ADHESION OF TORCH-ON AND SELF-ADHESIVE ASPHALTIC MEMBRANES OVER GREEN CONCRETE

Laurence Matzek, RCABC, Leslie Peer, RJC Engineers, Jason Teetaert, SMT Research

INTRODUCTION

Roofing contractors are often asked by general contractors to start roof installation earlier than 28 days, the time typically specified for strength gain measurement after concrete placement in new construction. Application of membranes to 'green' concrete can be problematic, evidence of problems appearing as blisters and delamination of the membrane after application. Some applications are successful, and some rules of thumb exist in the industry about when application can proceed. The RCABC RoofStar guarantee standards defer the decision to a structural engineer to allow installation earlier than the 28 day cure time, but industry professionals are reluctant to do so because concrete strength time differs from concrete drying time. The authors carried out this parametric study of membrane installation to quantify effects on membrane adhesion strength related to its installation during the first month after casting of concrete, when initial strength gain and moisture loss are taking place.

The RCABC has concerns that with the new wind uplift requirements coming into effect in both the National and Provincial Building Codes, a premature approval for membrane application could cause the roof to fail the wind uplift requirement.

EXPERIMENTAL WORK

Concrete Slabs

Two concrete slabs were built at RCABC's facility in Langley BC. The slabs were 1.2 m x 3m (4' x 10') in size and 0.15m (6") thick. They were cast against polyethylene vapour barrier on all 5 sides except the top surface which was left open to air after finishing. The concrete was a Class C4 25 MPa mix from a local ready mix supplier, with 14mm aggregate and 6% air entrainment, W/C ratio less than 0.55. Figures 1 and 2 show the slab configurations.

Each slab was built in two halves for installation of the two different membranes, one thermofusible membrane (TFM) and the second a self-adhesive membrane (SAM).

Figure 1: Concrete slab after casting

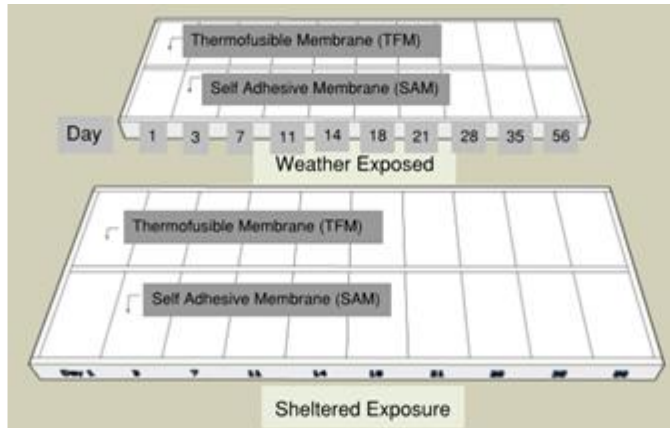

Figure 2: Layout of concrete slabs

One slab was left outside in the weather for July and August 2016, while the second slab was moved into an open sided shelter immediately nearby. This second slab was thus shaded all day, and not exposed to rainfall.

Moisture sensors were cast into the slabs 40 mm from the top surface in two opposite corners of each slab. Temperature and Embedded Moisture Sensors and data logging equipment were provided by a local instrumentation company.

Membrane Installation

On pre-determined dates, a 0.3m wide section of concrete was primed, and membrane was installed, Figure 3. The application methods were both torch applied membrane and self-adhesive membrane. The membrane was trowelled or rolled down, similar to membrane flashing applications.

The dates selected for membrane installation and adhesion testing are shown in Table 1. In general, new membrane was installed 24 hours after casting of the concrete, and then every few days after that over the course of a month. Adhesion tests were carried out the day of installation for the torch applied membrane, and the following day for the self-adhesive membrane. Further adhesion tests were carried out for several weeks after membrane installation. The adhesion testing schedule varied by a few days due to weekend and holiday staffing, but was maintained as close to the experimental rotation as practical.

The primer and membrane system used were as follows:

- Thermo-Fusible system: Commercially available asphalt based primer, and SBS modified elastomeric bitumen waterproofing membrane with non-woven polyester reinforcement 180g reinforced torch grade base sheet
- Self-Adhesive system: Commercially available polymer based primer, and self-adhesive SBS modified bitumen waterproofing membrane with non-woven polyester reinforcement 180g reinforced torch grade base sheet

Figure 3 Application of Primer to Concrete Slabs on Day 1

Figure 4 Adhesion test using 3" steel puck on Day 1

Adhesion Tests

For each adhesion test, a puck was glued to the membrane and then attached to the tensiometer to perform the pull test, Fig 4. This method is described in ASTM D4541 and the results are reported in this paper with adhesion values and failure type, adapted from the standard, similar to Nelson *et al* 2012 and Moser *et al* 2015. The puck placement on the exposed slab was selected where no blisters were visible. As such these represent upper bound results, since blistered areas would have 0 adhesion value. On the TFM the pull test was performed approximately 30 to 45 minutes after puck installation. The Day 1 pull test for the SAM was performed the following day, as the adhesive primer needed to cure for 24 hours.

For each test the pull test tension was recorded, as well as the failure mode observation. Failure definitions:

A. Primer: Adhesion failure of primer to the concrete.
B. Membrane: Failure or separation of the membrane.
C. Concrete: Adhesion failure between the primer and the membrane.
D. Puck Adhesion: Adhesion failure between the puck and the membrane.

Several puck types were used for the tensile adhesion tests. One of the most significant experimental challenges in this work was developing a reliable method of attaching the pucks to the membrane top surface, particularly as the adhesive strength of the membranes went up during the course of the experiment. The following puck types were used during the testing, and are noted in Table 1.

a. 3” round metal plates adhered in torch heated SBS membrane
    i. Un-primed
    ii. Primed
    iii. Abraded and primed
    iv. Adhered to membrane using a low-rise two part polyurethane adhesive

The pucks were welded to the TFM by heating the membrane surfaces and then installing the puck. The adhesion on the scuffed and primed metal plates worked well until the pull test strengths started to deform the plates, which caused a concentrated load at the centre and then at the outside areas of the plate. The adhesion of the metal plate to the foamed urethane adhesive did not hold well. As measured strengths increased, this puck method was switched to the following:

b. 3” round plywood. The time to cut round samples, and delamination of the plywood forced another puck change.
c. 3” square maple hardwood, primed and adhered in torch heated SBS membrane.

This final method of adhering the pucks resulted in a low number of type ‘D’ failures between the puck and membrane at the top surface of the membrane later in the testing. In Table 1, early type D failures with very low values were not recorded where they were an obvious a puck installation problem.

Strain rates for the adhesion testing were kept constant by the operators of the test equipment. Tests described by other authors indicate that strain rate affects measured material property values but there do not appear to be standardized strain rates for testing adhesion of asphalts in the literature.

After each pull test the site of the test was patched to re-establish the membrane seal to the top of the slab.

Data for the adhesion tests are shown in condensed form in Table 1. The data, expressed in kPa in this table, show that for even the lowest adhesive stresses measured, the adhesion of the membrane is comfortably higher than general values required to resist wind uplift of roofing.

Weather Data

The project was located at the RCABC training facility in Langley, BC. Weather data was pulled from a local weather station at Walnut Grove, Langley and also from the closest Environment Canada data station in Abbotsford and is shown in Figures 6 and 7. Note the rainfall event on the 2nd and 3rd of August that preceded membrane installation on Day 14 (Aug 4th). The rain events in September occurred a week before the last piece of membrane was installed on Day 56.

The adhesion test results in Table 1 are not adjusted for temperature. As noted, testing strain rates and other installation and testing variables were kept constant for the project, so rain days and warmer temperature affected results by re-wetting the outdoor slab and inducing higher asphalt temperatures. This field condition experiment was established to record real world conditions in the side by side sun and shade tests. The summer temperatures did not show great variation over the course of the July to September testing period (Figs 6 & 7). Repeating the testing during an equivalent period in winter conditions would be expected to produce quite different results.

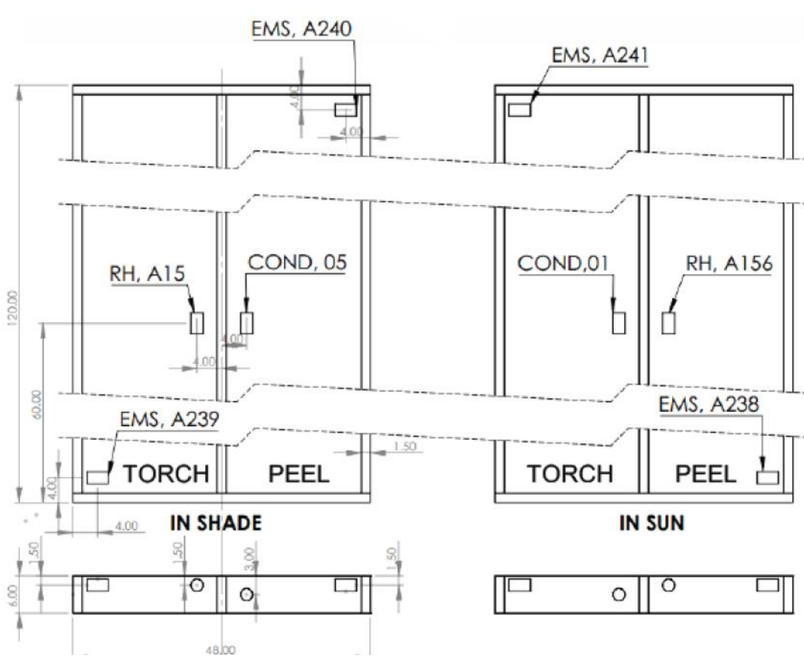

Figure 5: Moisture content sensors in concrete slabs

Table 1: Failure load in PSF at time of test and failure type

days after concrete pour	Membrane Installation Date	Time after memb install	DATE OF PULL TEST		Sun Slab: Torch Applied Membrane kPa	Sun Slab: Torch Applied Membrane Failure	Sun Slab: Self Adhesive Membrane (plus 1 day) kPa	Sun Slab: Self Adhesive Membrane (plus 1 day) Failure	Shade Slab: Torch Applied Membrane kPa	Shade Slab: Torch Applied Membrane Failure	Shade Slab: Self Adhesive Membrane (plus 1 day) kPa	Shade Slab: Self Adhesive Membrane (plus 1 day) Failure
1	22-Jul	0		3" Ø metal plate	24	A	0	A	49	A	0	A
		11	01-Aug						159	D		
		28	18-Aug		185	A	0	A	400	A	0	A
3	24-Jul	0		7.065	0	A	0	A	78	B	0	A C
		8	01-Aug						98	A	98	A
		25	18-Aug		210	A C	132	A	224	A C	107	A
7	28-Jul	0			63	B	0	A	98	B	49	A
		5							171	D	83	D
		4	01-Aug		44	D						
		21	18-Aug		137	A C	117	A	278	A C	219	A
		50	16-Sep				34	A	215	C A	102	A
11	01-Aug	0		3" Ø metal plate w/ duotack	137	A B	93	D	258	A B	195	D
		1	02-Aug						273	C		
		17	18-Aug		380	A C	180	A C	293	A C D	215	A C
		46	16-Sep		98	A C	127	A	137	A C		
14	04-Aug	0		3" Ø plywood	156	B			156	D	137	D
		14	18-Aug		190	A	195	A	229	C	254	A
		43	16-Sep		98	A C	98	A C	293	A C	234	A
18	08-Aug	0		3"x3" maple block	332	B D	439	B D	390	C	176	C
		10	18-Aug		585	D	312	A	332	C	190	A
		39	16-Sep		117	A C	137	A C	317	A C	161	A
21	11-Aug	0		9	195	D	400	D B	410	B D	507	A B
		1	12-Aug		527	D						
		7	18-Aug		595	A C	244	A	312	C	190	A
		36	16-Sep		293	A C	215	A C	254	C A	146	C
28	18-Aug	0			302	B	171	A B	234	A C	302	B
		29	16-Sep		332	B A	215	B A	254	A C	132	A
35	25-Aug	0			215	D	176	B	483	A	254	D
		22	16-Sep		293	A C	122	A C	297	A C	210	A
56	15-Sep	0										
		1	16-Sep		293	D	195	D A	429	A C	283	A C

Moisture Content and Temperature Data from Embedded Sensors

Moisture contents (MC) were measured with sensors cast into the concrete at opposite ends of the slabs, 40mm beneath the surface. In Figures 6 & 7 the red lines measure moisture content at the end of the slab which was covered on the first day after casting. The yellow lines are sensors at the other end of the slab, which were not covered until the 56th day (Sept 15). In Figure 6 for the sheltered and shaded slab, the covered sensor records nearly constant moisture content, which increases gradually as the slab ages. The other end of the slab dries steadily over the course of the dry summer months, as it is not exposed to rainfall, until it is covered with membrane on Sept 15, after which its MC also begins to trend gradually upward. The upward trend in moisture content measured by the sensors is likely due to gradually cooling weather, noted in the blue and grey temperature curves in the temperature data above, redistribution of moisture in the slabs, or to and may be affected by increasing maturity of the concrete.

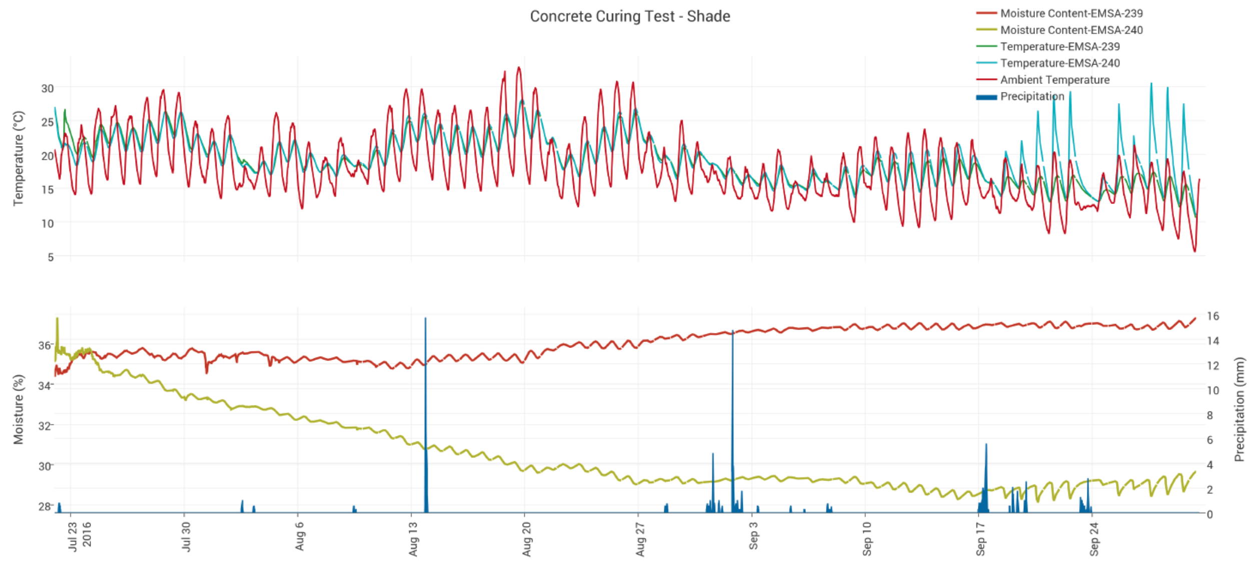

Figure 6: Temperature, Rain Events, and Concrete Moisture Content - Sheltered Slab

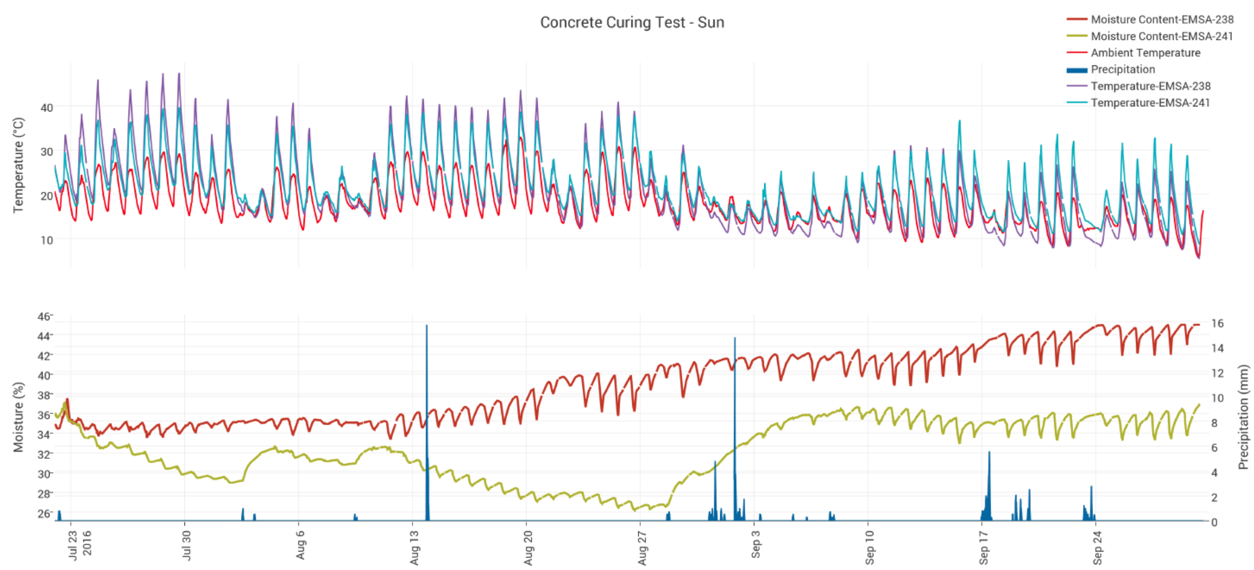

Figure 7: Temperature, Rain Events, and Concrete Moisture Content - Outdoor Slab

In Figure 7 for the outdoor slab, the sensors record the effects of rain and exposure. The yellow line for the uncovered MC sensor responds with moisture content increases after each rainfall event, and then dries again, until it is covered on Sept 15th. The time delays for the wetting events are related to the time it takes to record moisture content changes 40mm beneath the concrete surface after rainfall at the surface. Moisture content of the concrete at depth for membrane applied at 14 and 21 days (on Aug 4 and 11) on the exposed slab were similar to the MC on Day 3, even though the surface was dry again. At Day 56, the moisture content was similar to Day 1 due to extended rainfall the previous week.

OBSERVATIONS

Figure 8: Sample 1 SAM test day 1 Shade

Field Observations

1. Day 1 after concrete pour. The concrete surface was still visibly wet which resulted in poor primer bond to the concrete.
2. Puck adhesion to the membrane was the biggest challenge to overcome in the experimental methods. This is discussed above.
3. The TFM primer absorbed into the concrete better than the SAM primer.
4. There was significantly more blistering of the TFM versus the SAM. The membrane in the shade had no blistering. The puck placement was chosen where blisters were not evident by sight or touch. Membrane blisters appeared in TFM sections to the 35 day mark on the sun exposed slab.

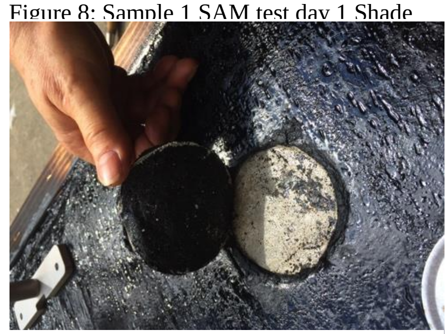

Figure 9: Sample 1TFM test day 1 Sun

5. The pull test results were generally higher for the TFM versus the SAM particularly at early ages where little adhesion was achieved with the SAM for the first 7 days. The SAM primer seemed to be less interactive with the slab surface (very clean detachment from surface) Figure 8, and seemed to allow vapour diffusion from under the membrane (few blisters).

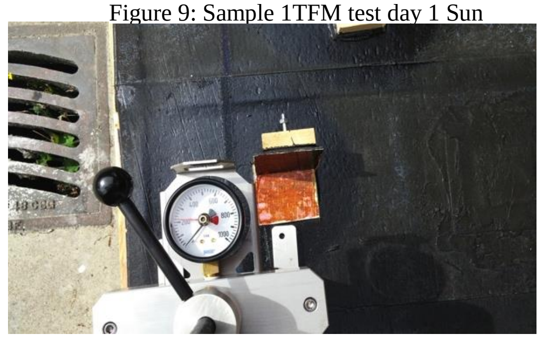

Figure 10: Sample 28 SAM Test day 28 Sun

6. Higher pull tests were achieved when the membrane exposed to the sun was still in the shade (from neighbouring building). This was most evident for the peel and stick membrane, mostly because the bitumen for these membrane have a lower softening point.
7. The concrete slabs were deconstructed on Oct 12, 2016, 83 days after the pour date. The membrane was easily pulled from the concrete slab. The top of the slab was moist to the touch, and the primer had been pulled up with the membrane.

Figure 12: Sample 28 TFM test day 27

Photos of typical pull test pucks are shown in Figures 8-11. Samples from Day 1 show nearly complete delamination of the primer from the concrete in both TFM and SAM. Membrane applied after 28 days, and left in place for 28 days before testing had failure passing through the membrane to primer interface, or in the case of the TFM partly through the membrane (Fig 10 & 11). At 28 days, the character of the primer to concrete adhesion, and the membrane to primer adhesion behaved as it appears to be intended. However the bond deteriorated significantly for all Sun samples between 56 and 83 days when during demolition of the experiment the membrane was easily removed by hand, parting at the interface of the primer with

Figure 11: Removing membrane by hand from Sun slabs at 83 days

the concrete surface. Figure12

Observations from Test Data

Figures 13 and 14 are graphs of the test data presented in Table 1. Figure 13 plots the data for SAM exposed in the sun and shade, and Figure 14 the data for TFM also in the sun and shade.

General trends in the SAM data show first day adhesion increasing after about a week after casting of the slab. Samples in the sun did not begin adhering to the slab until after 14 days, while in the shade the installation after 7 days had some bond.

Interestingly, the highest 1st day adhesion strengths occur when installation is delayed 18 to 21 days after casting for both sun and shade slabs.

Concrete surface strength was not a governing failure mechanism in any of the samples tested. Primer adhesion to the concrete appears to be the main failure mechanism at early ages.

Sun and Shade exposed SAM appear to have similar late age bond strengths, with shade values slightly higher.

At 7 to 14 days after installation the SAM has generally moderate strength, with the high initial strength samples decreasing, and the low initial strength samples increasing in bond strength to lie in the range between 100 to 250 kPa.

14 to 21 days after installation all the SAM samples show decreasing bond strength, a trend which continues for the samples out to 50 days.

Thermofusible membrane showed generally higher bond strengths, but otherwise many of the same trends as the SAM bonding. Only the Day 3 TFM installation had 0 bond strength on the first day. Early age installations generally gained strength for the first two weeks,

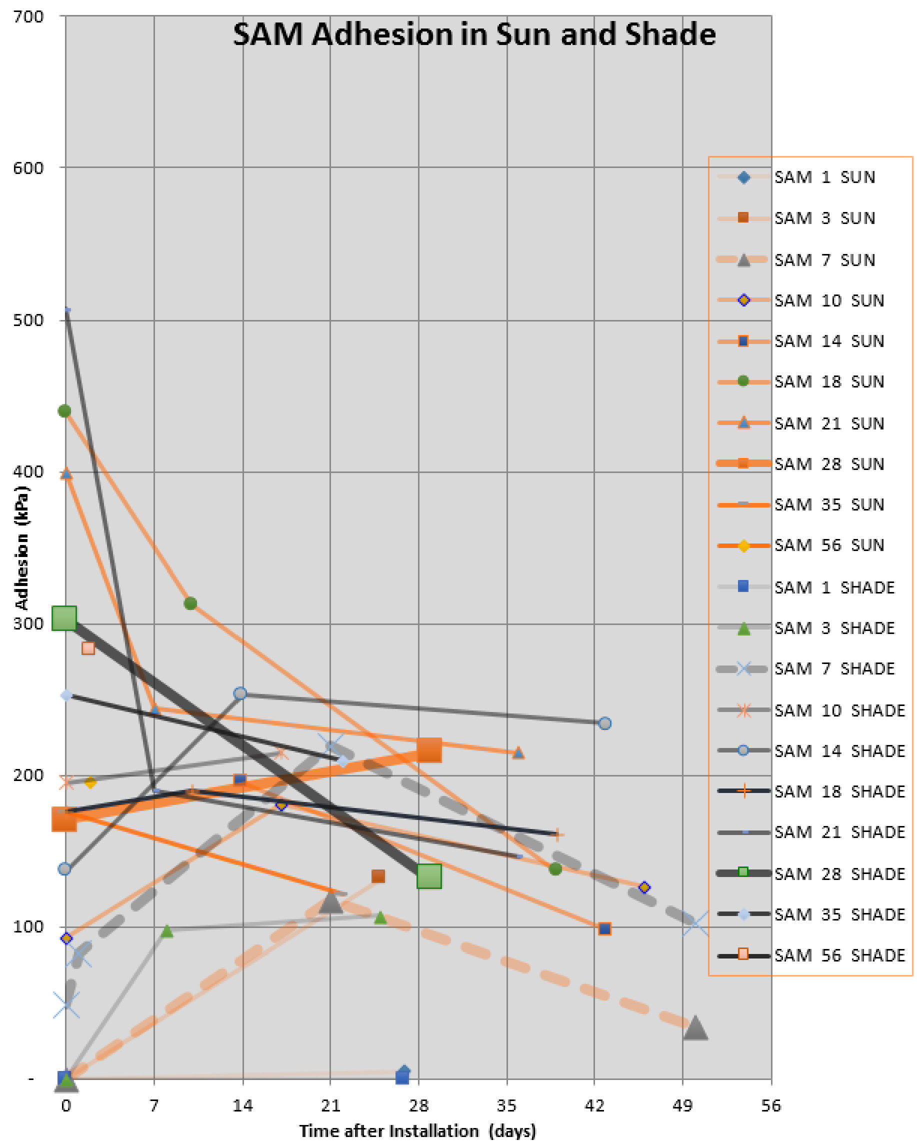

Figure 13: SAM Adhesion in Sun and Shade

while later age installations stayed at the same strength after installation, or in some cases (Sun 11, 18, 21) went quite high and then decreased again.

3 weeks after installation, most installed TFM were in the range of 150 to 400 kPa. After 18 to 21 days many early installed Sun strength curves were decreasing, a trend that continued out to 50 days. The membranes installed after 28 days had stable bond strengths but this trend was not verified past 28 days since most testing for these samples ended at 28 days.

Late age bond strength of the Shade samples appear to be consistently higher than Sun exposed samples.

Field observations of mainly the TFM on the Sun exposed slab noted blistering occurring in all installed samples out to 28 days. This is likely because the primer and membrane installation was vapour tight at the slab surface, and solar heating vapourised water from concrete at the top of the slab. Adhesion testing worked around the blisters so these zero bond samples do not appear in the TFM data.

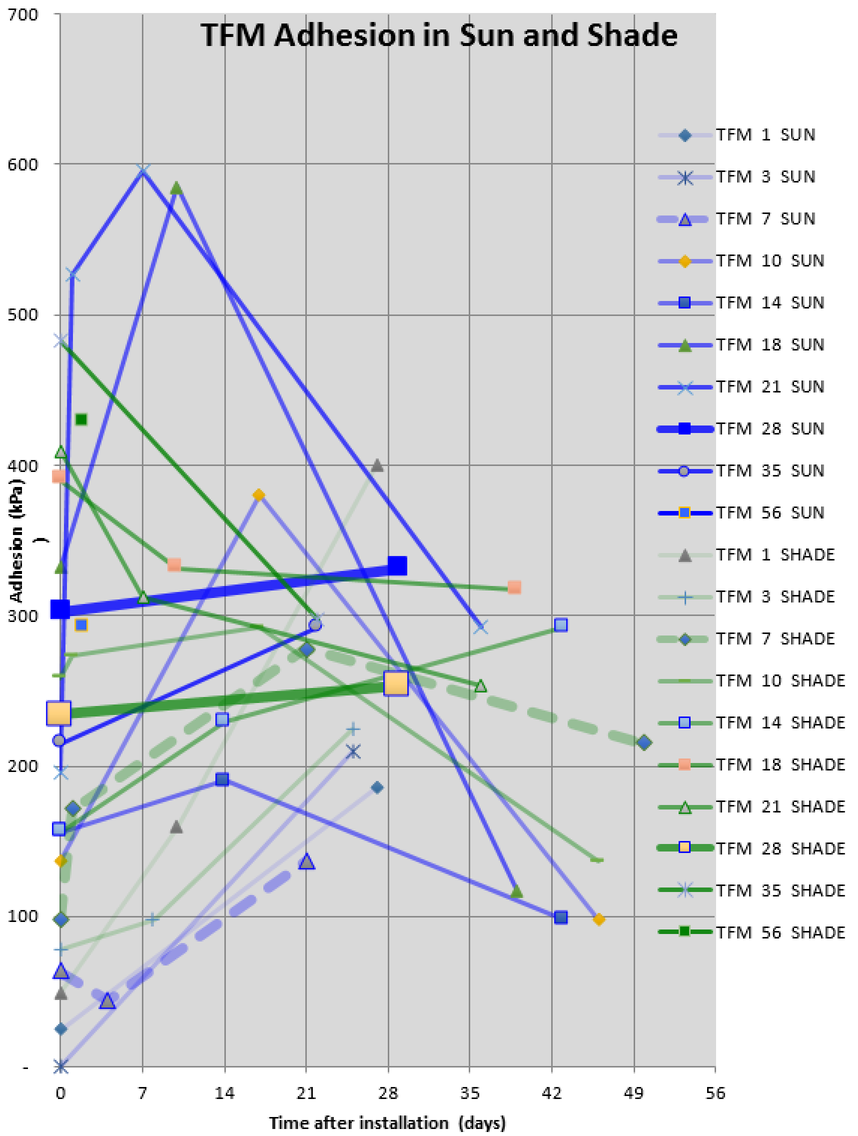

Figure 14: TFM Adhesion in Sun and Shade

The SAM membrane did not exhibit blistering to the same extent as the TFM. Perhaps the primer is sufficiently strong to resist blistering, or the small test area may have allowed vapour to diffuse out of the SAM samples. If this is the case, blistering could occur in the SAM installations also if the covered surface area were larger.

Blister formation was not noted in the Shade samples at any age.

After the conclusion of testing, the membranes were removed from the concrete surface before demolition of the concrete panels. The membranes were mostly easily removed from the concrete slabs by hand, with the exception of later aged TFM samples.

INTERPRETATION

The results show some decreasing bond strength with increasing time after membrane installation. This is not thought to be an artefact of the testing method. It is not known if this bond strength recovers at later ages, there was no sign of recovery during this study. Degradation of the membrane bond was apparently occurring on green concrete, possibly due to physical or chemical action of water at the bonding interface of the membrane.

Water Storage in Concrete and Release as Vapour

Water in concrete is held too tightly to be released as liquid water and must evaporate in order to dry out of the pore system. Water stored in concrete causes a high relative humidity to exist in the pore spaces, and the water vapour exerts a gas pressure. At 50C the partial pressure of water vapour can reach about 12 kPa, about 1/8th of an atmosphere.

In indoor drying tests at the British Cement Association (Parrott 1988), a sensor 7.5mm beneath the surface of concrete dried to 80% relative humidity about 40 days after casting. Drying to 15 mm took nearly 100 days. See Figure 15 showing drying rates at a series of depths inside a concrete surface. Concrete retains most of its water content at depths not far beneath the surface for all drying times out to 100 days, so

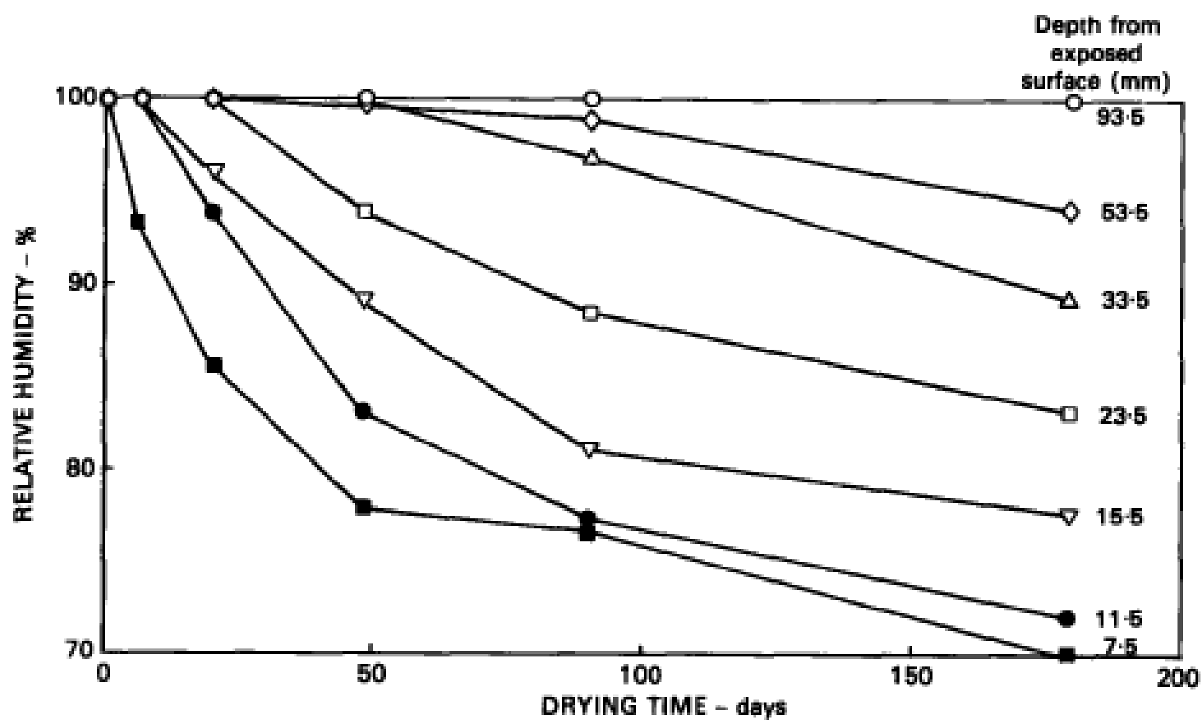

Figure 15: From Parrott 1988 Uniaxial drying rates in concrete at increasing depths beneath the surface

redistribution of moisture will bring stored water to the surface when a membrane surface barrier is installed.

Evaporation of stored water from concrete takes time and heat energy. If temperatures are low, there is little heat energy to evaporate liquid water into vapour, and drying times are extended. Green concrete not only has low matrix strength, it has high internal moisture content. Concrete in cool damp conditions will take longer to be ready for bonding than concrete in warm dry conditions. A period of drying is required after a period of 'wet curing' to prepare concrete to receive a coating, even if strength of the concrete is not an issue.

Concrete will absorb liquid water at a far higher rate than it releases vapour, and one small rain shower can undo days of drying (See Figure 7).

Installing an impermeable coating, such as the membranes in this work, across a concrete surface resists the interaction of moisture inside the concrete with moisture outside the concrete, and sets up stresses on the coating. Water inside and outside the concrete will exert stress on the coating and the stress may be detrimental to the coating or its bond. The forms of stress can be physical, gas pressure and liquid disjoining pressure, and chemical, attack by water or solute content in the water such as hydroxide or minerals. If the water can't physically push the barrier out of the way, which is what is observed in forming blisters on hot days, it can attack its bond chemically until adhesion forces at the molecular level yield.

In a study of the effect of moisture on integrity of roofing shingles, Dupuis and Graham (2002) noted that moisture had a detrimental effect on the bond of asphalt to embedded fiberglass reinforcement in asphalt shingles, possibly due to moisture interaction with the bitumen along the fibers.

Saponification Under Alkaline Conditions

Studies originating out of the asphalt industry (Robertson, 2000, and Little *et al* 2003), describe the adhesion of asphalt to mineral surfaces occurring through polarity of component molecules within the asphalt and the surface. In general, non-uniform charge distributions attract the opposite charge on the other material, leading to bonding. Some mineral aggregates show changes in surface charge with moisture content, however for most aggregates it is reported that surface polarity can be considered a constant. However, polarity in asphalt components can change with moisture content, for instance carboxylic acids are highly charged when dry but are easily stripped from mineral surfaces when wetted. The interaction of cation salts (caustic alkalis) such as sodium with carbon chain molecules form soaps (saponification) in basic solution, and completely eliminate polar bonding.

Green concrete has high moisture content, and a large amount of dissolved alkaline salts in the pore water. It is possible that degradation of membrane adhesion seen in this study is due in some way to action of water moisture or chemical related degradation of the polar bonding at the concrete surface.

CONCLUSIONS

All the membrane installations bonded sufficiently to the concrete surface to resist wind uplift requirements of the NBCC, with the exception of blistered areas, at early ages. Since blistered areas were avoided during the testing, we can say that they are potentially problematic and conditions that lead to their formation should be avoided. Direct sun exposure of the TFM and SAM membranes resulted in blistering, the other applications were visibly unaffected.

When left in the sun to 83 days, serious degradation of the bond of the membrane occurred to the point where it would likely not have been able to resist wind uplift.

In general TFM developed higher strength bond to the concrete than SAM.

Green concrete is not ready to receive membrane application when it is not dried. Concrete strength is typically higher than the asphalt bond after about a week of curing. In summer drying conditions, concrete appears to require about 14 and 21 days of drying (after any wet curing processes are finished) before a TF or SA membrane will form any substantial bond to the surface. The bond is subject to degradation as seen in our results, and direct sun exposure will damage bond by blistering. The integrity of the long term bond to green concrete requires further investigation.

Further work is required to evaluate drying times and adhesion of membrane to green concrete in winter conditions

Formation of blisters due to vapour pressure beneath the membrane occurred when the installation was exposed to direct sun, even when installation was delayed to 35 days after casting. Installation in the shade had no blisters. Blisters were much less severe under the SAM, possibly due to vapour dispersion from under the primer.

Many membrane samples installed before 28 days suffered bond reduction, possibly degradation due to wetting or saponification processes at the interface between asphalt and green concrete. A longer and more detailed study is required to evaluate the bond strength of membranes after 28 to 56 days, for up to a year would be interesting, and determine why bond strength loss occurs.

Strong adhesion of the membrane on green concrete appears to depend largely on behaviour of the primer. Development of a specialty primer may allow earlier installation of membranes on concrete by improving vapour control and resisting possible water chemistry problems.

REFERENCES

Dupuis R. M., Graham M. S., The effects of moisture and heat on the tear strength of glass fiber-reinforced asphalt shingles, *Proceedings of the 12th International Roofing and Waterproofing Conference*, NRCA 2002

Little D.N., Jones D.R., Moisture sensitivity of asphalt pavements *Proceedings of the Seminar* Chapter 2 San Diego Feb 4-6, 2003

Nelson, P. E. and Hopps, E. R., "Moisture Sensitive Adhesives and Flooring Adhesive Failures," *Journal of ASTM International*, Vol. 9, No. 2, 2012, pp. 1-6

Moser P.S., Doelp G. R., Haydu J., Shear Resistance of Paving and Waterproofing Systems *ASTM STP*

1590, 2015

Parrott L.J., Moisture Profiles in Drying Concrete *Advances in Cement Research* 1 **3** July 1988

Robertson R.E., Chemical properties of asphalts and their effects on pavement performance, *Transportation Research Circular* No 499 Chapter 4 July 2000