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Solutions to Address Osmosis and the Blistering of Liquid Applied Waterproofing Membranes

Citation

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ABSTRACT

The transport of water through waterproofing membranes over concrete substrates resulting in water-filled blisters and leaks has been demonstrated by the authors to be caused by osmosis. Although this issue has now been studied for more than a decade, there is currently no industry standard to test for the risk of osmosis in waterproofing membranes. The authors have developed a protocol to measure the osmotic flow and evaluate the risk of osmotic blistering in waterproofing membranes including a standardized osmotic flow rate test, ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*, inverted wet cup vapor permeance testing, and modified ASTM long-term absorption testing. This testing protocol has measured osmotic flow rates and ASTM E96 inverted wet cup vapor permeance for a range of different waterproofing membrane types. The authors propose that this set of testing protocols or another proxy test be adopted by ASTM to determine the risk for osmosis, including thresholds above which a membrane may be deemed "high risk." To reduce the potential for osmotic blistering over concrete, it is recommended that waterproofing membranes used in inverted roofing

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assemblies should have an osmotic flow rate near 0.0 g/m^2/day when tested using the proposed protocol, an ASTM E96 inverted wet cup vapor permeance less than that of the substrate (i.e., less than 0.1 US perms on a concrete slab), and minimal long-term water absorption uptake. In addition to these thresholds, the long-term aging effects of the membrane should be determined.

Keywords
waterproofing, membrane, osmosis, absorption, vapor permeance testing procedure

Introduction

Waterproofing membrane failures due to osmotic blistering have occurred in some types of protected membrane/inverted concrete substrate waterproofing and roofing assemblies and have been observed in many parts of the world over the past two decades. Water blisters have been observed between the waterproof membrane and the concrete substrate and are often under considerable pressure. These self-contained, pressurized water blisters have no identifiable leakage path through or around the membrane. Blisters have ranged from millimeters to an entire roof area and contain significant quantities of water under pressure. Due to the hidden nature of a membrane within an inverted roofing assembly, the issue can go unnoticed for some time until other, more visible problems result from the large quantities of water held by the blisters. For example, large blisters have displaced concrete pavers, creating hazardous walking conditions, and water leaks have occurred as the blisters expand over cracks and joints in the concrete substrate. The issue is not exclusive to horizontal surfaces; blisters have also been observed on vertical applications in planter boxes and water features. Issues have not been observed with membranes over steel or wood substrates or in conventional roofing assemblies where the membrane typically is exposed or directly applied to insulation or a cover board substrate.

Several years ago, the authors set out to understand the cause of this phenomenon. Hygrothermal analysis shows that vapor diffusion can transport water through membranes with relatively high vapor permeance such as asphalt-modified polyurethane. Even though the membranes that were found to have the most water blisters also typically had high vapor permeance, the quantity of water found in the blisters is orders of magnitude higher than what can be expected from vapor permeance alone. Additionally, the water vapor pressure differences on either side of the membrane are not great enough to explain the high hydrostatic pressure that exists inside the blisters. The hypothesis that was later confirmed with further research was that the physical process of osmosis was drawing water through the semipermeable waterproofing membranes such as asphalt-modified polyurethane.[1,2] The solute concentration under the membrane (i.e., from the concrete/substrate or from the membrane itself) was measured and confirmed to be high enough to generate extremely high osmotic pressure within the blisters—up to 1,500 kPa (15 bar).[3]

Not all waterproofing membranes are at risk for developing osmotic blisters. For example, blistering has not been observed for hot rubber or styrene butadiene styrene (SBS) membranes, which are very common in this application. Research by the authors into the systematic failure of asphalt-modified polyurethane waterproofing membranes in the Pacific Northwest has led to the development of a testing procedure to estimate the risk for osmotic blistering of various other waterproofing membranes. The internally developed testing methodology has been used to measure osmotic flow through—and risk for osmotic blistering of—dozens of different waterproofing membranes including SBS, hot rubberized asphalt, poly(methyl methacrylate) (PMMA), ethylene propylene diene monomer (EPDM), thermoplastic polyolefin (TPO), high density polyethylene (HDPE), polyurea, asphalt emulsion, asphalt-modified polyurethane, and various other two-component cold-applied membranes. There is currently no industry-wide, standardized test to assess the risk of osmotic blistering of waterproofing membranes. The authors recommend that the testing methodology described in this paper be adopted by the ASTM Committees E06 and D08, including recommended target maximums for tested osmotic flow rate, ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*,[4] inverted wet cup vapor permeance, and a modified ASTM procedure for long-term water absorption.

WHAT IS OSMOSIS?

The process of osmosis can be described as the flow of a solvent, usually water, across a semipermeable membrane from a solution of low solute concentration to a solution of high solute concentration. This is possible when the membrane separating the two solutions is slightly permeable to water yet impermeable to the solutes. Thus, the water flows across the membrane to balance out the solute concentrations on either side of the membrane, as shown in figure 1.

If the vessel is open such as in the diagram in figure 1, the water level on one side rises until the hydrostatic pressure equals that of the osmotic pressure as defined by equation (1):

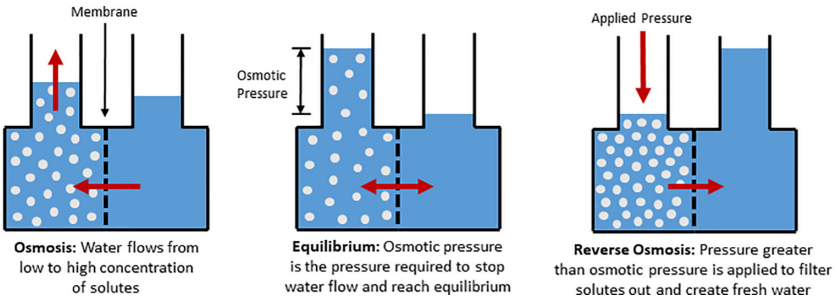
$$\pi = \varphi \cdot C \cdot R \cdot T \tag{1}$$

where:

π = osmotic pressure (bar, SI unit of pressure),
φ = osmotic coefficient (unitless, value that characterizes the dissolution of the individual salts in solution),
C = concentration of all dissociated solutes (mol/L where mol is the standard unit of measurement for an amount of substance),
R = universal gas constant (0.083145 L·bar/mol·K), and
T = temperature (Kelvin, absolute measure of SI temperature equal to °C+273).

Osmotic pressure is a colligative property, meaning that the property depends on the concentration of the solutes and not on their identity. In other words, the osmotic flow across a system with 1.0 M sodium chloride (NaCl) as the solute is the

FIG. 1 Diagram showing the process of osmosis and reverse osmosis. Water flows across a semipermeable membrane to dilute a high concentration of solutes on the other side (osmosis) until the hydrostatic head equals the osmotic pressure (equilibrium). Water can be forced back across the membrane by application of pressure (reverse osmosis).



same as an identical system with 1.0 M potassium iodide (KI) or a 1.0 M mixture of dissolved solids that come off a concrete slab when water is trapped within a blister below a waterproof membrane. Typical solutes that have been measured in osmotic blisters from inverted roof assemblies include calcium, carbonate, magnesium, potassium, sulfur, and silicon from the concrete substrate and, in many cases, organic compounds from the membranes themselves.[3]

Methodology

Currently, there is no industry standard to evaluate the osmotic risk of waterproofing membranes. The authors have shown in previous research that vapor permeance and water absorption are often related to the osmotic flow potential of waterproofing membranes.[1] As such, the proposed protocol includes both ASTM E96 wet cup and inverted wet cup vapor permeance testing and long-term water absorption testing in addition to the internally developed osmotic flow rate methodology. The proposed osmosis test protocol includes three parts:

1. Osmotic flow rate testing (method developed by the authors)
2. Water absorption testing (method adapted from ASTM D570, *Standard Test Method for Water Absorption of Plastics*,[5] for a longer time frame)
3. Vapor permeance testing (by wet cup and inverted wet cup per ASTM E96)

OSMOTIC FLOW RATE TEST

The test methodology to measure osmotic flow rate has been refined by the authors over the past decade. A solution of 1.0 M NaCl (equivalent to total dissolved solids [TDS] of 58,500 ppm) is placed in a glass container; the test membrane is cut to fit the top of the container and sealed to separate the salt water inside the container

from the distilled water in a water bath outside the container. The apparatus is designed so the osmotic flow of water from the freshwater side to the saltwater side is easily measured by the mass increase within the container. The test containers are removed for gravimetric measurements taken at regular intervals, and the osmotic flow of water into the container ($g/m^2/day$) is calculated after some baseline adjustments.

The following procedure was used to measure the osmotic flow rate through waterproofing membranes:

1. The samples of membrane are cut into circular discs to fit within a powder-coated, corrosion-resistant, screw-top lid fitting of glass containers. Each membrane sample is initially weighed, and the thickness is measured at a minimum of five points to determine an average thickness.
2. A known volume (approximately 80 mL in a 250-mL glass jar) of salt water is poured into the glass containers. The salt water is typically 1.0 M NaCl, but other salts (to represent specific solute conditions at a site) and varying concentrations (to represent different osmotic pressures) may be tested.
    - Triplicate blank samples (with distilled water, 0.0 M NaCl) and triplicate test samples (1.0 M NaCl) should be produced for each membrane type being tested. Triplicate samples are used as a balance between having enough samples to see if there are outliers due to jar leaks and few enough samples to manage in a small lab space and minimize measurement time.
3. Two component fast-set epoxy is applied to the perimeter of both sides of the cut membrane disk to create a sealed gasket between the lid and membrane and the glass container. Once the lid with membrane has been sealed to the container, the system is let to set for 24 h.
4. After the epoxy has cured, the container is leak tested by placing it upside down on an absorbent material such as shop towel for 24 h, and checking the absorbent material for signs of water, which may indicate a slow leak through the epoxy seal. Samples that show signs of leakage should be rejected from the test.
5. The initial mass of the container, membrane, and salt water together is measured using a scale with at least 0.01 g precision.
6. A freshwater bath is prepared using distilled water, and the samples are placed inverted on a rack in the bath to allow for fresh water under the containers where the membrane is located.
    - The water bath should be filled to a level so that the waterline is approximately level with the internal waterline of the inverted sample containers to eliminate the effect of hydrostatic water head on the samples.
7. At regular intervals (typically weekly), the containers and blank samples are removed from the freshwater bath, dried thoroughly using a durable and absorbent material such as a shop towel, and weighed using a scale with

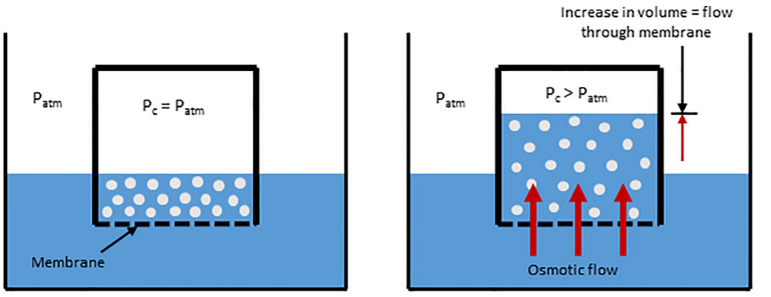
0.01 g precision. This process is repeated approximately once a week for several months.

8. Throughout the experiment, the TDS levels in the water bath are monitored regularly using a TDS meter, and water is changed when the TDS is elevated above 10 ppm, or approximately every two weeks, to maintain fresh water outside the sample containers.
9. The flow of water through the membrane is estimated by subtracting the mass of the initial container from each of the measurements throughout the experiment. There are also baseline corrections that may be carried out (i.e., sample containers with distilled water). Pros and cons of each baseline correction option are discussed later in this paper.

The duration of the osmosis flow rate experiment is typically four to eight months and may be shorter for membranes that have high osmotic flow rates or longer for membranes that are very impermeable to water (**fig. 2**).

The sample containers in the osmotic flow test undergo an initial wetting process during which they absorb water, although this does not necessarily contribute to water permeating through the material into the osmotic cell. The internally developed osmosis test procedure decouples the test container wetting from actual osmotic flow into the container by carrying out simultaneous absorption testing and control samples to subtract out this effect. In addition to blank samples with no salts (i.e., containers with distilled water), control samples with impermeable metal lids sealed with the same epoxy may be added to the experiment and their small weight gain throughout the experiments can be subtracted from the sample osmotic measurements.

FIG. 2 Diagram of an individual sample container in water bath for osmotic flow experiment. If the membrane is semipermeable, fresh water can flow into the jar of saline water over the course of the four- to eight-month experiment due to the process of osmosis.



Initial Setup: Pressure within container is equal to atmosphere

Effect: Osmosis occurs until the pressure within container reaches the osmotic pressure

LONG-TERM ABSORPTION TEST

Water absorption measurements are part of the authors' proposed standard osmosis testing procedure for two main reasons:

a) *To understand the long-term effects of contact with liquid water*
The absorption of water by waterproofing membranes can change their properties over time. Water absorption can dissolve some components of the material over time as well as loosen the adhesion of layers including fiber reinforcement. These changes to the chemical and physical properties of membranes can lead to decreased performance and failures in the field. Very high moisture absorption rates have been shown to fail waterproofing membranes on their own without osmosis occurring due to swelling, reemulsification, softening, or material degradation.[6,7]

b) *To calibrate the osmosis results*
Most membranes in the osmosis experiments go through a wetting process during which they absorb water, although this does not necessarily contribute to water permeating through the material. The osmosis test procedure developed decouples these two processes.

The absorption testing procedure generally follows industry standard water absorption tests (immersion of sample in room temperature water), yet for a longer time than most procedures specify. The 24-h moisture absorption specified in various ASTM standards (including ASTM D570 for plastics) is insufficient to accurately assess the long-term moisture uptake of a waterproofing membrane in an inverted roofing application that can be installed for 30 to 40 years. Longer-term testing is important as long-term water absorption into a waterproofing membrane may affect its durability and material properties (e.g., vapor permeance, susceptibility to osmosis, material strength).

1. The samples of membrane are cut into circular discs of similar size as for the concurrent osmotic flow rate test. Each membrane sample is initially weighed, and the thickness is measured at a minimum of five points to determine an average thickness.
2. Membrane samples are placed on a grate within a clean waterproof container. The grate serves to prevent membranes from sticking to the base of the container and to maintain water flow underneath the membranes.
3. The container is filled with fresh water until membrane samples are just covered with water (approximately 5 mm above samples). If the membranes float, a light grate is placed on top to maintain membrane submergence in the water bath.
4. At regular intervals (typically weekly), the membrane samples are removed from the freshwater bath, dried gently using a durable and absorbent material such as a shop towel, and weighed using a scale with at least 0.01 g precision. This process is repeated approximately once a week for several months, on the same days as gravimetric measurements for the concurrent osmotic flow test.

As part of the proposed standard osmosis testing protocol, the water uptake and moisture content of a membrane is measured for the duration of the concurrent osmotic flow rate test, typically four to eight months.

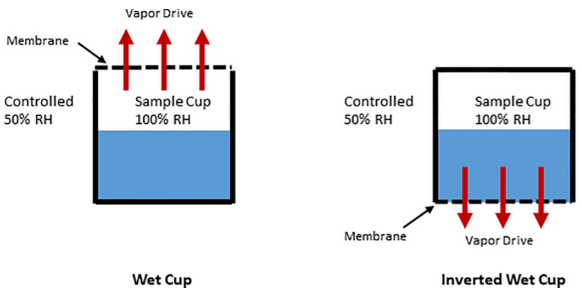
VAPOR PERMEANCE TEST

The third and final piece of the proposed standard osmosis test procedure is vapor permeance testing in general conformance with ASTM E96 for both wet cup and inverted wet cup vapor permeance measurements. Distilled water is placed within a glass container, and the material being tested is sealed on top such that it separates the interior of the cup to the controlled relative humidity (RH) conditions of a climate chamber. The vapor pressure gradient created between the water in the cup (100% RH) and climate chamber conditions (50% RH) results in the moisture leaving the cup through the test material. Wet cup measurements typically are recommended over dry cup for describing the in-service properties of water resisting barrier sheathing membranes as they are exposed to high RH levels for most of the year.

The inverted wet cup test is different from the regular wet cup method in that it inverts the standard wet cup apparatus in the climate chamber and exposes the top side of the membrane to liquid water (see diagram in fig. 3). The average RH the material sees in this case is the same as the wet cup; however, liquid water and capillary flow are present. Inverted wet cup measurements are recommended for the in-service properties of waterproofing membranes that are in contact with liquid water for significant periods of time, especially those used in protected membrane/inverted roofing assemblies, although this is currently not a common industry practice (typically dry cup measurements are used for product specifications as they generate lower permeance results).

The change in mass of the apparatus is measured using a laboratory scale, and the resulting vapor permeance is calculated from the loss of mass over time per unit area of material (see ASTM E96). The preparation of the samples for the wet cup and inverted wet cup tests follows the same steps as sample preparation for the

FIG. 3 Wet cup (left) and inverted wet cup (right) vapor permeance test procedures per ASTM E96.



osmosis measurements, although the water inside the containers is distilled water instead of salt water as in the case of the osmosis test samples.

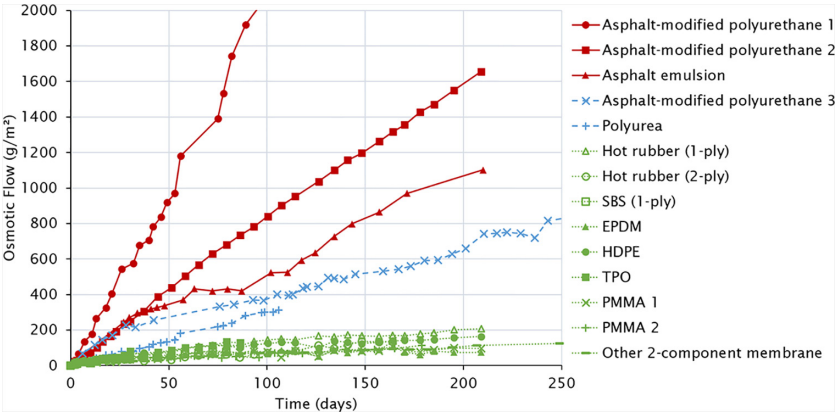
Results and Discussion

OSMOSIS PROTOCOL TESTING RESULTS

The osmotic flow testing protocol developed and refined by the authors has been used to estimate the risk for osmotic blistering of waterproofing membranes in the field. Although at first the concern was specifically for two-component cold-applied membranes, a wide range of membrane types has been tested including other cold-applied polymer membranes and hot rubber and torched SBS.[1–3,8] A summary of some of these results is shown in figure 4.

Waterproofing membranes may be grouped into different levels of risk for osmosis to occur in the field using osmotic flow rates determined through the proposed testing protocol. In figure 4, high-risk membranes are shown with solid lines and typically have osmotic flow rates between 5 and 20 g/m^2/day or higher. Membranes that fall into this high-risk category are typically two-component, cold-applied systems such as asphalt-modified polyurethanes (especially aged samples) and asphalt emulsions or other semipermeable materials. Membranes that fall into the medium-risk category (shown with dashed lines in the figure) typically have osmotic flow rates between 2 and 4 g/m^2/day and include some new asphalt-modified polyurethanes and polyureas. These medium-risk membranes may have unknown long-term performance in the field due to aging and degradation

FIG. 4 Graph of osmotic flow test results from a subset of experiments over the past decade using the authors' proposed testing protocol. The membranes determined to be at high risk for osmotic blistering in the field are shown with solid lines. The medium-risk membranes are with dashed lines, and the low-risk membranes are with dotted lines.



(discussed later). Membranes that typically test near 0.0 ± 1.0 g/m^2/day are deemed to be low risk and have not been known to exhibit osmotic blistering in the field (shown with dotted lines in the figure). These low-risk membranes include hot rubber, SBS, PMMA,* EPDM, TPO, and HDPE sheet (60 mil).

To minimize the risk for osmotic blistering in the field, the authors propose that a testing protocol such as the one presented in this paper be adopted by ASTM for waterproofing membranes. It is recommended that an osmotic flow rate—tested using this methodology—not exceed 0.0 ± 1.0 g/m^2/day for a membrane to be considered low risk and acceptable for application in areas with high moisture and water exposure such as inverted or protected roof assemblies.

VAPOR PERMEANCE AND MEMBRANE AGING

The past decade of osmosis testing by the authors has revealed some trends regarding which membranes perform better or worse in the osmotic flow rate test. Two key membrane characteristics have been linked to high osmotic flow rates: vapor permeance and aging.

At first, a trend with membrane thickness was discovered, though with further experiments it became clear that the correlation of membrane thickness with osmotic flow rate was in fact linked to the difference in vapor permeance. Thicker membranes generally have lower vapor permeance. Since the process of osmosis hinges on the permeability of the membrane for water transport, this result further corroborates the findings that water-filled blisters are due to osmosis. Graphs showing the correlation of osmotic flow rate with both membrane thickness and membrane permeance are provided in figure 5 and figure 6. A more consistent correlation with permeance (rather than with thickness) is observed.

The trend of higher osmotic flow rate for membranes with higher vapor permeance makes sense because the process of osmosis depends on the membrane being semipermeable to water yet impermeable to dissolved solids (e.g., salts, organic compounds). The higher the permeance of the membrane, the more easily water may be transported across it.

Another key finding from the osmosis testing by the authors is the uncertainty in performance of aged membranes. Figure 7 shows the osmotic flow rates and vapor permeance of three sets of asphalt-modified polyurethane membranes. As seen in figure 7, both aged membranes (shown in triangles) perform worse than the lab-cured new membrane (shown in open diamonds), which indicates membrane degradation and increase in vapor permeance of the membranes over time. These results illustrate that a new membrane may perform adequately in testing, although a membrane that has been installed in the field for five to ten years (i.e., from Sites 1 and 2 in the figure) may have significantly different properties. Even between two sites, from which asphalt-modified polyurethane membrane is recovered and tested, results can vary

*Although PMMA membranes are listed as low risk in these osmotic flow rate results, some PMMA membranes have been tested to have high long-term water absorption and may have unknown long-term aging impacts.

FIG. 5 Osmotic flow rate determined by the testing protocol developed by the authors versus membrane thickness. High-, medium-, and low-risk membranes are shown with triangles, circles, and squares, respectively. The correlation between thinner membranes and higher osmotic flow rates is further explained by the difference in membrane permeance as shown in figure 6.

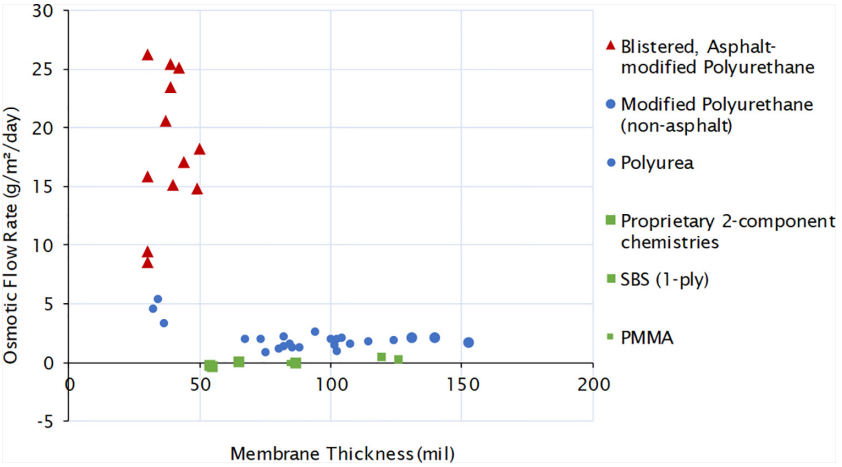


FIG. 6 Osmotic flow rate determined by the testing protocol developed by the authors versus vapor permeance determined through inverted wet cup testing per ASTM E96. High-, medium-, and low-risk membranes are shown with triangles, circles, and squares, respectively.

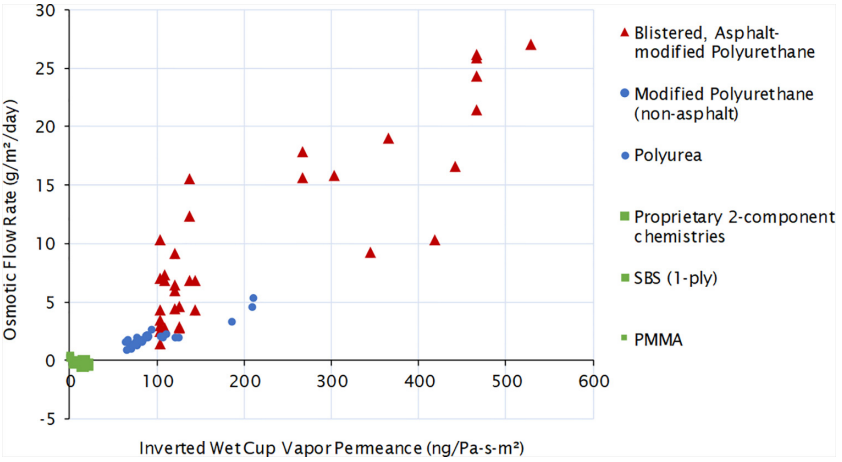
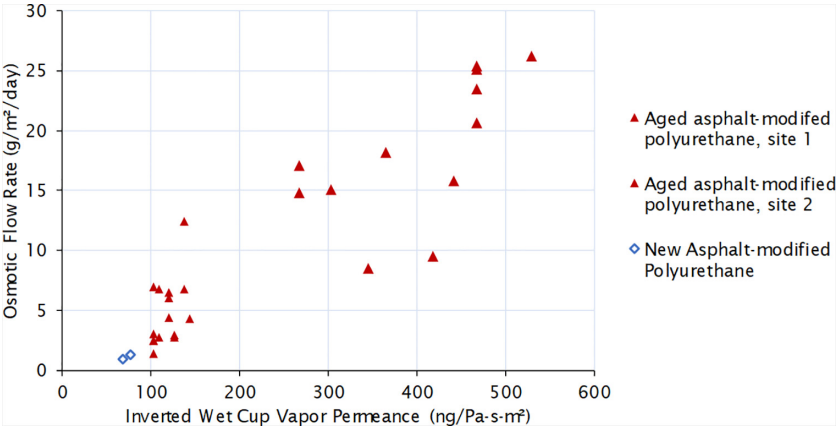


FIG. 7 Osmotic flow rate determined by the testing protocol developed by the authors versus vapor permeance determined through inverted wet cup testing per ASTM E96 for three sets of asphalt-modified polyurethane membranes, two aged membranes recovered from sites, and one unaged lab-cured membrane.



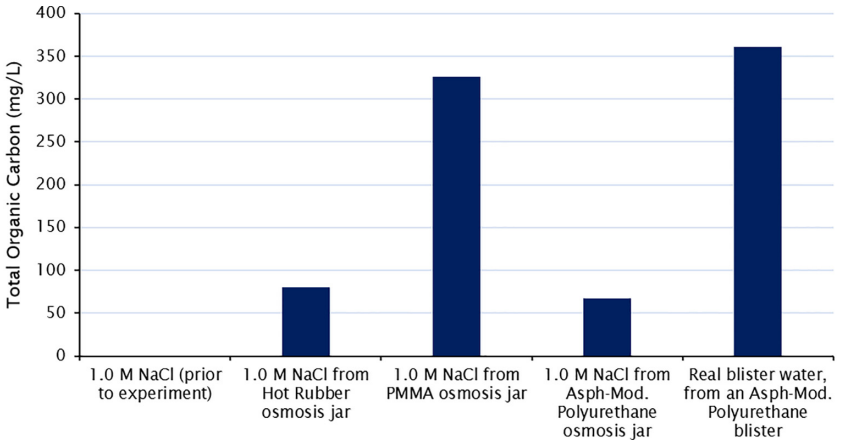
significantly. This illustrates that the locations and conditions in which membranes age may influence how much their properties change over time.

The unknown impact of aging in different locations and conditions (i.e., Site 1 versus Site 2 in fig. 8) highlights the importance of long-term testing for degradation of membranes over time. When membranes are exposed to liquid water, ultraviolet (UV) light, salts, metals, or organic substances over long periods of time, the properties of the membranes may be altered. For example, a membrane that has been in contact with water throughout an eight-month osmosis experiment, as described in this research methodology, has been shown to release organic compounds into the adjacent water. To quantify the amount of organic material that can be released from membranes in contact with liquid water over time, the water within a sample container from an osmosis experiment was collected and sent to a third-party analytical laboratory.

The measurable degradation of membranes that are submerged in water for even eight months cannot be ignored. Most membranes are tested for compliance with ASTM protocols as new membranes or after simulated aging for a limited amount of time. The results here show that some membranes may be losing some of their mass into the surrounding water over longer periods of time. This effect is currently being studied through ongoing experiments by the authors.* It is important to consider

*RDH Building Science, Inc., has nearly one dozen membranes currently in a membrane soaking experiment. The membranes have been submerged in separate containers of water for more than one year. The water in each container will be tested for compounds emitted from the membranes in the second year of the experiment.

FIG. 8 The total organic carbon (TOC) measured by a third-party analytical laboratory for various water samples. The 1.0 M NaCl water solution from before an osmosis experiment as well as from several osmosis test jars (hot rubber, PMMA, and aged asphalt-modified polyurethane—eight months later) and a sample from a real blister (approximately ten years after membrane installation) were measured.



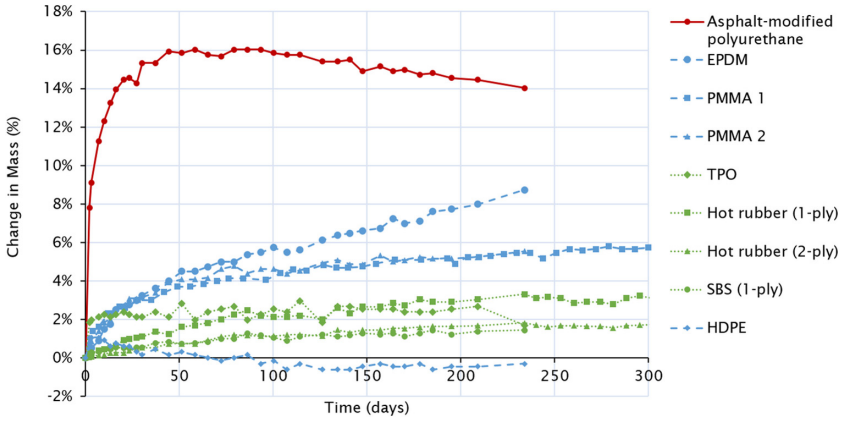
how membranes may degrade over time when they are in contact with liquid water, especially with different alkalinity from concrete or other substrates. Further study on this effect may elucidate and help predict how membrane characteristics can change in the field.

Another method to detect membrane degradation is long-term water absorption testing. Water absorption measurements are taken gravimetrically throughout the length of the osmotic flow rate testing. The weight of membrane samples is recorded, which generally shows an initial uptake of water, then equilibration as the membrane saturates. Figure 9 shows that in some cases, such as for asphalt-modified polyurethane, there is very high water absorption (more than 15%) followed by a gradual decrease in mass over the course of the measurements. This decrease in mass indicates that some of the membrane material is being lost to the surrounding water bath. The other membrane that shows a decrease in mass over time is the HDPE sheet with an adhesive that dissolved in the water over time. In the field, the adhesive side of the membrane should not be in contact with liquid water.

OPTIONS FOR BASELINE ADJUSTMENTS

The unknown effects of membrane degradation can impact the methodology for osmotic flow measurements, specifically for baseline subtraction. The following section provides an overview of different methods for baseline corrections that can be carried out for consistent osmotic flow estimates.

FIG. 9 Example data from absorption measurements concurrent to the osmotic flow measurements. Categories of high-, medium-, and low-risk membranes as determined by the level of water absorption are shown in solid lines, dashed lines, and dotted lines, respectively.



a) **Option 1: Blank sample subtraction**. In this methodology for baseline correction, triplicate sample containers are assembled for the osmotic flow test with 0.0 M NaCl solution (i.e., distilled water) instead of 1.0 M NaCl solution. In this methodology, the weight of water taken up by the sample by osmosis may be estimated by subtracting the blank sample mass increase from the osmosis sample mass increase using equation (2) for each measurement date.

$$M_o = \Delta M_c - \Delta M_b \tag{2}$$

where:

M_o = mass of water uptake into sample container due to osmotic flow,
ΔM_c = change in mass of sample container, and
ΔM_b = change in mass of blank container (with distilled water).

Recommendation: Include blank samples in each experiment as best practice for quality assurance, though using the results from these blanks may not be ideal for baseline correction for the reason stated as follows.

Issues: Total dissolved solids concentration inside the container may be nonzero by the end of the experiment due to membrane degradation, as discussed in the previous section. This option also increases the number of containers in the osmotic flow test.

b) **Option 2: Absorption subtraction**. This methodology for baseline correction utilizes the absorption measurements that are taken concurrently with

the osmotic flow rate testing. If absorption measurements are not taken on the same days as the gravimetric analysis for osmosis, the absorption measurements may be used to create a best-fit curve and estimate absorption at other dates to match the osmosis analysis. The amount of water absorption may be subtracted from the gravimetric measurements of the osmosis sample jars using equation (3) for each measurement date.

$$M_o = \Delta M_c - (\%_{H_2O} * M_m * f) \tag{3}$$

where:

M_o = mass of water uptake into sample container due to osmotic flow,
ΔM_c = change in mass of sample container,
$\%_{H_2O}$ = percent of change in mass determined by water absorption measurements,
M_m = mass of membrane sample, and
f = a factor, typically near 0.25, to account for less water absorption by the membrane once it is sealed in the sample container compared to what it experiences in the water bath for absorption measurements (because water absorption from only one side and not the edges will impact the weight of the sample container).

Recommendation: This baseline correction is adequate for membranes that exhibit high osmotic flow (i.e., 5 to 20 g/m^2/day or higher). In all cases, absorption measurements should be used to gauge when water absorption has equilibrated, at which point the osmotic flow can be determined from the slope of the gravimetric analysis from the osmosis test.

Issues: Membranes with very low or no osmotic flow have lower signal-to-noise ratios, which reveals a need for further baseline correction to remove the initial wetting impact of the sample container and epoxy (see Option 3).

c) **Option 3: Epoxy blank subtraction**. This baseline correction methodology uses triplicate control samples with impermeable lids in place of the membranes being tested. Gravimetric measurements of these controls reveal a slight weight increase over time of the sample containers even when no membrane is present, indicating that the epoxy had a minor water absorption that needs to be accounted for in cases of low signal-to-noise ratios. The amount of weight increase from water absorption of the epoxy blank may be subtracted from the gravimetric measurements of the osmosis samples using equation (4) for each measurement date.

$$M_o = \Delta M_c - \Delta M_e \tag{4}$$

And, optionally, with additional membrane absorption subtraction, using equation (5):

$$M_o = \Delta M_c - \Delta M_e - (\%_{H_2O} * M_m * f) \tag{5}$$

where:

M_o = mass of water uptake into sample container due to osmotic flow,
ΔM_c = change in mass of sample container,
ΔM_e = change in mass of epoxy blank container,
$\%_{H_2O}$ = percent change in mass determined by water absorption measurements,
M_m = mass of membrane sample, and
f = a factor, typically near 0.25, to account for less water absorption by the membrane once it is sealed in the sample container compared to what it experiences in the water bath for absorption measurements (because water absorption from only one side and not the edges will impact the weight of the sample container).

Recommendation: This baseline correction is adequate for most membrane types, though the additional samples and analysis may not be necessary for membranes with high osmotic flow rates (i.e., 5 to 20 g/m^2/day or higher).

Issues: This option increases the number of sample containers that are included in the methodology. Care must be taken to not overcorrect with compounding the epoxy blank and the membrane absorption subtraction—a low f factor may be used in the absorption subtraction to minimize this.

Each of these baseline adjustment options has its pros and cons. Having an estimate for how high the expected osmotic flow rate will be can help in choosing an appropriate baseline correction option. Because the database of osmotic flow risk for different membrane types is currently being developed, it may not always be possible to estimate a risk for osmosis prior to conducting the osmotic flow test. As such, it may be useful to develop a simpler proxy to estimate osmotic risk prior to a long experiment, such as using vapor permeance as an indicator of approximate osmotic risk.

USING A PROXY FOR OSMOTIC RISK

One recommendation for estimating the risk level for osmosis is to consider the inverted wet cup vapor permeance of a membrane. As discussed in this paper, there is a correlation between vapor permeance and osmotic flow rate due to the dependence of osmosis on membrane permeability to water and not solutes.

For vapor permeance to be used as a proxy metric for osmotic risk, the authors recommend that inverted wet cup testing be required for waterproofing materials. It is currently common industry practice to report vapor permeance testing using the dry cup protocol and—at times—the wet cup protocol; yet, the inverted wet cup protocol in ASTM E96 is very rarely used. This inverted wet cup methodology reports measurably higher vapor permeance than dry cup testing because it includes conditions for capillary flow and is more representative of the environment in which waterproofing membranes are installed in situations such as protected/inverted roof assemblies.

Conclusion

Currently, there is no industry standard to test for the risk of osmosis in waterproofing membranes. The authors have developed a protocol to measure the osmotic flow and evaluate the risk of osmotic blistering in waterproofing membranes including an osmotic flow rate test, inverted wet cup vapor permeance testing, and long-term absorption testing.

This paper summarizes the results from a decade of osmosis testing for various waterproofing membranes. It is recommended that the osmotic testing protocol developed by the authors be adopted by ASTM as a standardized approach to estimate osmotic risk.

Ongoing osmotic testing is continuing to help develop a database of test results for different membrane types. The authors are also further investigating the degradation of membranes after long-term exposure to liquid water. Nearly one dozen membranes are currently in a membrane soaking experiment. These membranes have been submerged in separate containers of water for more than year. The water in each container will be tested for compounds emitted from the membranes in the second year of the experiment to better understand how the membrane properties may be changing over time.

It is also recommended that accelerated aging testing be considered to better understand how membranes perform after years on sites. Additional analysis of membranes after soaking in water with different alkalinity (or in contact with concrete) is important to understand membrane characteristics in the field, including risk for osmosis. Further testing should be carried out on aged versions of membranes as a comparison to the new, lab-cured samples to identify potential changes in properties such as vapor permeance or osmotic flow rate.

DEVELOPING A STANDARDIZED APPROACH

The testing protocol described herein has been used to measure osmotic flow rates ranging from near zero to more than 20 g/m^2/day for more than a dozen different waterproofing membrane types. In addition to recommending that this protocol be adopted by ASTM, the authors propose to establish thresholds above which a membrane may be deemed high risk. To reduce the potential for osmotic blistering over concrete, the authors recommend that a low-risk waterproofing membrane for use in inverted roofing assemblies should have an osmotic flow rate near 0.0 g/m^2/day when tested using the proposed protocol ($\pm$ 1.0 to account for experimental error). Additionally, the inverted wet cup vapor permeance should be less than that of the substrate (i.e., less than 0.1 US perms on a concrete slab), and the long-term water absorption should plateau around 5% or less.

In addition to the standardization of this osmotic testing protocol, the authors recommend that inverted wet cup vapor permeance testing be required for waterproofing membranes that are used in inverted roof assemblies. This test is more representative of the conditions that these membranes experience in the field.

The results from this test may also be used as an interim proxy to estimate the risk of osmosis because it has been determined that the inverted wet cup vapor permeance and osmotic flow rate are correlated.

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