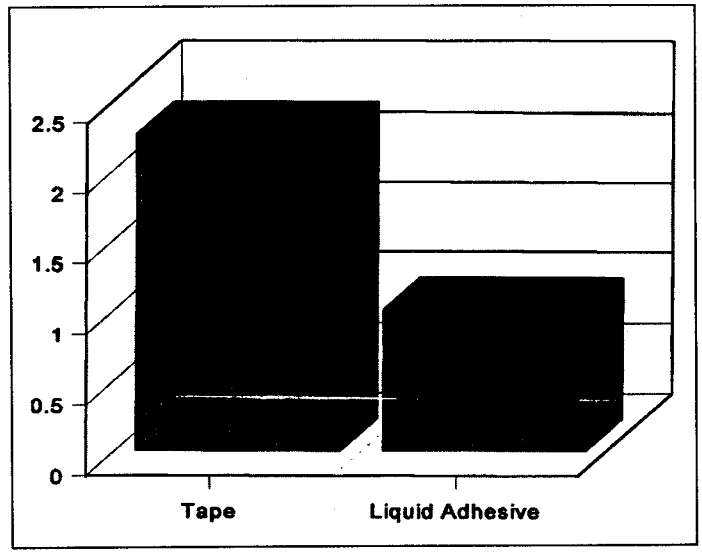


Graph 2.

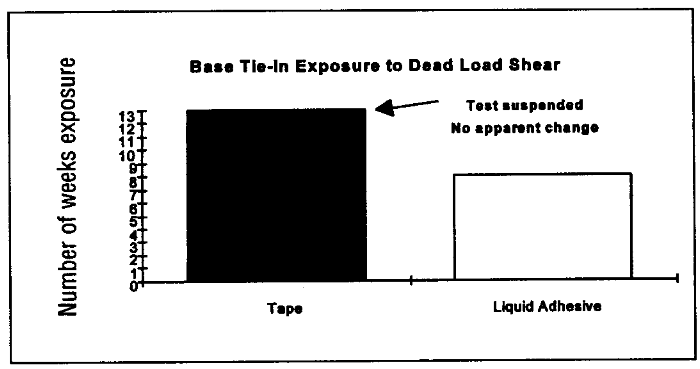
When the membrane is adhesively bonded to a reinforced perimeter fastening strip that has been secured using a batten bar attached to the vertical substrate, neither the tape or butyl-based liquid adhesive bonds fail before other components.

A greater difference was observed in the performance of the two adhesives when the reinforced perimeter fastening strip was secured using seam plates anchored into a horizontal substrate. In this system, the tape bond sustained twice the load as the butyl-based liquid adhesive bond (Graph 3).

Bond at Perimeter Securement Creep Rupture Tested
The performance of the tape bond also exceeded that of the butyl-based liquid adhesive bond in continuous creep shear testing of the vertically attached reinforced perimeter fastening strip secured with a batten bar (Graph 4). The membrane of the 0.91-m (36-inch) model was progressively subjected at a 0-degree angle to an increasing creep load up to 667.5 N (150 lbf) over five weeks. The loading remained at that level until failure or discontinuation of the test. The butyl-based liquid adhesive bond failed after a total of eight



Graph 3.



Graph 4.

weeks' exposure. After 13 weeks, the tape bond still had not failed, and the test was suspended.

Wind Uplift Test
The mode of failure of in-seam mechanically anchored systems (both reinforced and nonreinforced) in 3.7- by 7.3-m (12- by 24-foot) wind uplift testing is not the seam. In this testing, no failure of tape or butyl-based liquid seam is evident, as other components of the roof system fail prior to seam failure.

Full-Scale Field Evaluation

Preparation
Previous in-house experience with tape showed that a more reliable tape seam is obtained when the seam area is treated with a primer. Furthermore, tape vendors and system manufacturers specify the use of primers to prepare the EPDM membrane to receive tape. In order to avoid the need for a separate solvent wash of the membrane before primer application, a technique was developed[9] utilizing a scrub pad and handle for cleaning and priming the membrane in one step. The thickness of primer required is about half that of a standard butyl-based liquid adhesive so that the flash-off time is reduced by half.

Application
A survey of roofing contractors confirmed that the tape can be installed in less time than the butyl-based liquid adhesive,

offering opportunities for increased productivity and quality. The primer for tape flashes off in about 15 minutes, compared to the flash-off time of a butyl-based liquid adhesive of about 30 minutes. Of great benefit to the applicator is that there is no gauging whether the correct thickness of adhesive was applied. The tape thickness is controlled by the manufacturing process. The ease of cleaning and priming the membrane and application of a predetermined thickness of tape leads to a more consistently secure seam.

Environmental Factors
Tapes are 100 percent solid and emit no volatile organic compounds (VOCs). The overall reduction in VOC emissions of tape seams including a liquid-based primer compared to a butyl-based liquid adhesive is about 70 percent.

Equipment Requirements
Field testing of tapes verified that contractors can make tape seams successfully with a minimum amount of equipment and over the wide range of conditions encountered across the United States. The scrub pad and handle applicator for aggressive priming of the membrane optimizes this operation and offers improvement in adhesion over brush application of primer.[9]

Storage and Handling
Also verified was the usability of the material during the shelf life period of one year. Unused rolls of tape and primer were subjected to accelerated aging at 37.5°C (100°F) for three and six months. The six-month aging period was effectively greater than 12 months' aging at room temperature [22.2°C (72°F)]. These aged materials were used on a roof, along with newer unaged materials. Both products performed effectively in seaming EPDM membrane.

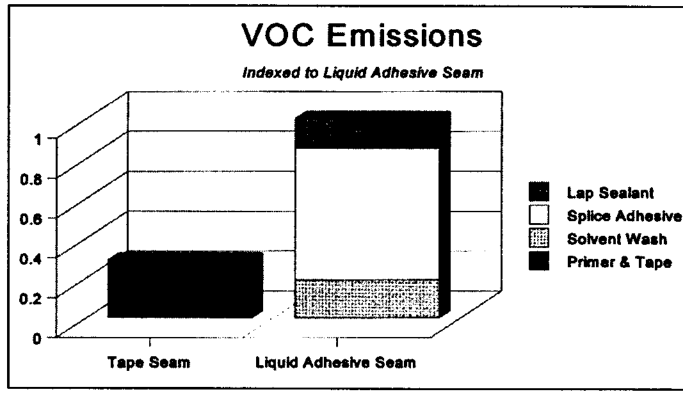
Code Agency Evaluation
Tape seams were tested by code agency testing companies (FM and UL) and obtained the same code ratings as butyl-based liquid adhesives seams.

SUMMARY AND CONCLUSIONS

Seaming techniques and materials have evolved over the history of single-ply membranes in commercial roofing applications. During that time, the development of seam evaluation methods have resulted from the efforts of individual research departments and from collaboration through industry technical committees. This paper presents a comprehensive array of testing methods that are relevant to the service life of a single-ply membrane seam. The selection starts with laboratory-scale methods for screening qualities and culminates in full-scale evaluation of the complete seaming system, in different application situations, on roofs in various localities.

In order to adequately investigate a full range of performance questions, a broad selection of conditions have been outlined. The seam must resist peel and shear forces. The preparation, aging, and testing exposures must include humid and dry conditions, ambient and elevated pressures, as well as high and low temperatures. Loading schemes must include static, dynamic and cyclic configurations. Test samples include small-scale specimens for focused measurements and full scale modules to evaluate system performance, installation feasibility, and the interaction of related components.

If a relevant performance benchmark does not exist, a separate engineering investigation would be necessary to establish acceptable minimum values. In the case of the tape seam, which is used as the model in this paper, the established seam made with butyl-based liquid adhesive provided a readily available and very reliable control for direct comparisons. As long as the proposed tape seam was found to be as good or better than the butyl-based liquid adhesive seam, it could be used with confidence for seaming EPDM membrane.



Graph 5.

Initial in-house experiments on the cured tape itself showed that it possessed higher tensile strength and lower elongation than the uncured tape. As a seam adhesive, the tape showed T-peel values directionally higher than those obtained from the butyl-based liquid adhesive at ambient temperature. This is consistent with the results reported by Rossiter.[5] The same relationship existed when the comparison was made after the seams were aged and tested at high and low temperatures. In a separate test, where the seams were exposed to stringent conditions of high and low temperature cycles in the presence of moisture for 28 days, the tape seam showed a T-peel strength double that of the satisfactory performance of the butyl-based liquid adhesive seam.

The performance of the cured tape seam in shear testing was crucial. In static dead load shear testing, the cured tape performed very well. When the dead load was periodic, the tape was at least 2.5 times superior to the butyl-based liquid adhesive seam. When testing was extended to large-scale mock-ups, such as base tie-ins, the tape seams significantly outperformed the butyl-based liquid adhesive seams with respect to the time a 667.5-N (150-lbf) load was supported. In wind uplift testing, other system components failed while the tape seams remained intact.

To simplify the overall seaming procedure, cleaning and priming of the membrane was incorporated into one operation using a scrub pad and handle to dispense the primer. The overall tape seam preparation is simplified compared to the butyl-based liquid adhesive. The tape priming and placement is easier and faster compared to the cleaning and application of butyl-based liquid adhesive. Solvent flash-off from the primer is more rapid, and the tape offers consistent material thickness. The tape was field tested in various regions in the United States under hot and cold conditions.

The strong performance of the tape adhesive relative to the butyl-based liquid adhesive supports confident adoption for use by roofing contractors and specifiers. This reported methodology is recommended for seam performance, regardless of the membrane or adhesive used.

APPENDIX: IN-HOUSE TEST METHODS

Sample Preparation and T-Peel Testing

Peel samples were prepared from 1.14-mm (0.045-inch) thick membrane and 76-mm (3-inch) wide by 0.89-mm (0.035-inch) thick tape. The membrane was cleaned and primed in one step using a 17 percent solids primer solution with a scrub pad saturated with the primer to scrub the EPDM membrane and apply the primer with four back-and-forth motions. There was no separate washing of the EPDM membrane. After the primer was applied, it was allowed to flash off for 30 minutes. The tape was then applied to two primed EPDM surfaces to form a tape seam.

Butyl-based liquid adhesive samples are also made under controlled conditions. EPDM sheets with dimensions of 152 mm by 254 mm by 1.14 mm (6 inches by 10 inches by 0.045 inches) were solvent-washed with lab wipes using hexane or solvent naphtha, followed by a 30-minute flash-off time. Butyl-based liquid adhesive was metered (12 CC) on the EPDM sample, spread evenly over the EPDM surface with a paint brush and followed by a 30-minute flash-off time. The dry film thickness of the adhesive was about 0.1 mm (0.004 inches). The sample was then folded over to result in a 152- by 127-mm (6- by 5-inch) seam, which was cut into five 25- by 127-mm (1- by 5-inch) samples. All solvents, primers, and adhesives were flashed-off under an air circulating hood.

All seam samples were rolled using a 6.8-Kg (15-pound), 76-mm (3-inch) wide roller, followed by exposure to the specific aging conditions. After aging, T-peels of 25-mm- (1-inch-) wide seam samples were conducted at room temperature, at 70°C (158°F), or at -40°C (-40°F) using a tensile testing machine at 50 mm (2 inches) per minute. A minimum of five samples were tested for each aging condition. Refer to Photos 1 and 2.

Creep Rupture/Static Mode

Seam samples are prepared essentially as just discussed, but the overlapping and trimming of the samples results in 25- by 25-mm (1- by 1-inch) seam areas. The shear samples are aged at 70°C (158°F) for 24 hours, then a 300-g (0.66-lb.) weight is affixed to the bottom of the sample while it is still in the oven. The dead load shear sample is monitored for failure or slippage for 24 hours. Refer to Photo 3.

Creep Rupture/Periodic Mode

Seam samples are prepared as discussed under "Sample Preparation and T-Peel Testing," but samples are cut and trimmed to result in 25- by 76-mm (1- by 3-inch) seam areas. The top of the sample is attached to a fixture to restrain the tip of each sample in place. The bottom of the sample has a 11.1-N (2.5-lbf) load applied. A method of subjecting the shear sample to cyclical loads is employed, such as an air-operated cycler. The weight is allowed to exert its force on the sample, and then the force is released at about 30 cycles per minute. The test is monitored for performance, and the number of cycles are recorded. Refer to Photo 4.

Perimeter Securement Tensile Testing

Base tie-ins are prepared per system manufacturer specifications, including seam preparation on a 0.61-m- (24-inch-) long mock-up. The mock-up is affixed in a tensile test machine. The roofing membrane of the base tie-in mock-up is pulled at a 45° angle to the roof plane at the rate of 2 inches (50 mm) per minute until failure. The force the overall base tie-in withstands is recorded, along with the mode of failure.

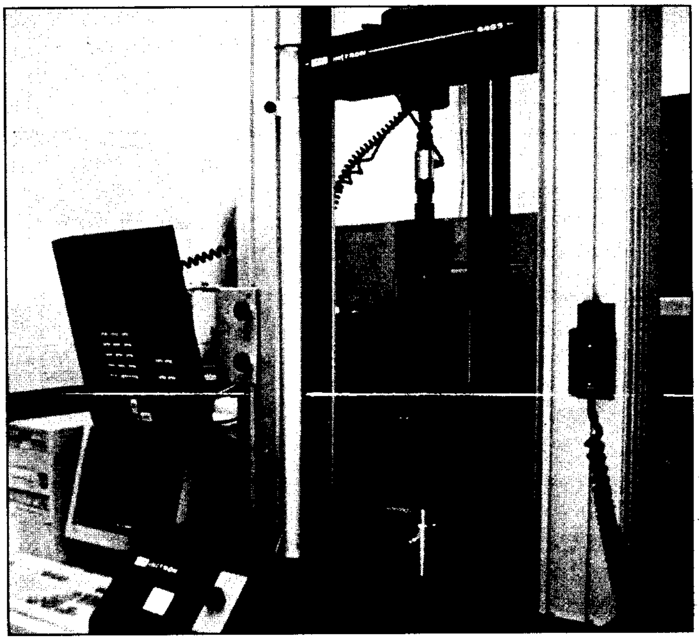


Photo 1. T-peel test in progress at ambient temperature.

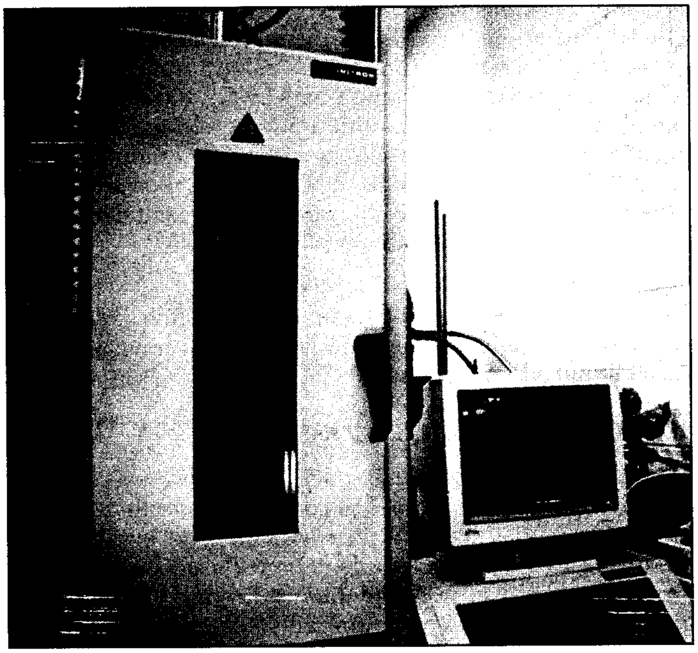


Photo 2. Tensile test apparatus fitted with environmental chamber to perform T-peel testing at high or low temperature.

Perimeter Securement Creep Rupture Testing

Base tie-ins are prepared per system manufacturer specifications, including seam preparation on a 0.91-m- (36-inch-) long mock-up. The roof membrane of the mock-up is loaded in dead load shear, with the load acting to pull the roof membrane in the same plane as the roof. Typically, 133.5 N (30 lbf) is the starting load, and the load is increased by this amount weekly until failure or 667.5 N (150 lbf) is attained. After 667.5 N (150 lbf) is reached, monitor until failure and record. Refer to Photo 5.

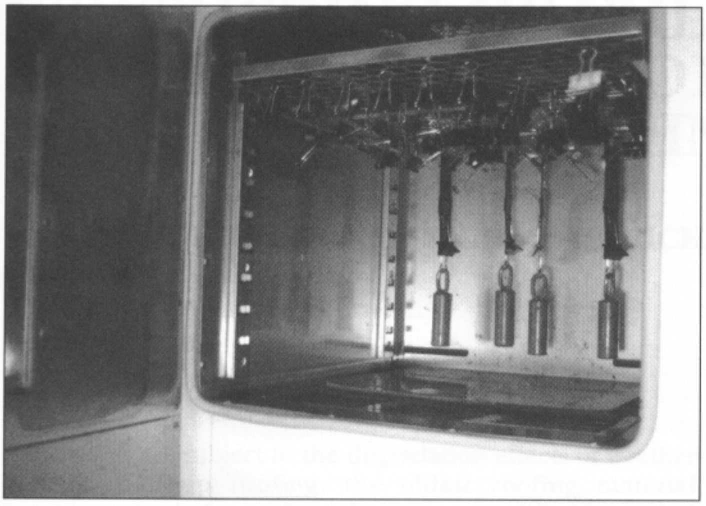


Photo 3. *Dead load shear test in progress.*

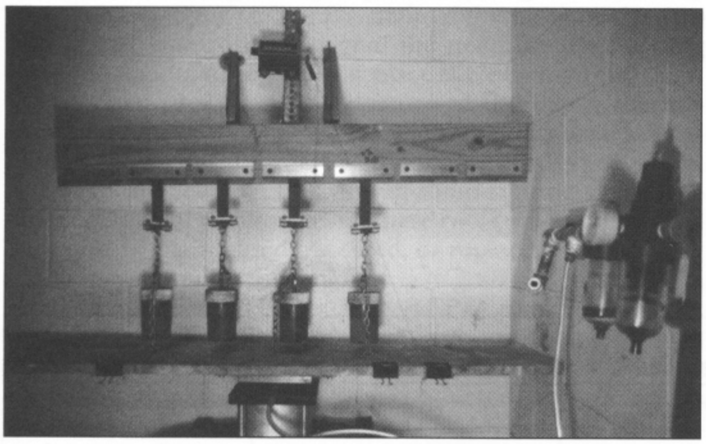


Photo 4. *Periodic dead load shear test in progress. Platform below weights reciprocates to alternate the weight hanging on the seam sample.*

Wind Uplift Testing

A method of evaluating mechanically anchored EPDM roof systems is by wind uplift testing as specified by FM *Approval Standard for Class I Roof Covers, Class Number 4470,* Supplement Number (2).[6] The test assembly consists of a 3.7- by 7.3-m (12- by 24-foot) roof section situated on a steel deck and includes the seaming technique under evaluation. The entire assembly is subjected to positive air pressure from underneath the assembly, simulating the vacuum produced on a rooftop from wind forces. The air pressure is introduced in 718.2 Pa (15 lbf/ft^2) increments starting at 1436.4 Pa (30 lbf/ft^2). The pressure is maintained for 60 seconds at each interval before being increased to the next level. The highest pressure the overall assembly (including seams) can withstand without failure is recorded, along with the mode of failure. Based on the system's performance, it will be issued a 1-60, 1-90, 1-120, 1-150, or 1-180 uplift rating. Refer to Photo 6.

Summary of Testing

Table 3 summarizes the various in-house tests and related details.

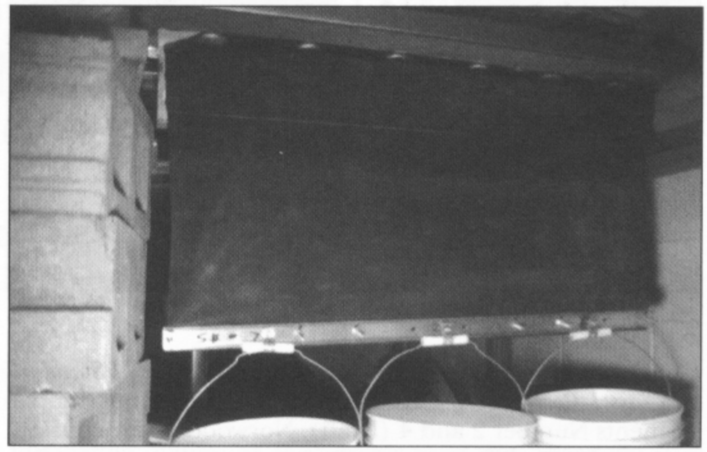


Photo 5. *Perimeter securement creep rupture testing in progress. Pails with weight are affixed to the hanging EPDM membrane in the roof plane.*

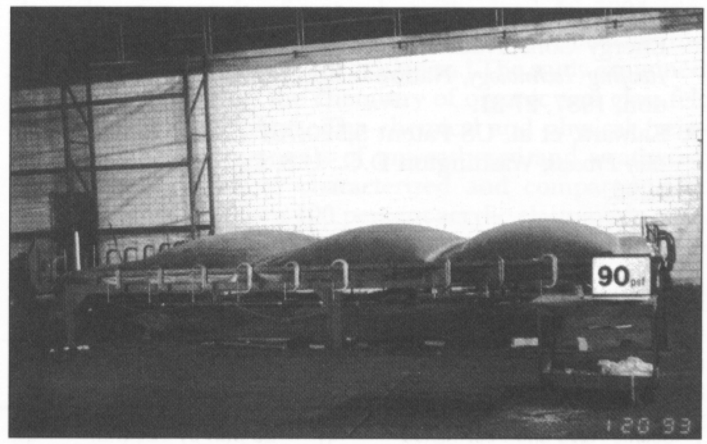


Photo 6. *Wind uplift test in progress on 3.7- by 7.3-m (12- by 24-foot) apparatus.*

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1. Kalwara, Joseph and Chester Chmiel. "The Evolution of Seaming Technology for EPDM Roofing Membrane," *RCI Interface,* Volume XIV, January 1996, 8-12.
2. American Society for Testing Materials, ASTM D 1876-93 "Standard Test Method for Peel Adhesion of Adhesives (T-Peel Test)," *1994 Annual Book of ASTM Standards,* Volume 15.06, Philadelphia, Pennsylvania, 1994, 105-107.
3. Rubber Manufacturers Association, Roofing Products Division, *Minimum Peel Strength Requirements for Adhesives Used in Seaming Black EPDM Sheets,*" RP- 10, 1989 Technical Publications, Washington, D. C., 1989.
4. American National Standards Institute. ANSI/RMA/SPRI. *Wind Design Guide for Ballasted Single Ply Roofing Systems,* Washington, D.C., 1988, 12.
5. Rossiter, et al. *Performance of Tape-Bonded Seams of EPDM Membranes: Comparison of the Peel Creep-Rupture Response of Tape-Bonded and Liquid- Adhesive-Bonded Seams,* NIST Building Science Series 175, Gaithersburg, Maryland: U.S. Department of Commerce, Building and Fire Research Laboratory, National Institute of Standards and Technology, 1996.

Photo 7. External fire test in progress.

6. Factory Mutual Research Corporation, *Approval Standard Class I Roof Covers, Class Number 4470,* including Supplements Number 2 and 4 (Draft), Norwood, Massachusetts, April 1986.
7. Underwriters Laboratories Inc.™ *Roofing Materials and Systems Directory,* Northbrook, Illinois, 1996.
8. Backenstow, "Comparison of White vs. Black Surfaces for Energy Conservation," *Proceedings of the 8th Conference on Roofing Technology,* National Roofing Contractors Association, 1987, 27-31.
9. Kalwara, et al. US Patent 5,520,761 *Roofing Seam Installation Process,* Washington D.C.: U.S. Patent Office, May 28, 1996.

Tests & Section References	Sample Size	Time Required	Test Rate	Test Temperature
Seams Aged and Peel Tested at Room Temperature	25 mm by 127 mm	7 Days	50 mm/min	22°C (72°F)
Seams Aged at High Temperature and Peel Tested at Various Temperatures	25 mm by 127 mm	7 Days	50 mm/min	22°C (72°F) -40°C (-40°F) 70°C (158°F)
Seams Exposed to Cycled Temperature/Moisture and Peel Tested at Room Temperature	25 mm by 127 mm	35 Days	50 mm/min	22°C (72°F)
Seams Creep Rupture/Dead Load Shear Tested at High Temperature Static Mode	25 mm by 127 mm with 25mm by 25mm Seam	24 Hrs	Static	70°C (158°F)
Seams Creep Rupture/Dead Load Shear Tested at Room Temperature Periodic Mode	25 mm by127 mm with 25 mm by 75 mm Seam	Varies	30 cycles per minute	22°C (72°F)
Bond at Perimeter Securement Tensile Tested at Room Temperature	Full scale model of securement for a length of 0.61 m	7 Days	50 mm/min	22°C (72°F)
Bond at Perimeter Securement Creep Rupture Tested at Room Temperature	Full scale model of securement for a length of 0.91 m	Varies	Weekly observation and load adjustment	22°C (72°F)
Wind Uplift Test	3.3 m by 7.3 m	Varies	60 second duration at increasing pressure intervals	22°C (72°F)

Table 3.