HIGH PERFORMANCE PSA IN SHEET MEMBRANE IN WATER PROTECTION

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Concrete is a durable composite material used to build a variety of buildings and infrastructures. It is a mixture of aggregate, cement, and water that hardens into a solid. It is susceptible to cracking due to shrinkage as it sets and builds strengths. Concrete is vulnerable to ground water and atmospheric contaminants that penetrate either due to the porosity of the concrete, shrinkage cracks or details such as cold joints, penetrations etc. It is critical that a structure be protected against water and harmful chemical ingress to maintain its durability and longevity. External waterproofing membranes are widely used to prevent water from penetrating below-grade steel-concrete structures and protect them from the ingress of water and harmful chemicals from groundwater or moisture in the soil. Typical sheet waterproofing membranes include plastic film/sheet as primary water resistant barrier and pressure sensitive adhesives (PSA) as a bonding layer between the plastic sheet and the concrete substrate. Waterproofing membranes can be installed as pre-applied or post-applied, depending on construction practices and site conditions. Pre-applied waterproofing refers to the system where waterproofing membrane is applied on a mud slab or blind side before concrete is poured. Post-applied waterproofing is installed after a structure is formed. In both methods, the ability of the waterproofing system to form a continuous, intimate bond to the concrete is the key to preventing water migrating between the waterproofing membrane and the concrete structure along the interface and achieving ultimate water protection.

The waterproofing membrane systems for below-grade construction are designed to provide flexibility to perform over a broad range of installation techniques, application temperatures, service temperatures, substrates and substrate conditions. The products also require good thermal, UV and water resistance attributes to accomodate construction site conditions and schedules. For below-grade slab waterproofing, pre-applied waterproofing is the preferred method, as it prevents water ingress from outside of the building structure. For the wall, either pre-applied or post-applied waterproofing methods can impart adequate performance. In modern construction, where the availability of land is limited and the structures are built right up to the property line, pre-applied waterproofing is the only solution. The adhesive side of such pre-applied membrane needs additional features that accommodate harsh construction site conditions, like high traffic, construction dust and direct sun exposure.

This paper will discuss the performance requirements in the below grade waterproofing segment and the rigors of the testing necessary to develop a product for such applications. The focus will be on the pre-applied waterproofing membranes, comprised of pressure-sensitive adhesives as the bonding component.

Pre-applied Waterproofing Membrane Design

In order to achieve waterproofing integrity for below grade applications, membranes need special considerations for the choice of carrier sheets and pressure-sensitive adhesives. Plastic sheets are typically used as carrier sheets to provide primary protection from water and other harmful chemicals from soil and ground water. The sheets need to have high resistance to water and chemicals, low vapor transmission, resistance to micro-organisms in soil, and puncture resistance for the job site activities. Typically polyolefin based sheets provide the best balance of performance for this application.

The second component of adhesively bonded pre-applied membranes is the choice and formulation of the pressure-sensitive adhesive (PSA). Typical adhesives used in this application are rubberized asphalt, synthetic adhesives like styrene-isoprene-styrene (SIS), styrene-ethylene/butylene-styrene (SEBS), butyl (a copolymer of isobutylene with isoprene) and other rubber-based adhesives. In designing the adhesive, special consideration has to be given to adhesion, creep, thermal and UV stability. It is important that the PSA is chosen and optimized for the performance attributes as well as long-term performance.

Third critical feature of the pre-applied membrane is the top trafficable surface. This is more important for the horizontal application than the vertical. It is generally achieved by adding a top layer that mechanically bonds to concrete, or a trafficable coating that bonds to concrete and bridges the PSA and the concrete substrate.

Test Criteria

Adhesion: Adhesion is an important performance attribute of a durable pre-applied membrane. As water tables fluctuate, unstable soils settle and the soil retaining systems degrade, and the materials supporting the waterproofing system may fall away. Therefore, if a membrane is not fully and strongly adhered to the concrete, the movement stress may cause seams to open, leading to the potential for water leakage.

For a long-term waterproofing performance of the membrane, it is important that not only immediate adhesion tests are performed, but also tests to understand long-term performance are designed. Various ASTM tests, like ASTM D1876 to test the lap adhesion and ASTM D903 to test the adhesion to substrate, are conducted. The contruction generally takes place in the temperature range of 25 °F-120 °F, depending on regional conditions and practices. Therefore, it is important to test adhesion at application temperatures. Adhesives can degrade after the UV or thermal exposure, so it is important to maintain its high bond strength to concrete after such exposure conditions. Low bond to concrete may lead to the potential failure of the membrane at the concrete interface, compromising waterproofing integrity. Depending on the length of exposure time before concrete placement recommended by the manufacturer, membrane is subjected to UV aging by natural sunlight or EMMAQUA accelerated exposure per ASTM G90-05 and tested for adhesion after aging. Adhesive in the membrane also experiences oxidation and degradation during storage, installation and in service, which can be evaluated through performance change after accelerated aging at elevated temperatures.

There are various ways to test the long-term performance of adhesively bonded membranes. One of the common testing criteria in the waterproofing industry is the adhesion of membrane after water immersion as a function of time as the worst case scenario. The bonded samples are placed in water and tested at regular intervals to see the change in adhesion value. There are no criteria set for minimum adhesion after water immersion; however, the results of testing of lateral water migration (to be discussed later) and adhesion after water immersion can provide confidence on long-term performance.

Hydrostatic Head Resistance: Hydrostatic head resistance is important to provide guidance on the performance of the membrane to resist the head of water under pressure. Testing is performed using ASTM D5385, however modified to test pre-applied membranes. Samples are prepared by casting concrete against the trafficable side of the membrane with a lap joint included. Hydrostatic head pressure test results are reported as ultimate pressure in psi (pounds per square inch) when no water leakage is observed through a concrete crack. Low hydrostatic head resistance represents lower resistance to water head pressure and water infiltration in below-grade waterproofing applications.

Lateral Water Migration: For pre-applied membrane, there is additional risk associated with field-created defects or damage resulting from puncture by an uneven surface, from rebar handling and installation, heavy equipment on site and imperfection of detail preparation. Water may seep through a waterproofing membrane via these defects. If the water is free to travel laterally between the adhesive bond and the concrete, it will find its way into the building through the cracks in the concrete. A waterproofing system that prevents lateral water migration between the membrane and the foundation is essential to keeping the building interior dry. Bond to concrete strength is a good indication of a membrane strongly attached to concrete structure, but the intimate bond to concrete is more important to prevent water migration along the interface of membrane and concrete. A modified ASTM D5385 is used to test the lateral water migration under different pressure conditions. To prepare a sample for lateral water migration (LWM), a 1-inch wide defect is created at the center of the membrane to simulate a breach of the waterproofing membrane (Figures 1 and 2). Two pipes, 1 inch in diameter, are attached to the membrane 3 inches away from the edge of the hole during the concrete casting. Concrete casting and evaluation under hydrostatic pressure follows the same procedure as hydrostatic resistance. Resistance to lateral water migration is reported as ultimate pressure in psi without water flowing out of pipe. Should there be any water migration at the membrane/concrete interface, either though product design or defect, the instrument will detect the pressure drop and water will flow out of pipes.

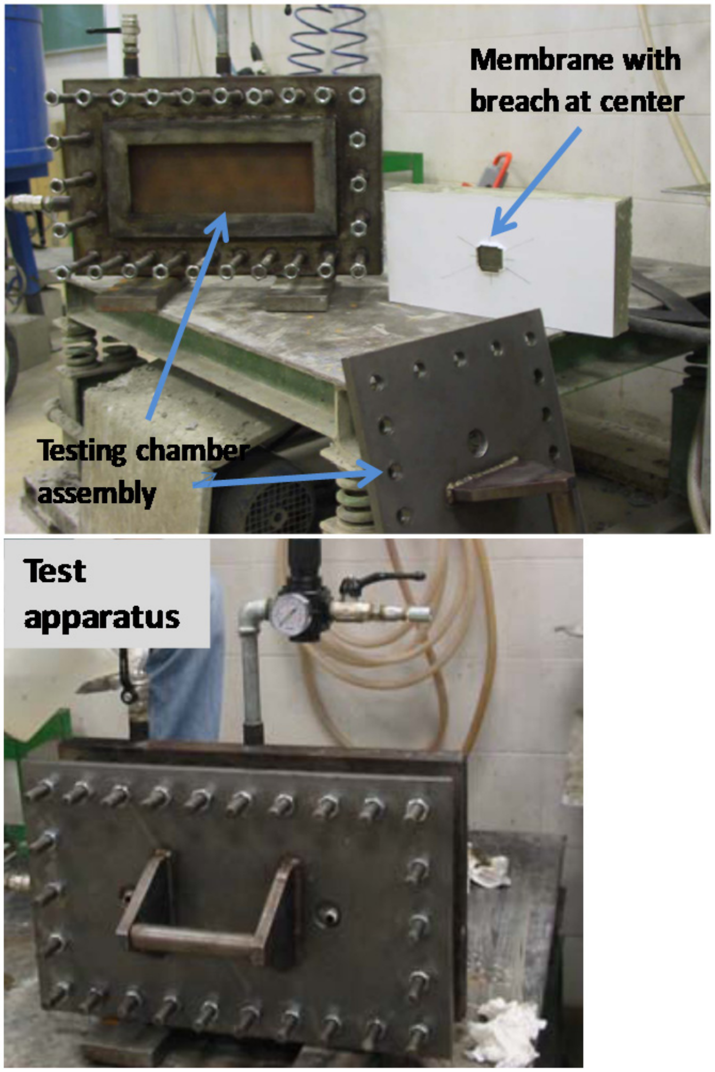

Figure 1. Membrane with breach and LWM test apparatus

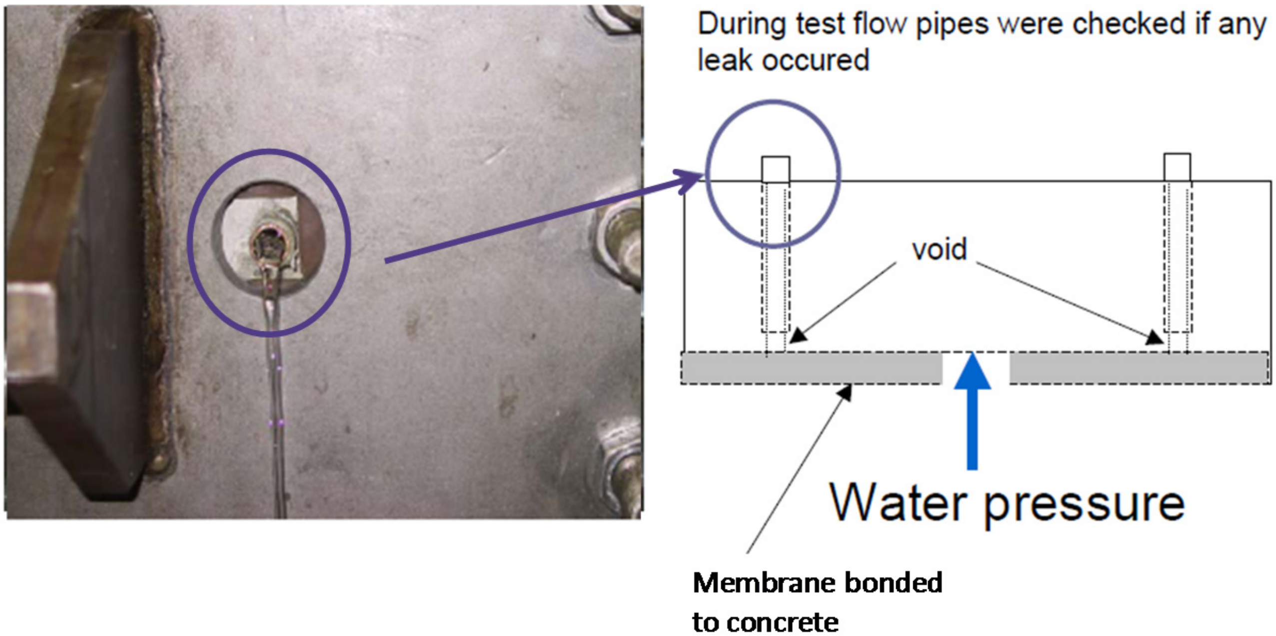

Figure 2. Setup for lateral water migration

Examples of Membrane Design for Pre-applied Application

There are different ways to design membrane with good trafficability for pre-applied application while still achieving bond to concrete performance. Table 1 lists some representative designs of commercially available pre-applied membranes.

Table 1. Various Membrane Designs for Pre-applied Application

Membrane ID	Method to achieve trafficability	BTC (pli)	LWM resistance
Sample 1	Heavy filler load in adhesive	<=2	-
Sample 2	Thick geotextile layer on top of adhesive	~ 3	Fail at 2 psi
Sample 3	Thin fabric layer on top of adhesive	~ 7	Fail at >=45psi
Sample 4	Specially designed particulates on surface and embedded in adhesive	>=10	Pass 100psi
Sample 5	Protective coating on top of adhesive	>=10	Pass 100psi

All membranes are able to support foot traffic and the normal construction activities. The bond strength depends on product design. The one with a high filler loaded in the adhesive has very low bond to concrete, which can easily debond from concrete at vertical configurations. Samples 2 and 3 have improved the bond by incorporating geotextile fabric on top of the adhesive to form a mechanical bond with concrete. However, both membranes cannot prevent the lateral water migration at elevated hydrostatic pressure at 90psi or above. Membrane sample 2 fails at 2 psi (Table 1) and sample 3 can hold 45 psi pressure. A green fluorescent dye can be added into the water during LWM testing to visually observe the water migration path after the failure. As shown in Figure 3, green color clearly shows the water migration path between the concrete and membrane interface of sample 2. For such a membrane design, water can travel along the interface and find a way into the building through a concrete crack or cold joint. Sample 4 comprises 300-600 um reflective particulates like hydrated white cement. It exhibits good bond to concrete and resistance to lateral water migration up to 100 psi. Sample 5 has acrylate based protective coating layer to provide trafficability and intimate adhesion as shown in Figure 3. It has 10 pounds per inch (pli) bond strength and can resist lateral water migration at 100 psi. Figure 4 shows that the pressure in test apparatus can hold the same level as the setting pressure and confirms the water tightness.

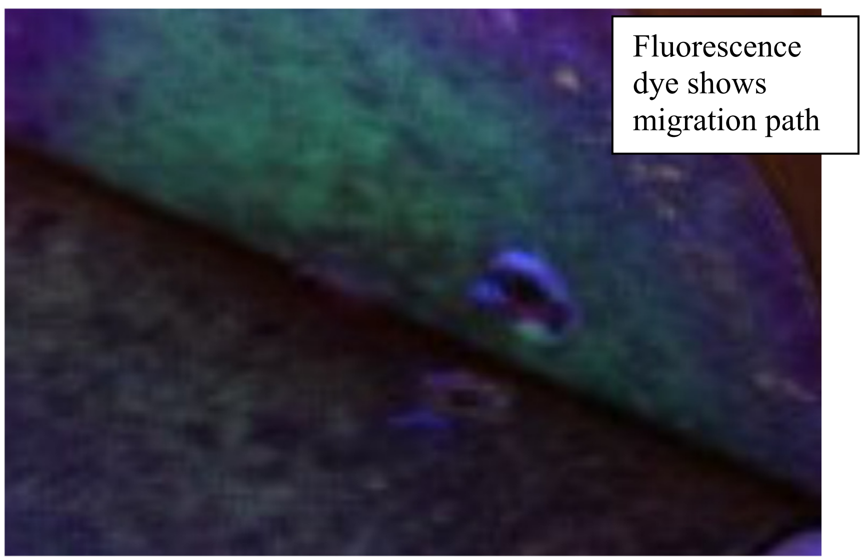

Figure 3. Sample 2 after LWM Test-Interface of Membrane and Concrete; Green Fluorescent Dye Indicates Water Migration Path.

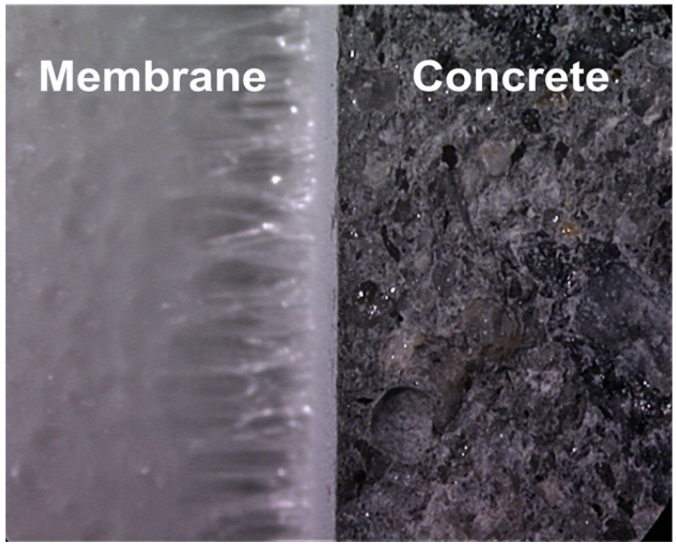

Figure 4. Intimate Bonding Between Membrane and Concrete

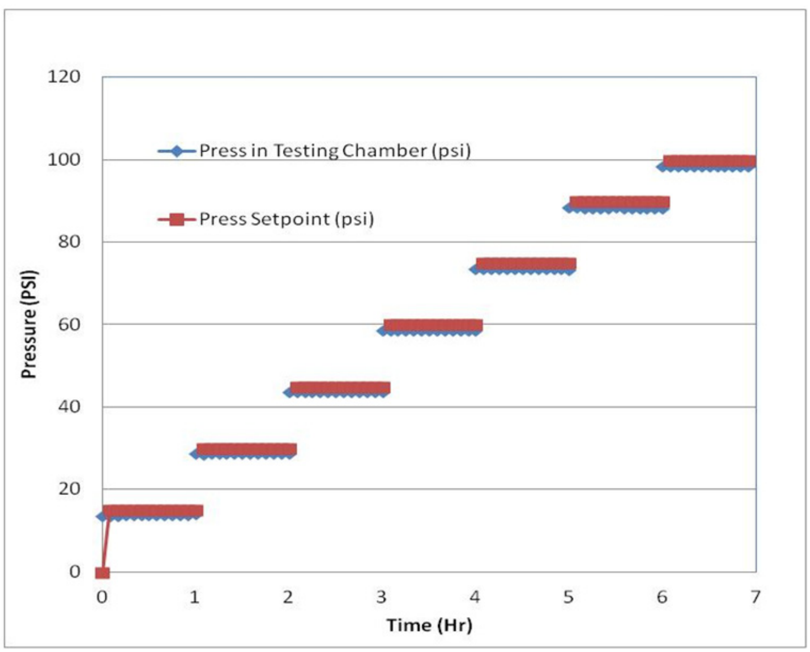

Figure 5. LWM Test of Sample 5-Pressue Curve in Test Chamber

Optimized coating and adhesive formulation is very important for the durability and long-term performance of membrane. The physical and chemical interaction between coating and adhesive, their resistance to thermal aging, UV degradation, their water resistance and interfacial properties all play roles for overall performance. Table 2 lists the performance of different top coatings with PSAs to illustrate the effect of coating formulation on product performance.

Table 2. Performance of Membrane with Different Coating/Adhesive Combination

	5-A	5-B	5-C
Bond to Concrete (pli)			
Membrane without aging	11.0	13.0	14.0
7 MJ EMMAQUA			9.0
14 MJ EMMAQUA			5.0
28 MJ EMMAQUA	8.5	6.8	
56 MJ EMMAQUA	7.3	0.9	
1 month natural UV exposure	7.9	12.1	
2 month natural UV exposure	7.6	5.3	
30Days @150°F	6.9	13.7	
1 month water immersion before concrete casting	11.3	15.1	
4 month water immersion after concrete casting	11.2	1.1	
1 month heavy traffic	15.4	9.0	
Hydrostatic Resistance (psi)	100	100	100

Membrane 5-C has large drop of bond strength after short time UV exposure, more than 50% after an accelerated EMMAQUA exposure at 14MJ (equivalent to 14 days natural sunlight exposure). Membrane 5-B has improvement on UV resistance properties and superior thermal resistance but poor bond strength after long term water immersion. Membrane 5-A achieves the bond strength above 5 pli at all aggressive aging conditions. It has overall very good balance of bond performance for pre-applied application.

The ultimate durability and long-term performance is evaluated by lateral water migration of the membrane after aging. Membrane 5-A proves it ability to prevent lateral water migration at 100psi after UV exposure at 56 MJ EMMAQUA (2 month equivalent natural sun exposure).

The lateral water migration of 5-A membrane bonded to concrete is evaluated after long-term water immersion in lab-controlled conditions. Results are summarized in Table 3. After up to 31 months of water immersion, the samples show no water leak at 100psi and the LWM performance remains at the same level as the one without water immersion confirming long-term performance.

Table 3. Lateral water migration resistance of membrane 5-A after long-term water immersion

Water immersion (months)	44 psi 10 minutes	87 psi 10 minutes	100psi 60 minutes
0	pass	pass	pass
1	pass	pass	pass
7	pass	pass	pass
11	pass	pass	pass
27	pass	pass	pass
31	pass	pass	pass

Summary

This paper summarizes the critical performance needs and testing methods for pre-applied waterproofing membranes. To achieve overall good performance, an optimized PSA and compatible coating combination is critical. With proper design on chemistry and interaction between two materials, pre-applied membrane with excellent durability for below-grade water protection can be achieved.