SOLUTIONS TO ADDRESS OSMOSIS AND THE BLISTERING OF LIQUID APPLIED WATERPROOFING MEMBRANES

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ABSTRACT

Waterproofing membranes are widely used in the building industry as a barrier for water entry into a building enclosure. Over the past two decades, waterproofing system failure due to osmotic blistering has occurred in some protected membrane/inverted roofing assemblies. Not all waterproofing membrane assemblies are at risk for this process and the authors have developed a test protocol to establish the relative risk level of waterproofing membranes to osmosis. Using this protocol, the osmotic flow rate of SBS, hot rubberized asphalt, PMMA, EPDM, TPO, HDPE, polyurea, asphalt emulsion, asphalt-modified polyurethane, and various other 2-component cold applied membranes was measured to determine a threshold osmotic flow rate for low risk waterproofing membrane systems.

In this research, a wide range of osmotic flow rates were obtained for the various membrane types. Most asphalt-modified polyurethane membranes consistently exhibit osmotic flow rates significantly higher than the low-risk threshold of ~0.0 g/m²/day (typically 1.4 to over 20 g/m²/day) after data corrections, which results in osmotic blistering and premature membrane failures. Some polyurea and asphalt emulsion membranes have flow rates above 2.0 g/m²/day with unknown long-term performance, while most other membranes that were tested have flow rates around 0.0 g/m²/day after data corrections from control samples. To reduce the potential for osmotic blistering over concrete, it is recommended that waterproofing membranes used in inverted roofing assemblies should have an osmotic flow rate near 0.0 g/m²/day when tested using the methodology herein, an inverted wet cup vapour permeance less than that of the substrate (i.e. <0.1 US Perms on a concrete substrate), and minimal long-term water absorption.

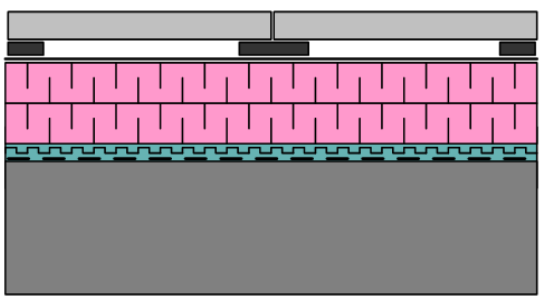
To study the effects of aging, water that was in contact with three membrane types for seven months was analyzed and chemical components from the degradation of membranes were identified. The dissolution of membrane components into the blister side water serves to self-propagate the osmotic blistering by increasing the solute concentration, and thus the osmotic potential, and by increasing the vapour permeance of the material. Future work will further analyze the degradation components of waterproofing membranes to understand how their properties and susceptibility to osmotic blistering may change throughout their lifespan.

INTRODUCTION

Over the past two decades, failures due to osmotic blistering have been noted to occur in some protected

membrane/inverted roofing assemblies. The authors have been researching the systematic failure of asphalt-modified polyurethane waterproofing membranes in the Pacific Northwest for over a decade. Dozens of sites have been reviewed after water-filled blisters formed and caused issues with the buildings 5 to 15 years after membrane application. The waterproofing membranes studied are generally applied to low-sloped concrete slabs in both insulated inverted roof and podium deck assemblies, as well as water features. Water-filled blisters were observed to form between the membrane and the concrete deck and are often under considerable pressure. These self-contained, pressurized water blisters have no identifiable leakage path through or around the membrane. Early work by others on roofs, planters, and water features (Farahmandpour, 2001; Depuis, 1994) has suggested that the source of water may be from drying of the concrete or perlite board substrate, although the quantity of water within many blisters is too large to be explained solely from drying of the substrate.

Blisters have ranged from millimeters to an entire roof deck area and contain significant quantities of water under pressure. Due to the hidden nature of 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.



- Concrete pavers, ballast or soil overburden
- Pedestals (optional)
- Filter fabric (optional though good practice)
- Extruded polystyrene insulation (over living spaces, not-present in many podium decks/planters over unconditioned spaces)
- Geotextile drainage mat (optional)
- **Waterproofing membrane**
- Concrete slab (6”)

Figure 1: Typical protected membrane/inverted roofing assembly when blistering of membranes has been observed. Due to the local climate is it not uncommon in the Pacific Northwest for water to remain at the membrane surface for much of the fall, winter, and spring.

Several years ago, the authors set out to understand the cause of this phenomenon. Hygrothermal analysis shows that vapour diffusion can transport water through membranes with relatively high vapour permeance such as asphalt-modified polyurethane (Finch et al. 2010). However, the quantity of water found in the blisters is orders of magnitude higher than what one would expect from vapour permeance alone. Additionally, the water vapour pressure differences on either side of the membrane is not great enough to explain the high hydrostatic pressure that exists inside the blisters. The hypothesis that was later confirmed with further research (Finch et al. 2009) was that osmosis was drawing water through the semi-permeable waterproofing membrane. The solute concentration under the membrane (e.g. from the concrete) was measured and confirmed to be high enough to generate extremely high osmotic pressure within the blisters.

In previous research by the authors as well as by other consultants, contractors and roofers across North America, osmotic blistering has been found to occur with cold applied asphalt-modified polyurethane membranes used in inverted roofing assemblies and not with liquid applied rubberized asphalt or sheet applied SBS modified bitumen. Observations have also noted that blisters are almost always larger and

more frequent in older membranes, which leads to questions of how membrane characteristics change over time. Ongoing research by the authors is being conducted to assess the susceptibility of various other membranes to this phenomenon as well as the link between degradation of older membranes and increase in osmotic flow and are presented in this paper.

Osmosis

The process of osmosis can be described as the flow of a solvent, usually water, across a semi-permeable 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.

Figure 2 depicts this process.

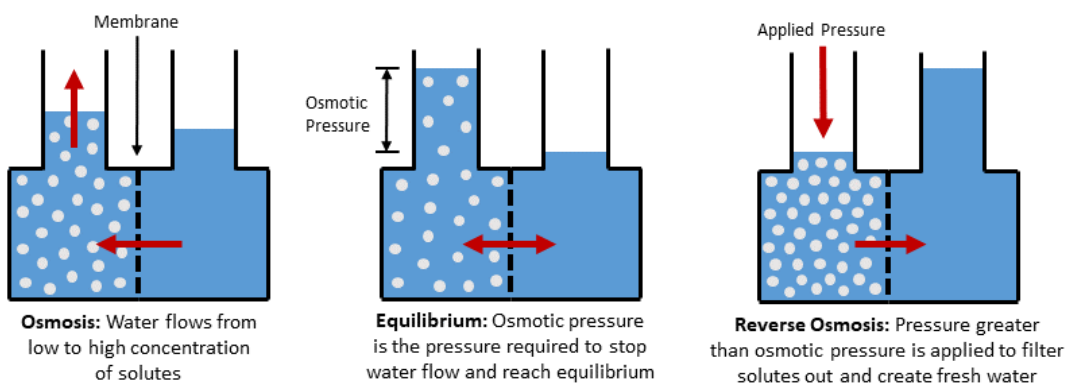


Figure 2: The process of osmosis, including its equilibrium state and reverse osmosis in a system with a semi-permeable membrane separating fresh water from a solute with high solute concentration.

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

$$\pi = \varphi \cdot C \cdot R \cdot T$$

Equation 1

Where π = osmotic pressure (bar, SI unit of pressure)
φ = osmotic coefficient (unitless, value which 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)
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 same as an identical system with 1.0 M potassium iodide 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. Total dissolved solids (TDS) in water extracted from beneath in situ waterproofing membrane blisters was measured to be great enough to exhibit osmotic pressure up to 15 bar. The salts found within these blisters comprise mostly of organic compounds and various inorganic compounds including calcium, magnesium, potassium, sulfur, and silicon.

Table 1: Total dissolved solids measured from blister water extracted from two sites in 2016 (sites A and B) and one site in 2009 (site C), as well as the rainwater on top of the blistered membrane.

TDS and equivalent osmotic pressure	Blister water sample from site A	Blister water sample from site B	Blister water sample from site C	Rain water pooled above membrane
Total Dissolved Salts (TDS), mg/L	17,500	13,056	3,650	7
Osmotic Pressure, kPa [bar]	1,488 [15]	1,089 [11]	326 [3]	~3 [0]

Forward osmosis occurs naturally in biological systems, for example osmotic pressure is the main cause of support for plants. Osmosis can be opposed by applying pressure greater than the osmotic pressure to the side with high solute concentration. This process is called reverse osmosis and is widely used in water purification technology.

Objectives

Although the process of osmosis has been thoroughly studied as it pertains to other industries such as water purification, traffic and bridge decking, and marine infrastructure, there is still very little research related to the process of osmosis in the roofing industry. There is a need to further understand of the susceptibility of different waterproofing membranes to this phenomenon. The main objectives of the ongoing research and this paper are to:

1) Determine the susceptibility of various waterproofing membrane types to osmotic blistering
2) Set recommendations for low-risk membranes (e.g. vapour permeance, osmotic flow rate)
3) Understand the aging effects of membranes in contact with liquid water for long periods of time

METHODOLOGY

There is currently no industry standard to test waterproofing membranes for osmosis. In previous research, it has been shown that wet/inverted wet cup vapour permeance and water absorption are often related to the osmotic flow potential of waterproofing membranes (Finch et al. 2009). Based on this past research the following osmotic testing protocol was developed and used:

1) Vapour permeance testing (by wet cup and inverted wet cup per ASTM E-96)
2) Osmotic flow rate testing (method developed by the authors)
3) Water absorption testing (method adapted from ASTM D-570 for prolonged periods of time)

Additional water analysis testing by an analytical laboratory supplements the test protocol and provides insight into the long-term degradation of membranes in contact with water for long periods of time.

Vapour Permeance – Wet Cup and Inverted Wet Cup

Samples were tested in general conformance with ASTM E-96 for both wet cup and inverted wet cup vapour 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 vapour 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 are typically 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 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, below). The average RH the material sees in this case is the same as the wet cup however liquid water, and capillary flow, is 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.

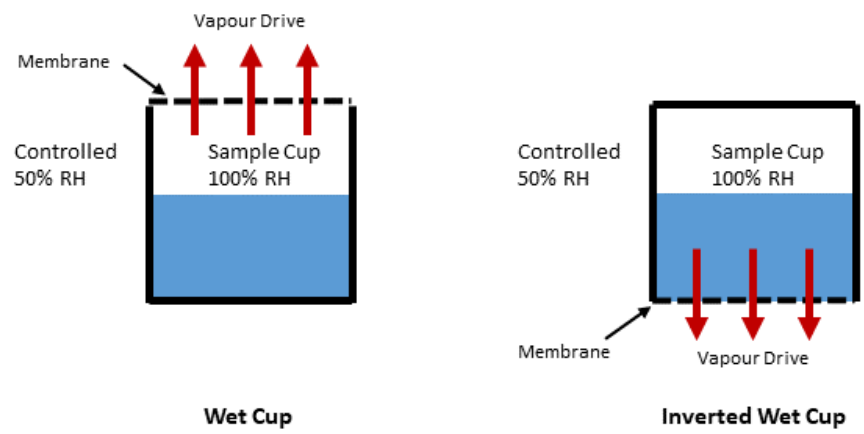


Figure 3: Wet cup (left) and inverted wet cup (right) vapour permeance test procedures per ASTM E-96.

The change in mass of the apparatus is measured using a laboratory scale and the resulting vapour permeance is calculated from the loss of mass over time per unit area of material. The preparation of the samples for the wet cup and inverted wet cup tests follows the same steps as sample preparation for the osmosis measurements, although the water inside the containers is distilled water instead of salt water as in the case of the osmosis test samples.

Osmotic Flow Rate

To measure osmotic flow through the membranes a solution of 1.0 M NaCl with a TDS of 58,500 ppm is placed in a glass container, the top of the container is sealed to the test membrane to separate the salt water from the distilled water. The apparatus is designed so the osmotic flow of water from the fresh side to the

salty side is easily measured by the mass increase within the container. Gravimetric measurements were taken at regular intervals and the osmotic flow of water into the container (g/m²/day) was calculated after subtracting the water absorption of the membranes that was measured concurrently. Control samples with impermeable metal lids sealed with the same epoxy were also tested and their small weight gain throughout the experiments was also subtracted from the sample osmotic measurements.

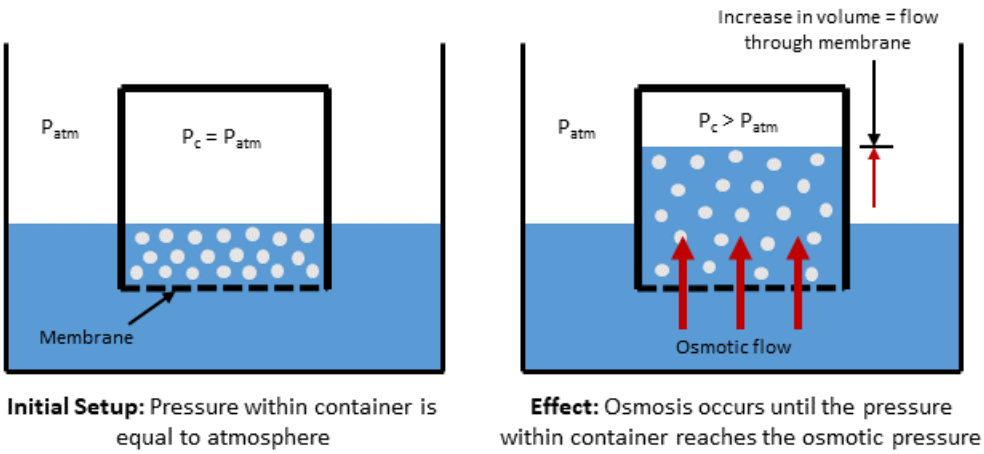


Figure 4: The osmosis testing apparatus at the beginning of the experiment (left) and once osmotic flow into the container has occurred (right).

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 5 points to determine an average.

2) Two component fast-set epoxy is applied to the perimeter of both sides of the membrane to create a sealed gasket between the lid and membrane and the lid and glass container and close off any gaps between the lid and container to improve the measurement procedure.

3) A known volume (~80 mL) of salt water is placed into the glass containers. The salt water is usually 1.0 M NaCl, but other salts and varying concentrations are also tested. When enough membrane was available, one blank sample is produced for each membrane, where distilled water is used instead of salt water within the container.

Figure 5: Example of one osmosis sample container. The membrane (black) is sealed between the powder-coated lid (green) and the glass container (clear) with epoxy. Salt water is inside the container. Samples were given code numbers, which can be seen on the bottom of this container (*3.11*).

4) After the epoxy has cured and the container is leak tested, the initial mass of the container,

membrane, and salt water together is measured.

5) A fresh water bath is prepared using distilled water and the samples are placed on a rack in the bath (to allow water circulation). The bath is filled to a height so that the water line is equal with the internal water line of the inverted sample containers to eliminate the effect of hydrostatic water head on the samples.

6) At regular intervals, the containers and blank samples are removed from the fresh water bath, dried thoroughly, and weighed. This process is repeated approximately once a week for several months. The TDS levels in the water bath are monitored regularly and water is changed approximately every two weeks to maintain TDS close to 0 ppm outside the sample containers.

7) The flow of water through the membrane is measured by subtracting the incremental mass from the initial container, water, and sample mass. Measurements from control samples are also subtracted from the osmotic flow rate calculations.

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 standard osmosis test procedure developed decouples these two processes by carrying out simultaneous absorption testing and control samples to subtract this effect.

Absorption

Water absorption measurements were taken for two main reasons:

1) *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 fibre 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, re-emulsification, softening, or material degradation (Yang 2001, Howard 2002).

2) *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), but for a longer time than most tests procedures specify. The 24-hour moisture absorption specified in various ASTM standards (including ASTM D-570 for plastics) is insufficient to accurately assess the long-term moisture uptake of a waterproofing membrane in an inverted roofing application. This is important as long-term water absorption into a waterproofing membrane will affect its durability and material properties (i.e. susceptibility to osmosis and material strength etc.). As part of the standard test, the water uptake and moisture content of a membrane is measured until saturation of

the membrane is reached. For some membranes, this may take several months to occur.

Water Analysis

As a complementary analysis to the osmosis testing protocol, water samples from the osmosis containers were sent to a third-party analytical lab to measure what compounds dissolved off the membranes throughout the course of the experiments. The water sample analysis provides insight into how the membranes may change by losing small amounts of material over time when in direct contact with water. The third-party lab reported the following:

1) Anions, by ion chromatography with chemical suppression of eluent conductivity
2) Total organic carbon, by high temperature combustion – infrared CO_2 detection
3) Hardness (as $CaCO_3$), by calculation of total Ca and total Mg
4) Total dissolved solids, by gravimetry (dried at 103-105 °C)
5) Total metals, by HNO_3+HCl hot block digestion – ICP-MS detection

RESULTS

The authors have been researching the phenomenon of osmotic blistering in waterproofing membranes for over a decade (Finch 2009, Finch 2010, Finch 2014). The results presented here build off past research by further investigating a wider range of membrane types and including more experiments to elucidate membrane degradation over time throughout osmosis experiments as a proxy for in situ aging.

Osmosis Results

Osmotic flow rate experiments were performed on a series of traditional waterproofing membranes, including SBS modified bitumen (single ply sheet), 2-ply hot rubberized asphalt, two brands of reinforced PMMA, as well as an EPDM, a TPO, and an HDPE sheet (Figure 6). The gravimetric analysis of mass increase over time shown in Figure 6 was corrected for contributions from water absorption of the membranes. An earlier set of experiments, uncorrected for absorption, is shown in Figure 7 with additional asphalt-modified polyurethane samples, an asphalt emulsion, the average of several different polyurea membranes, and the average of several different 2-component cold-applied membranes. In these experiments, the osmotic flow rates were measured only after the samples had stopped absorbing water and the rate of osmotic flow became relatively constant.

Asphalt-modified polyurethanes are known to exhibit osmotic blistering in the field (Finch 2009). A large range of observed membrane thicknesses and osmotic flow rates was measured for asphalt-modified polyurethane samples due to the macroscopic variations in the samples retrieved from sites. All other membranes that were tested show relatively small osmotic flow in comparison and in fact are approximately 0.0 g/m²/day after data corrections from the control samples.

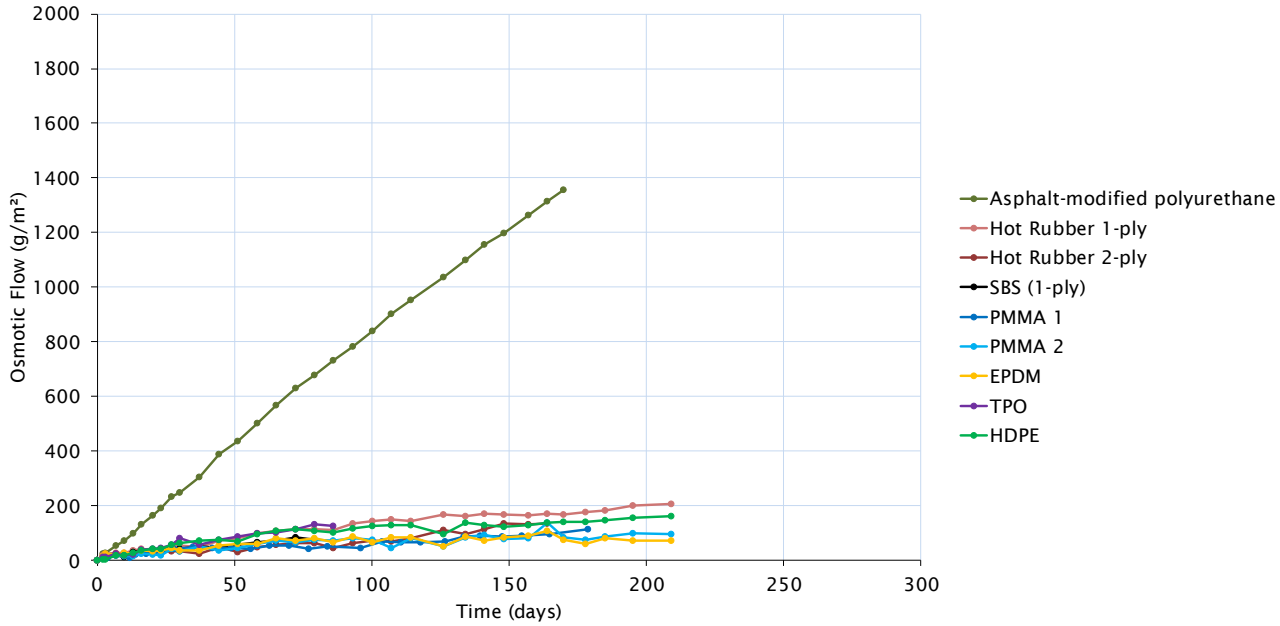


Figure 6: Osmotic flow of some membranes that were recently tested using the standard protocol. All samples here were tested with a 1.0 M NaCl salt solution in the containers.

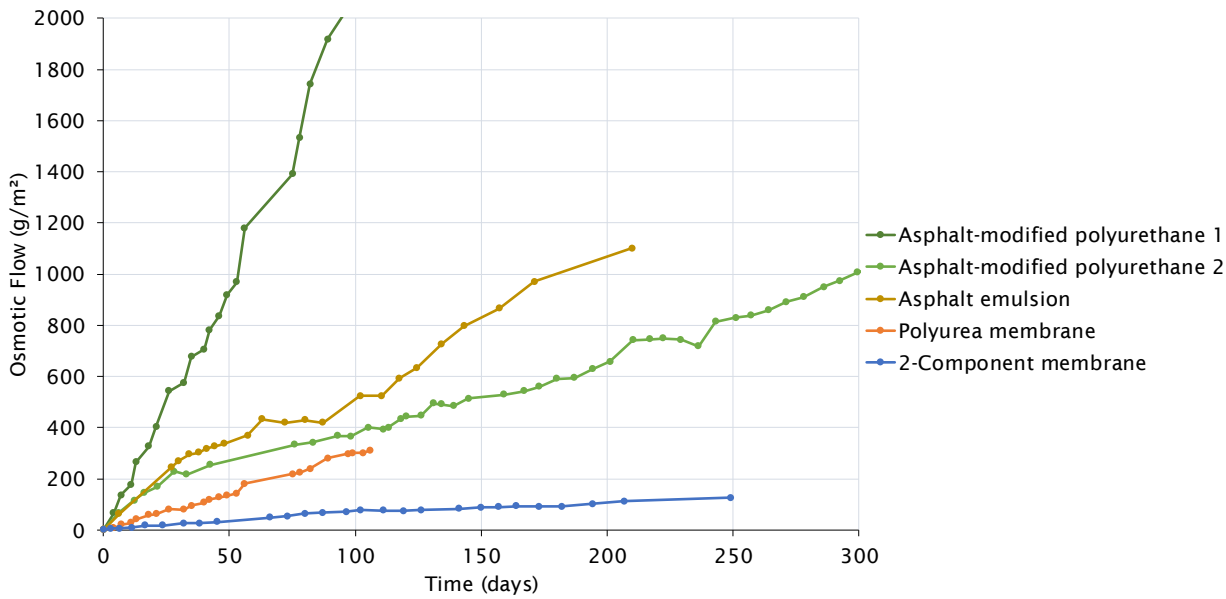


Figure 7: Osmotic flow of select membranes that were tested previously, including two asphalt-modified polyurethane membranes (green), an asphalt emulsion membrane (mustard), a polyurea membrane (orange), and a 2-component cold-applied membrane (blue). All samples were tested with a 1.0 NaCl salt solution in the containers.

Table 2: Membrane thicknesses and measured osmotic flow rates.

Membrane Type (name or material)	**Membrane Thickness (mil)**	**Osmotic Flow Rate (g/m²/day)**
Asphalt-modified polyurethane*	30 – 90	1.4 – 26.2
Asphalt emulsion	110	4.6 ±1.6
Polyurea	30 – 100	2.1 ±1.6
SBS (1-ply)	100	0.3 ±0.8
TPO	58	0.8 ±0.9
Hot rubberized asphalt (2-ply)	244	0.0 ±0.7
HDPE	52	0.0 ±0.7
PMMA	70 – 80	-0.2 ±0.8
2-Component cold-applied	40 – 90	-0.3 ±0.8
EPDM	47	-0.3 ±0.7

*There is a large range of observed membrane thicknesses and osmotic flow rates for asphalt-modified polyurethane samples due to the macroscopic variations in the samples retrieved from sites.

To understand the effect of solute concentration on the osmosis process, additional experiments were carried out using asphalt-modified polyurethane and hot rubberized asphalt membranes. The NaCl salt concentration was varied from 0.0 M (distilled water, negligible osmotic pressure) to 1.0 M (TDS of 58,500 ppm, equivalent to 49 bar of osmotic pressure). Since the osmotic pressure is a colligative property, one may expect higher salt concentrations to increase the osmotic flow through a semi-permeable membrane. This effect can be seen with the asphalt-modified polyurethane in Figure 8. Even at 0.0 M and 0.1 M salt concentration, osmotic flow into the jar may be propagated by the dissolution of membrane material into the container, increasing the equivalent osmotic pressure. In contrast, all concentrations of salt in the hot rubberized asphalt samples show very similar, low osmotic flow. These results show that even at high salt concentrations (1.0 M, 49 bar of osmotic pressure), low risk membranes do not exhibit significant osmotic flow. Note, the osmotic flow rate is calculated from the slope of the graph after subtracting the effects of water absorption by the membrane. The 0.0 M samples with negligible osmotic potential still exhibit very slight increase in mass over the course of the experiments. This can be attributed to the minor absorption of water by the epoxy that seals the membrane and lid to each sample container. This effect is minor and consistent for all samples. Control jars with impermeable metal lids sealed with the same epoxy were concurrently tested and the small amount of weight gain from these controls was subtracted from the end results of all test samples.

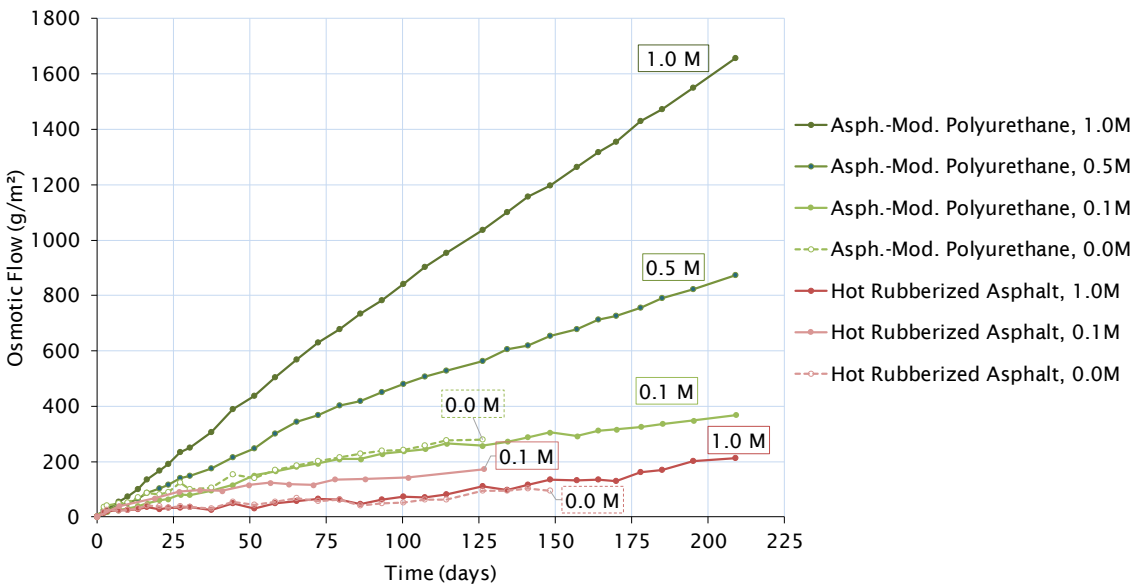


Figure 8: Osmotic flow of asphalt-modified polyurethane (green) and hot rubberized asphalt (red) with varying salt concentrations. Osmotic flow rate is calculated from the slope of the data.

The osmotic flow rate and inverted wet cup vapour permeance was measured for new and aged asphalt-modified polyurethane samples from sites that experienced osmotic blistering and is shown in Figure 9.

New asphalt-modified polyurethane membranes have significantly lower vapour permeance (68-77 ng/Pa-s-m²) than the aged samples (up to 529 ng/Pa-s-m²). The osmotic flow rate of the new samples is over 1.0 g/m²/day, whereas the aged samples have osmotic flow up to 26 g/m²/day. There is also a very large range in performance of aged membranes, likely due to different chemistry, thickness, primer, application conditions, and substrate conditions. In Figure 9, aged membranes were obtained from sites with osmotic blistering. Aged asphalt-modified polyurethane samples from roofs that had experienced osmotic blistering had laboratory osmotic flow rates as low as 1.8 g/m²/day.

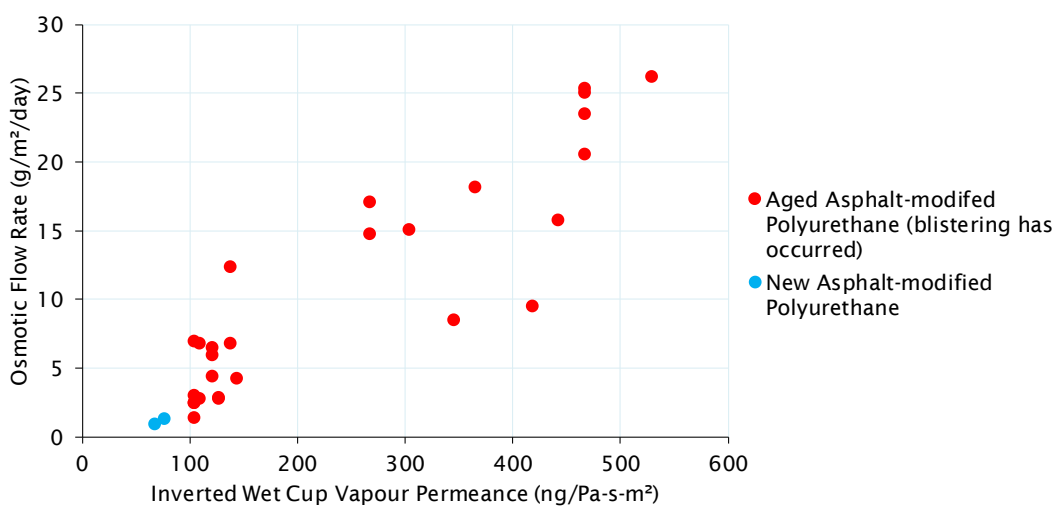


Figure 9: Correlation between osmotic flow rate and vapour permeance for asphalt-modified polyurethane samples, aged (red) and new (blue). Aged samples were obtained from sites with osmotic blistering.

These results suggest that the properties of asphalt-modified polyurethane membranes may change over time as the membranes age in service. The laboratory osmosis experiments revealed visible signs of aging of the membranes over the course of 7 months. The changes included stiffening and discoloration, as well as a yellowing of the water within some sample containers. To explore the potential dissolution of membrane samples into the water, supplementary water analysis was carried out after the osmosis testing protocol.

Absorption and Water Analysis Results

Absorption measurements are carried out in conjunction with the osmosis experiment as part of the developed protocol for osmotic flow analysis. The change in mass of the membranes throughout the absorption measurements is subtracted from the gravimetric measurements and calculation of osmotic flow rate. The change in mass for the membranes in the absorption test is shown below. All membranes have an initial uptake of water. After the initial uptake, some membranes show a decrease in mass for the remainder of the measurements. The decrease in mass, coupled with an increase in TDS in the absorption water is an indicator of membrane degradation over time (Strong 2004). This effect is most notable for the asphalt-modified polyurethane membrane. The HDPE sheet membrane, a proprietary below grade waterproofing product also exhibits a decrease in mass, which is likely due to compounds from the adhesive layer dissolving into the water bath and not the membrane itself. Other membranes may be losing fillers or may be slowly dissolving into the water bath. This effect can increase the TDS in the water blisters (Table 1) and self-propagate osmosis in waterproofing applications.

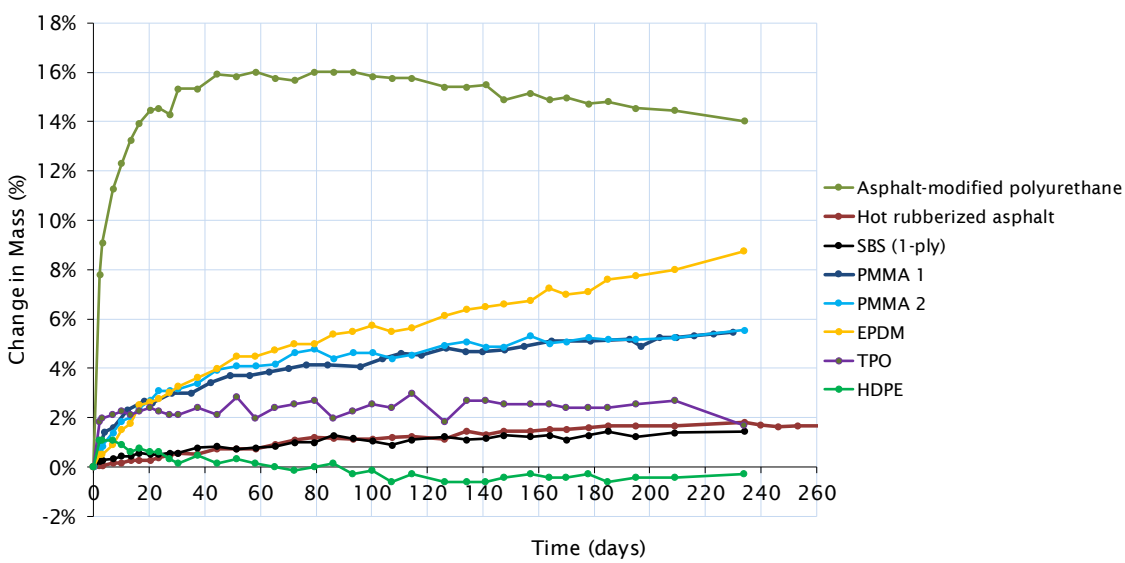


Figure 10: Absorption experiment results for the membranes. Note the high % change in mass from asphalt-modified polyurethane and the slight decrease in % change in mass for some of the samples.

The water inside the osmosis containers was analyzed after the gravimetric analysis was complete to test for compounds that were released from the membranes into the water over the test period. The following samples were tested:

1) 1.0 M NaCl solution before osmosis experiment

2) 1.0 M NaCl from the hot rubberized asphalt containers after 30 weeks in the osmosis experiment
3) 1.0 M NaCl from the asphalt-modified polyurethane containers after 30 weeks in the osmosis experiment
4) 1.0 M NaCl from the PMMA containers after 30 weeks in the osmosis experiment

Solute concentrations were compared to the reference solution of 1.0 M NaCl before the osmosis experiments, within which only sodium (Na) and chloride (Cl) were present. The post-experiment solute concentrations are shown below, in Figure 11, for water from the containers with hot rubberized asphalt, asphalt-modified polyurethane, and PMMA membranes. A real, in-situ blister water sample is also shown for reference.

The total dissolved solids (TDS) decreases over the course of the experiments due to osmotic flow of water into the containers and the resulting dilution of initial TDS. This effect is most pronounced the asphalt-modified polyurethane as these samples exhibited the highest rates of osmotic flow. In addition to the gravimetric analysis, this confirms that water is flowing through some membranes into the containers. The amount of water required for the dilution noted in the asphalt-modified polyurethane case is approximately 6 mL, equivalent to 6 g of water. The total amount of weight increase measured in the osmosis experiment is 8 g of water. Approximately 2 g of water is absorbed by the membrane (as measured during the absorption experiment), which leaves approximately 6 g of weight increase that can be accounted for by osmotic flow into the jar.

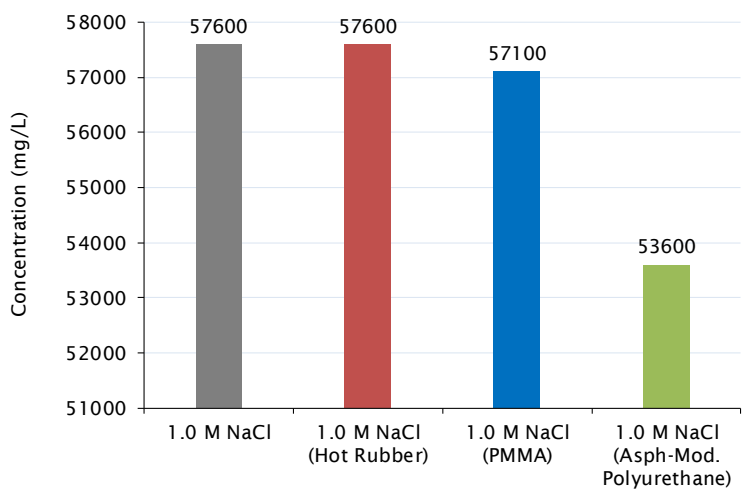


Figure 11: Change in concentration of total dissolved solids (TDS) in the 1.0 M NaCl solution over the course of experiments in contact with hot rubberized asphalt (red), PMMA (blue, and asphalt-modified polyurethane (green) membranes. Decrease in TDS points to water influx into the containers (i.e. osmotic flow).

In addition to TDS, individual solutes were measured in real in-situ blister water as well as the water from lab sample containers after over 30 weeks in the osmosis experiments (shown in Figure 12). In contrast to the TDS measurement, these solutes were not present in the initial 1.0 M NaCl solution in the hot rubber, PMMA, or asphalt-modified polyurethane samples and must have come from the membrane or sample container throughout the osmosis experiment. In the case of the in-situ blister water extracted from blisters after 10 years in service, these solutes may have originated from the asphalt-modified polyurethane membrane or the concrete substrate.

Significant amounts of total organic carbon (TOC), calcium, potassium, silicon, and sulfur can be seen in the water extracted from the osmosis experiment sample containers. The TOC measurement is particularly interesting since it points to degradation of the carbon-containing structural components of the different membranes. Sulfur is present in bitumen-based materials as well as some plasticizers, which may be used to obtain certain texture characteristics. Past research by the authors has identified silicon and magnesium as inorganic filler components in some waterproofing membranes. Calcium is also used as a filler in many membranes and is likely also present from the concrete substrate for the membranes that were extracted from sites. The high concentration of potassium in the blister water is likely from potash admixtures in the concrete substrate.

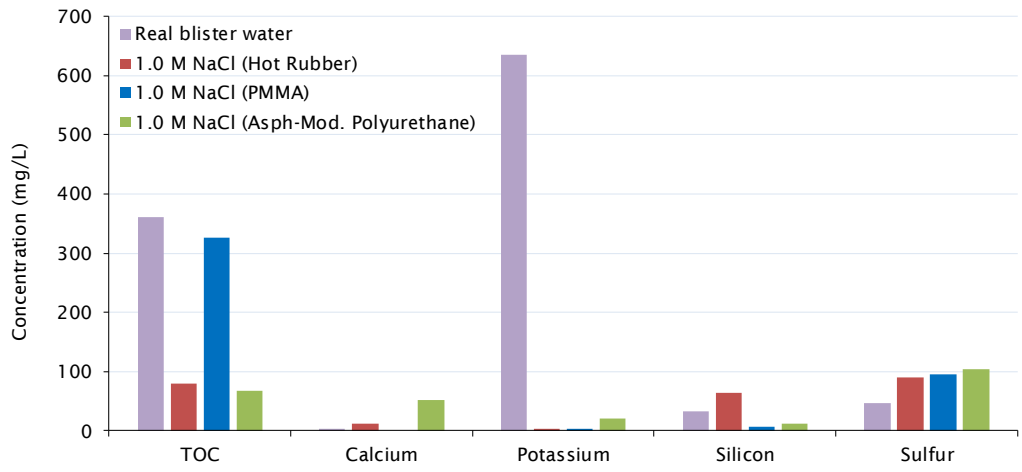


Figure 12: The solute concentrations from water extracted from a real osmotic blister (light purple), as well as from water inside osmosis experiment containers: hot rubberized asphalt (red), PMMA (blue), and asphalt-modified polyurethane (green). Note, for the lab experiments, the starting 1.0 M salt solution has 0 mg/L of all these solutes.

DISCUSSION

Past, current, and future work by the authors aims to establish thresholds for vapour permeance, water absorption, and osmotic flow rate utilizing a developed test method to predict the risk level for membrane failure in the field. Utilizing osmotic flow measurements of low-risk reference membranes such as SBS and hot rubberized asphalt, a low-risk threshold level of osmotic blistering can be identified. Membranes that exhibit osmotic flow rates near 0.0 g/m²/day when tested with a 1.0 M salt solution and corrected for background absorption using control samples, an inverted wet cup vapour permeance of <0.1 US Perms, and minimal long-term absorption that stops after a few months should have a low risk of osmotic blistering provided they are properly installed to an acceptable substrate.

The authors have found some membrane chemistries that demonstrate low osmotic flow and relatively low vapour permeance values, but these materials have long-sustained absorption during the several month test procedure. Long-term absorption is potentially a concern for other degradation mechanisms in waterproofing applications. Further long-term study of the behavior of these membranes is warranted in the field.

Osmotic flow rate, vapour permeance, and water absorption are interrelated with respect to membrane

durability and risk of osmosis. There is a visible correlation between inverted wet cup vapour permeance and osmotic flow rate, as shown in Figure 13 for many membrane types tested by the authors over the past decade.

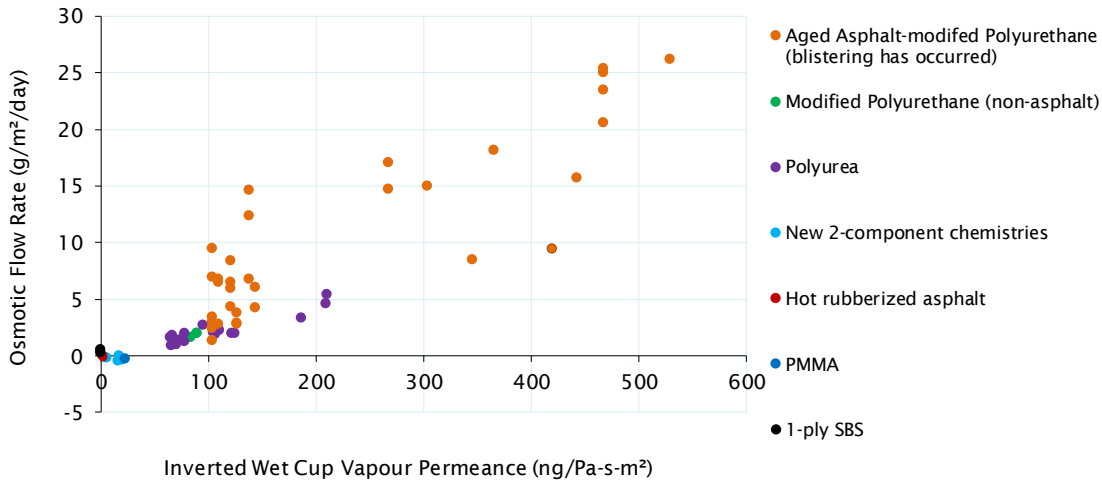


Figure 13: Osmotic flow rate measured by the RDH method versus vapour permeance measured by inverted wet cup. Note the positive correlation. The asphalt-modified polyurethane samples are aged and were extracted from sites that had experienced blistering.

To minimize the risk of osmotic blistering in inverted roofing assemblies, it is suggested that the waterproofing membrane has a vapour permeance (tested using the inverted wet cup ASTM E-96 procedure) lower than the vapour permeance of the substrate on which it is applied. This should prevent the accumulation of moisture and the resulting saturated concrete surface that is required to start the osmosis cell. The wet cup vapour permeance of a 6" concrete slab is generally reported to be in the range of 0.1 to 0.5 US Perms. Thus, the aged membrane vapour permeance should conservatively be lower than 0.1 US Perms (or <6 ng/Pa-s-m²) in this application. This guidance is summarized in Figure 14.

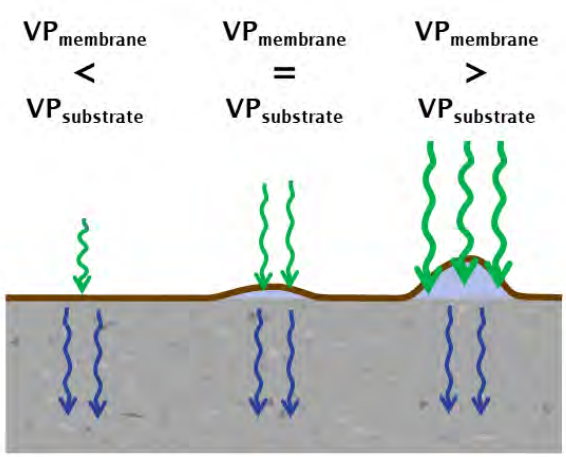


Figure 14: Diagram of vapour drive within concrete substrate. When the membrane (shown in brown) has higher vapour permeance than the substrate (concrete) this can lead to water accumulation and an osmotic cell.

The vapour permeance and osmotic flow rate thresholds that are set based on the results in current and past work correspond mostly to new membranes. The behaviour of aged membranes is still relatively unknown

and even the aged asphalt-modified polyurethane membranes tested in these experiments continue to change over the course of the experiments. The concentration of degradation byproducts from the sample membranes detected in the water after seven months is quite significant considering that the lifespan of waterproofing membranes is 20-30+ years.

The effect of membranes releasing solutes into the blister water has even greater implications than changing the texture and material properties. Since osmotic pressure is a colligative property, the release of solutes into the osmotic cell can increase the osmotic flow rate. Thus, the aging of membranes can self-propagate higher osmosis rates via two mechanisms:

1) As membranes age and release more solutes into the blister water, the osmotic potential of the blister increases, encouraging more water to flow into the blister. This increases the pressure within the blister and it delaminates more membrane from the concrete substrate, exposing even more salts from the concrete to dissolve into the blister water. This positive feedback cycle self-propagates the blistering process.

2) The aging of membranes changes their physical properties. One effect of aging is the increase in vapour permeance, which contributes to osmotic flow rate. Another effect of aging is the loss of certain components such as fillers and plasticizers, which can result in a more porous or brittle membrane and can lead to other, non-osmosis-related failures.

CONCLUSION

The osmosis testing protocol was used to determine the osmotic blistering potential of a sub-set of waterproofing membranes including SBS modified bitumen, hot rubberized asphalt, PMMA, EPDM, TPO, HDPE, polyurea, asphalt emulsion, asphalt-modified polyurethane, and various other 2-component cold applied membranes. Tested asphalt-modified polyurethane membranes consistently exhibit an osmotic flow rate significantly higher than the other membranes, typically 1.4 to over 20 g/m²/day which in our experience results in osmotic blistering over concrete. Some polyurea and asphalt emulsion membranes tend to have flow rates above 2.0 g/m²/day, while most of the other traditional waterproofing membranes that were tested have flow rates around 0.0 g/m²/day after data corrections using controls. It is recommended that waterproofing membranes using in inverted roofing assemblies should have an osmotic flow rate around 0.0 g/m²/day and an inverted wet cup vapour permeance less than that of the substrate is recommended (i.e. <0.1 US Perms on a concrete substrate). In addition, the long-term absorption should be minimal and should stop after a few months with no apparent negative consequences on the integrity of the membrane. Water that was in contact with three membrane types tested was analyzed and chemical components from the degradation of membranes were detected in the water.

The following research is ongoing:

1) More detailed chemical analysis of membrane solutes released into water to understand what components are being degraded and how this may affect membrane performance.
2) Perform more osmotic testing of aged membranes to compare to the new membranes that have already been tested.

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