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Waterproofing Membranes- a 2016 view of problems, standards, and solutions.

This paper was first prepared for the NZ Institute of Architects Technical Series- June 2011 by Bill Grayson BSc, FNZIC. This version was updated August 2016.

This paper was written in frustration at the destructive power of an assumption, particularly when combined with a brand name. The assumption is that 'waterproof' means what it says. However this may make an **ASS/U/ME.**
The brands and materials are many, and shall remain nameless for the present, but please contact us if you require specific advice.

Early membrane problems

Common themes:

- By 2004 problems with water ingress beneath membranes were surfacing in NZ. We later found membrane failures to be a big issue in Canada and in other areas of high rainfall/humidity.
- Exterior areas affected were flat roofs and exposed decks, particularly where tiles were directly stuck to membranes.
- A common factor was a lack of falls on decks and roofs, ponding at drain heads, and in gutters.
- Structural concrete and timber/plywood structures were all affected.
- Furthermore the continued rise of interest in green roofs and planter boxes will further accentuate this already problematic area.
- The problem with interior spaces has been leaks in showers where bathrooms are in daily use.
- The failure of sub-grade membranes particularly on deeply excavated carparks where the repair options are extremely limited/expensive; causes leaks, rebar corrosion and a loss of amenity.

Symptoms of leaks and membrane failure:

- Leaks into structure, corrosion of steel reinforcement, and water damage.
- Structural movement of timber constructions.
- Wear surfaces lifting and moving, cracking of tiles and grout lines.
- Paint and membrane colour changes, stickiness, sliminess and smell.
- Efflorescence especially on concrete blocks, structural concrete, and brick work.

Investigations and failure mechanisms

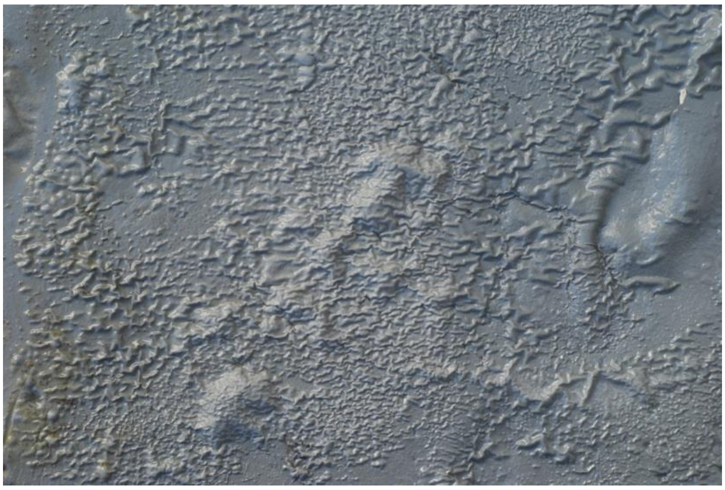
- Our work on many different sites and membranes is usually initiated by litigation relating to water damage.
- We must dismantle the affected area to photograph the membrane, particularly at movement joints and changes of plane.
- We are looking for membrane swelling, crinkling, blistering, and tearing due to structural movement, and delamination of seams.
- We take samples of the membrane in sealed containers, particularly at any lap joints, together with any associated materials such as acoustic and adhesive layers, and surrounding water.

Water absorption testing and the Second Law of Thermodynamics:

- *The Second Law of Thermodynamics asserts that a natural process spontaneously runs only in one direction, which is not reversible unless work is performed. In this case the process is the absorption of water into dry materials.*
- *Hence water on one side of a semipermeable membrane (Not a barrier) will be transmitted through to the dry side.*
- *The rate of transmission of water through a polymer is defined by Fick's law, which is called up appropriately in Standard ISO 62:2008- Water absorption of plastics.*
- *ISO 62 has long been the method of test adopted by Lloyds Register for approval of plastics used in ship building.*
- *The amount of water a membrane absorbs at equilibrium is proportional to its barrier properties (effectiveness as a waterproofing membrane).*
- *Typically an effective construction barrier membrane such as polyethylene has a water absorption of about 0.1%.*
- *On the other hand ineffective membranes such as water based acrylic emulsions absorb more than 10% water under these conditions.*
- *To accurately judge a membrane's waterproofing effectiveness, or otherwise, waterproofing membrane data sheets must disclose the % weight of water absorbed when immersed for 4-7days at 50°C* and 23°C.

Real world waterproofing membrane failure:

- Water is always trapped beneath tiles directly stuck to the surface of a membrane, causing it to remain constantly wet. It is this constant wetness that creates the conditions for membrane failure by water absorption.
- A common finding in membrane samples taken from site, is the surprisingly high levels of absorbed water, often more than 50%.
- Such absorption of water by a waterproofing membrane causes it to swell, giving a loss of tensile strength and adhesion, delamination/fracturing of tiles, fracturing of grout lines, and leading to further water ingress.
- A number of standards have attempted to use such indirect methods to demonstrate a waterproofing membrane; but with the NZBC regulatory requirements only an equilibrium water absorption test will provide the data required for durability.
- Laboratory prepared membrane samples immersed in water at 23°C and 50°C show that water absorption is a slow process that may take weeks or even months to generate an equilibrium water result.
- The rate that membranes absorb water is a function of the formulation/ composition Liquid applied acrylic, APP modified bitumen sheet, PVC sheet, Polyethylene sheet, etc.

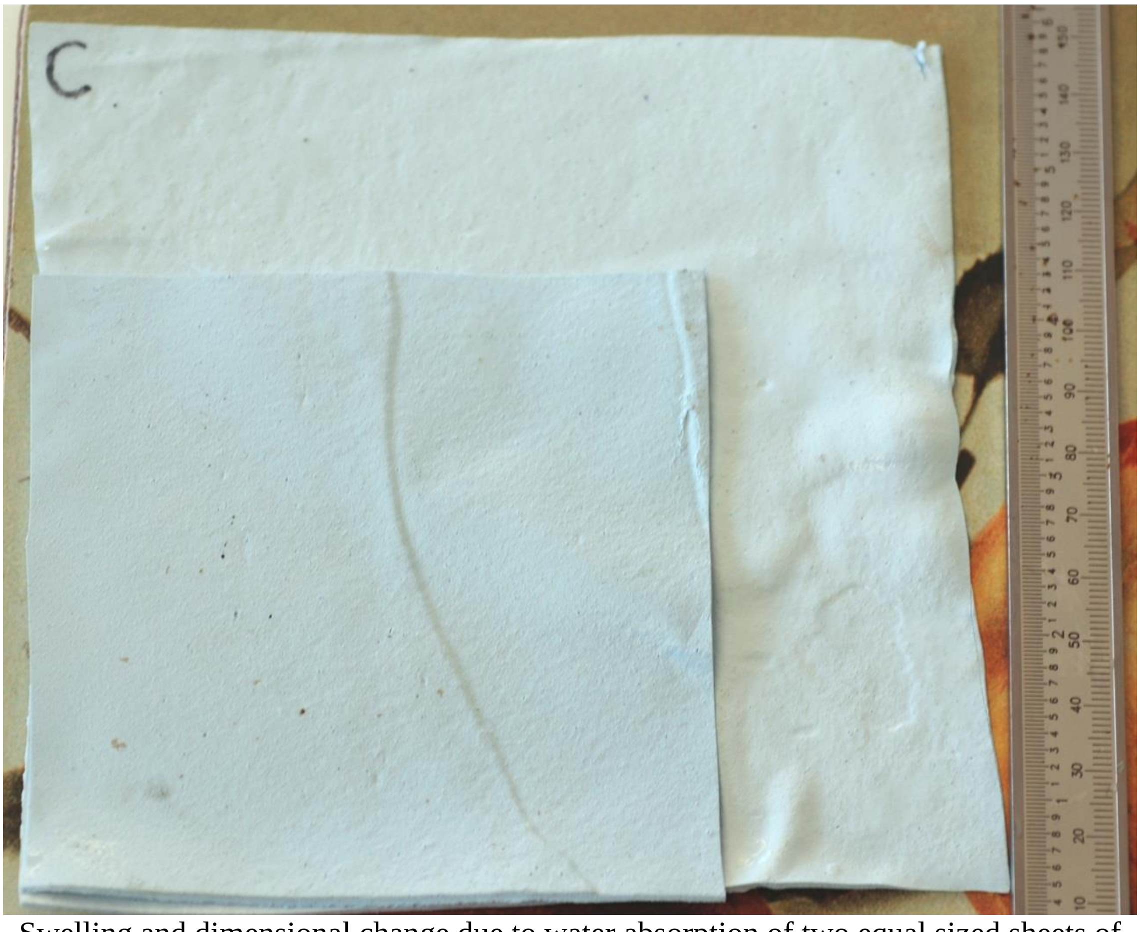


Swelling and wrinkling of urethane membrane beneath tiles due to water absorption.

Swelling and deformation of acrylic membrane during lab testing due to water absorption.

Water on acoustic cork mat substrate transmitted through bitumen/SBS membrane due to water absorption.

Water transmitted through an acrylic membrane due to water absorption, on concrete substrate.



Swelling and dimensional change due to water absorption of two equal sized sheets of the same acrylic membrane during lab testing.

Cracking of tiles and grout due to membrane swelling causing jacking effect due to water absorption.

Osmotic blistering:

- The Second Law of Thermodynamics also applies to the formation of osmotic blisters, which are caused by differences in salt concentration.
- When water is trapped against a semipermeable membrane surface, and salts are present either within the body of the membrane (as part of the formulation) or on the opposite side (such as from a concrete substrate) water is transmitted to even out the salt concentration.
- This results in large water filled blisters being formed in the body of the membrane.

Osmotic blister formation between 2 layers of urethane membrane beneath tiles.

Osmotic blisters in urethane membrane filled with water and solvents beneath tiles.

Other failure mechanisms:

- Compatibility issues have also occasionally been found. These are usually obvious due to other components such as acoustic barriers being present, and the dramatic effects on the membrane integrity.
- Poor welding of bitumen sheet membranes at lap joints, or tearing of the membrane at movement joints allowing water ingress.
- UV degradation caused by exposure to sunlight.

Poor lap formation between APP modified bitumen membranes allowing water ingress.

Degradation and cracking of SBS modified bitumen membrane due to UV exposure.

Applicable NZ Regulations and Standards for waterproofing membranes

- The NZ Building Code contains a number of Definitions, and Regulations for building elements (which includes membranes), which have been tested in the Courts and upheld.
- The definitions relating to membranes follow.

Building Code Handbook definitions:

Term	Definition
Damp-proof membrane (DPM)	A sheet material, coating or vapour barrier, having a low water vapour transmission, and used to minimise water and water vapour penetration into buildings. Usually applied against concrete in contact with the ground. (Also known as a concrete underlay.) Surprisingly this membrane type is almost invariably Polyethylene sheet, which is the most waterproof of all membranes we have tested, and yet it is referred to as damp-proof?
Impervious	That which *does not allow the passage of moisture*.
Membrane	A non-metallic material, usually synthetic, used as a fully supported roof cladding, deck surface or, in conjunction with other claddings, as gutters or flashings.
Waterproof and waterproofing	The *complete and total resistance* of a building element to the ingress of any moisture.

The NZ Building Code contains the following regulatory clauses which apply to membranes.

Clause B1 Structure:

- **Functional Requirement B1.2-** Buildings, building elements and sitework shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives.
- **Performance B1.3.3**- Account shall be taken of all physical conditions likely to affect the stability of buildings, building elements and sitework including:
  a) Self-weight
  b) Imposed gravity loads arising from use
  c) Temperature
  d) Earth pressure
  e) Water and other liquids
  m) Differential movement
  n) Vegetation
  q) Time dependant effects including creep and shrinkage (e.g. due to absorption and swelling)
- **B1.3.4**- Due allowance shall be made for:
  a) The consequences of failure
  d) Variation in the properties of materials and the characteristics of the site

Clause B2 Durability:

- **Functional Requirement B2.2**- Building materials, components and construction methods shall be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the building.
  This sets out a durability requirement of 50years for tanking and beneath concrete slabs, and 15years for membranes on top of concrete slabs, behind tiles, and for roofing membranes.
- **Verification Method B2/VM1 1.1**- requires consideration of the in-service exposure of a building element (3) for:
  a) Length of service (e.g. 15 or 50 years?)
  b) Environment of use (e.g. exterior or interior?)
  c) Intensity of use (think about this!)
  d) Reaction with adjacent material (compatibility?)
  e) Limitations of performance (do people read labels/ data sheets etc?)
  f) Degree of degradation (e.g. UV exposure)

Clause E2 External Moisture

- **Functional Requirement E2.2**- Buildings must be constructed to provide adequate resistance to penetration by, and the accumulation of, moisture from the outside.
- **Acceptable Solution E2/AS1**- 8.5.1 Limitations- This Acceptable Solution is limited to membranes composed of butyl or EPDM installed over plywood substrates
- **E2/AS1 8.5.4 Butyl and EPDM**- Butyl rubber and EPDM rubber sheet on timber, and system components used for membrane roofing or decks shall:
  b) Comply with the following parts of Table 1 in ASTM D6134:
    iii) Water absorption (maximum 2% for butyl and 4% for EPDM)
    iv) Water vapour permeance

Clause E3 Internal Moisture

- **Functional Requirement E3.2**- Buildings must be constructed to avoid the likelihood of: (b) Free water overflow penetrating to an adjoining household unit; and
  (c) Damage to building elements being caused by the presence of moisture.

- **Acceptable Solution E3/AS1 3.3.1 Showers**- b) Ceramic or stone tile finishes shall be laid on a *continuous impervious substrate or membrane*.

NZ and International Standards, and Industry Codes of Practice
While the regulatory environment, and types of site failures set out previously are reliable and must be kept in mind, we now enter the much less certain world of Standards. These should be considered much more carefully, due to their method of development, process of review for ongoing approval or not, and the industry funding of their development.

AS/NZS 4858:2004 for wet area membranes
The NZBC clause E2/AS1 used to state that wet area membranes (waterproof?) must meet the requirements of NZS 4858:2004. This no longer appears to be the case.
However NZS 4858:2004 still appears in in the Concrete Code of Practice CCP:01 and some of the Membrane Code of Practice documents.
It must be struck down as:

- NZS4858:2004 requires testing of a membrane by the methods given in AS 3558.1 Testing of plastics, composite materials, and sanitary plumbing fixtures.
- A water absorption test is performed by one sided exposure to water for 24hrs at room temperature- Result to be recorded?
- Water vapour transmission rate (WVTR), is tested by ASTM E96/M. The result if >8g/sqm/day, and if it is to be used on particleboard, the water absorption *into the particleboard* must be <10%.
- This approach is not sufficient for testing the long term performance/durability of waterproof membranes for the following reasons:
    1. The NZBC requires *a minimum 15 year durability to be assessed on a 24hour test period only?* NZ frequently has wet weather for more than 24 hours at a time, also entrapment of water beneath tiles leads to *constant wetness.*
    2. *But in NZS4858:2004 there is no maximum specified water absorption!* Rather, the result is simply recorded and reported, and frequently not disclosed in technical documentation.
    3. WVTR by ASTM E96 can only be carried out on carefully prepared lab samples, is useless for testing field samples for compliance, neither does it provide any assurance as to durability.
    4. Neither of these test methods respond to the primary definitions requiring a response in the NZBC, or in NZS 4858:2004 own scope; is *it waterproof?*

Default Standards for membranes

- We have carried out a review of applicable standards for waterproofing membranes, and as you can see the most comprehensive are the ASTM standards, but they are not perfect.
- To clarify the standards that provide testing criteria that will provide reliable data for Durability assessment, we have highlighted those titles in green.
- Disclosure—Bill Grayson sits on the ASTM technical committee D08 for roofing and membrane materials.

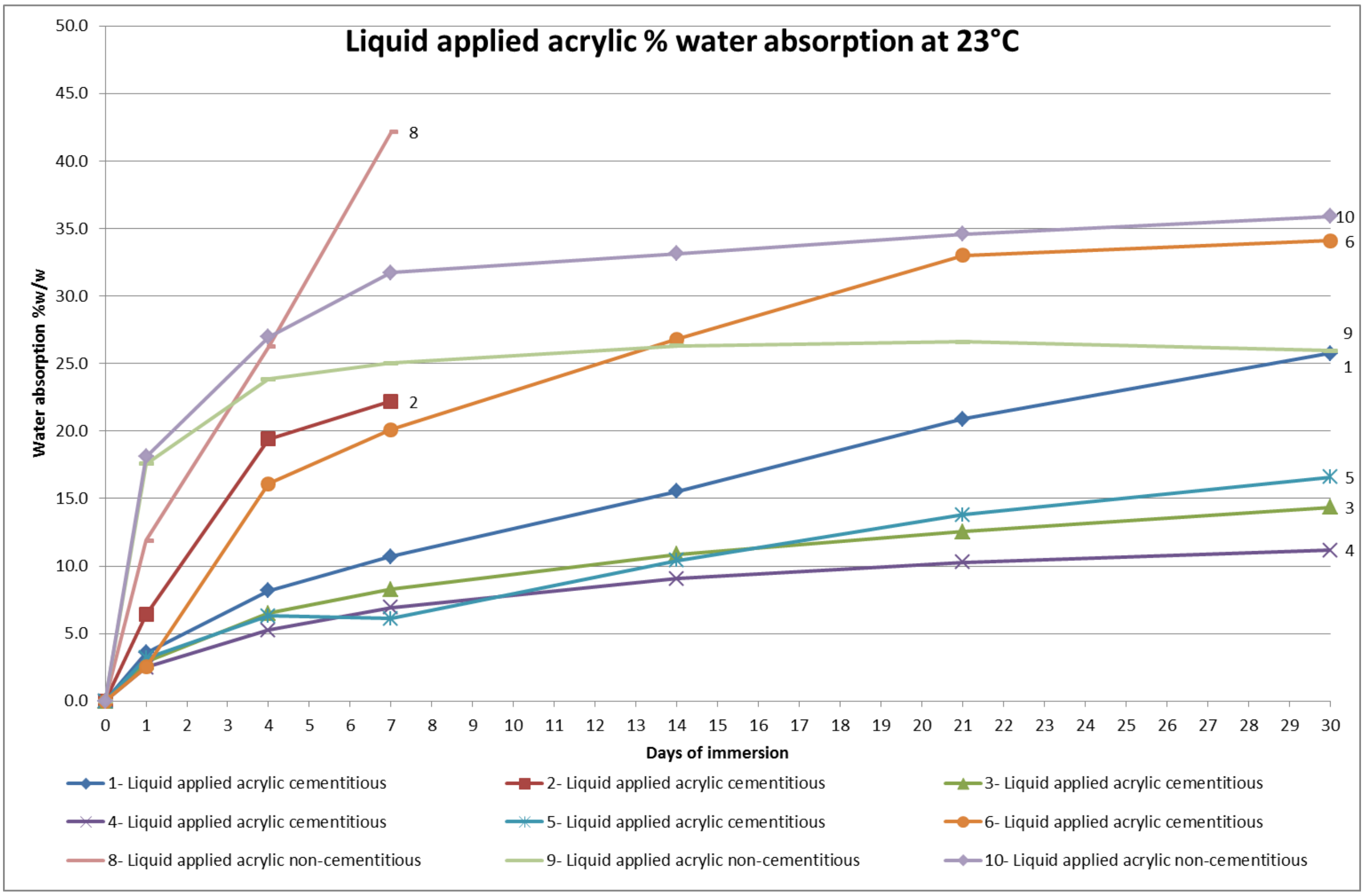
Membrane Type	ASTM Standard Specification Number	ASTM Standard Test Number	Immersion Test Parameters	Max Water Absorption
Liquid Applied Neoprene and Chlorosulfonated Polyethylene used in Waterproofing and Roofing	D3468-13	D471	7 days @ 23°C	4%
EPDM Sheet used in Single Ply Roof Membrane	D4637 / D4637M-14e1	D471	166hrs @ 70°C	Range +8, -2%
Nonvulcanised (Uncured) Rubber Sheet used as Roof Flashing Type 1 only	D4811-06(2013)e1	D471	**Type 1-** 166hrs @ 70°C **Type 2-** 46hrs @ 70°C	Range +8, -2%
Reinforced Chlorosulfonated Polyethylene sheet used in Single Ply Roof Membrane **Withdrawn 2011**	~~D5019-07a~~	~~D471~~	~~166hrs @ 50°C~~	~~10%~~
Liquid Applied Acrylic Coating used in Roofing **Withdrawn 2014**	~~D6083-05~~	~~D471~~	~~7 days @ 23°C~~	~~20%~~
Atactic Polypropylene Modified Bituminous Sheet Materials using Polyester Reinforcing	D6222 / D6222M-11	D5147	100hrs @ 50°C	3.2%
Atactic Polypropylene Modified Bituminous Sheet Materials using a Combination of Polyester and Glass Fibre Reinforcing	D6223 / D6223M-02(2009)e1	D5147	100hrs @ 50°C	3.2%
Atactic Polypropylene Modified Bituminous Sheet Materials using Glass Fibre Reinforcing	D6509 / D6509M-09(2015)	D5147	100hrs @ 50°C	3.2%
Thermoplastic Polyolefin based Sheet Roofing	D6878 / D6878M-13	D471	166hrs @ 70°C	3.0%
Liquid Applied, Single Pack, Moisture Triggered, Aliphatic Polyurethane Roofing Membrane **Withdrawn 2013**	~~D7311-07~~	~~ASTM E96 / E96M – 14 Desiccant method~~	~~32°C @ 50% RH~~	~~Water Vapour Transmission permeability Max = 8.52 g/m²/day~~
Spray Polyurethane Foam used for Roofing Applications	D7425 / D7425M-13	D2842	96hrs @ 23°C	5% v/v
Standard Specification for High-Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane With Integral Wearing Surface	C957	NA	NA	NA
Fiberglass Reinforced Styrene-Butadiene-Styrene (SBS) Modified Bituminous Sheets with a Factory Applied Metal Surface	D6298-13	D5147	100hrs @ 50°C	1.0%
Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using a Combination of Polyester and Glass Fiber Reinforcements	D6162 / D6162M-00A(2015)e1	NA	NA	NA
Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Glass Fiber Reinforcements	D6163 / D6163M-00A(2015)e1	NA	NA	NA
Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Polyester Reinforcements	D6164 / D6164M-11	NA	NA	NA
Thermoplastic Fabrics Used in Cold-Applied Roofing and Waterproofing	D5665 / D5665M-99a(2014)e1	NA	NA	NA
Thermoplastic Fabrics Used in Hot-Applied Roofing and Waterproofing	D5726 - 98(2013)	NA	NA	NA
Standard Specification for Vulcanized Rubber Sheets Used in Waterproofing Systems	D6134 - 07(2013)	D471	166hrs @ 70°C	**Type 1- EPDM** 4% **Type 2- Butyl** 2%

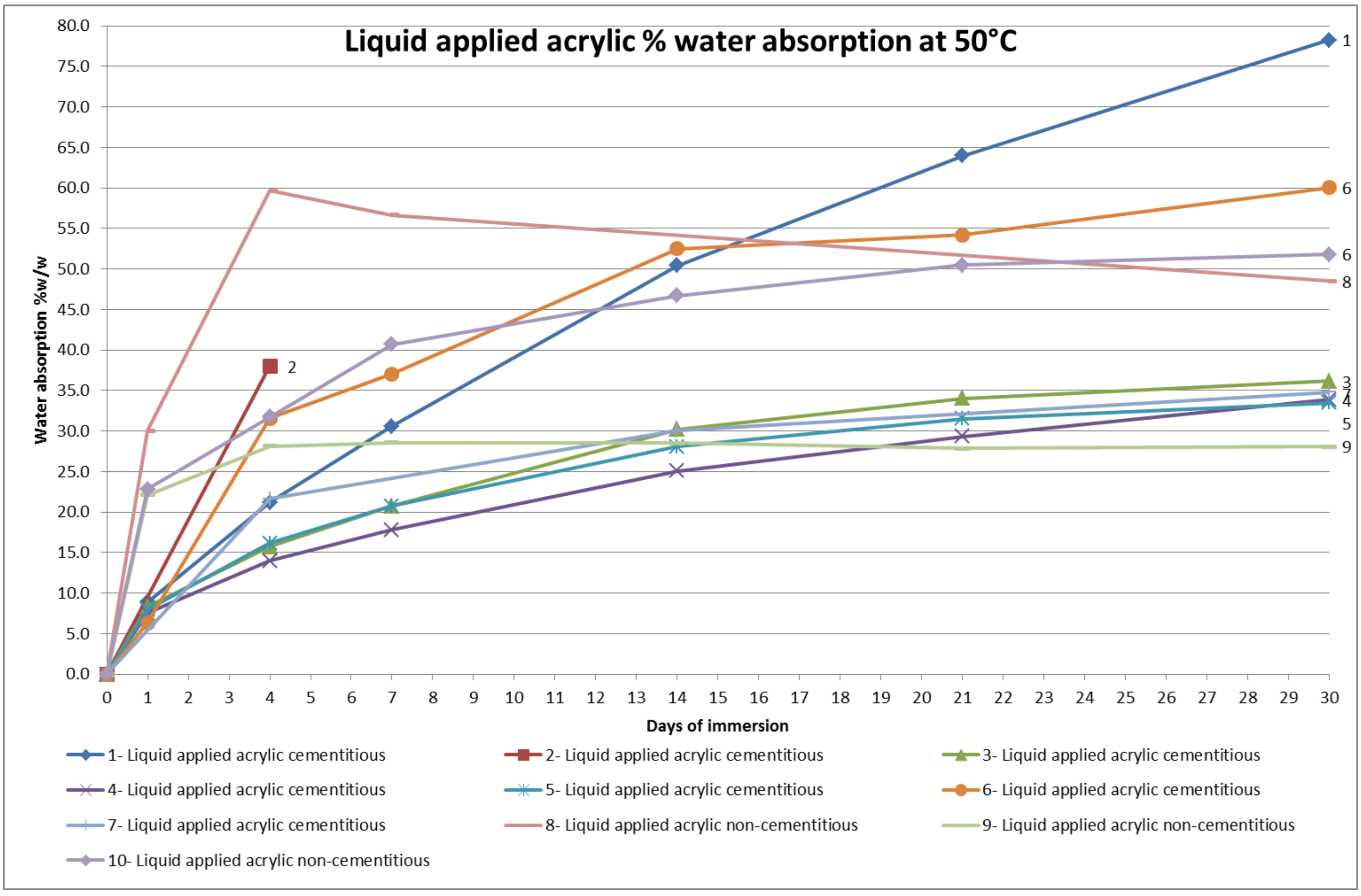
Membrane Type	Standard Number	Standard Test Method	Immersion Test Parameters	Max Water Absorption
Australian/New Zealand Standards for Wet Area Membranes	AS/NZ 4858:2004	AS 3558.1 - 1999 (AS Methods of testing plastics and composite materials sanitary plumbing fixtures. Method 1: Determination of water absorption characteristics)	24hrs @ Room Temperature	**Record and Report** Suitability for use over particleboard = 10% gain in moisture content of particleboard
Australian/New Zealand Standards for Wet Area Membranes	AS/NZ 4858:2004	ASTM E96 / E96M – 14 Desiccant method	32°C @ 50% RH	If >8g / m² / day. Testing to AS 3558.1 will be required for suitability over particleboard
ISO EN DIN-Plastics/ Lloyds Register	ISO 62:2005	Methods 1-3		
European/British Standards for coatings for exterior masonry and concrete	EN1062.1:2004	EN1062.3:2008	24hrs @ 23°C	**Class 1 High-** <0.5 kg/(m²xhr$^{0.5}$) **Class 2 Medium-** 0.1-0.5 kg/(m²xhr$^{0.5}$) **Class 3 Low-** <0.1 kg/(m²xhr$^{0.5}$)
European/British Standards for liquid-applied water impermeable products for use beneath ceramic tiling bonded with adhesives	BS EN 14891:2012	BS EN 14891:2012 Method A.7	7days @ 23°C and 150 kPa	No penetration and ≤ 20g weight gain of concrete/membrane sample
European Standards for plastics- determination of water absorption	DIN EN ISO 62:2008	DIN EN ISO 62:2008 Method 1	Until equilibrium @ 23°C	NA

- The ASTM standards test a variety of membrane types in different ways and with different specifications, however the common themes of the test methods are:
    a) Water immersion for ~7days/166hrs at 23°C Specification < 4%
    b) Water immersion for ~4days/100hrs at 50°C Specification < 3.2%
    c) Water immersion for ~7days/166hrs at 70°C Specification < 3.0%
- The good news about these three water immersion performance criteria is that they readily allow testing of field samples of problem membranes.
- Recently a number of ASTM standards have been withdrawn, it is worth noting that *the withdrawn standards all have water absorption >10%.*
- The use of water absorption testing to ASTM standard methods is a key requirement for determining the durability of any waterproofing membrane, and is referenced in a number of leading professional publications.

Will a particular membrane waterproof a structure?

- To clarify this question, we decided to test a number of membrane samples by ASTM methods, using water immersion at 23°C and 50°C, until they reached equilibrium, and stopped absorbing water.
- This data is presented for 24 unnamed membranes, all having been available in the NZ market, and all tested for 4-30 days as follows:
    a) 23°C water immersion results ASTM D471
    b) 50°C water immersion results ASTM D5147
- The results are separated into membrane families for ease of understanding:
    a) Liquid applied Acrylic emulsion
    b) Liquid applied Urethane
    c) Modified bitumen and sheet membranes
- Please note that the vertical Y axis on the following graphs vary, so please check the values.
- Note: this testing is currently being repeated to accommodate changes in formulations and product availability in NZ since 2011 when this data was generated.





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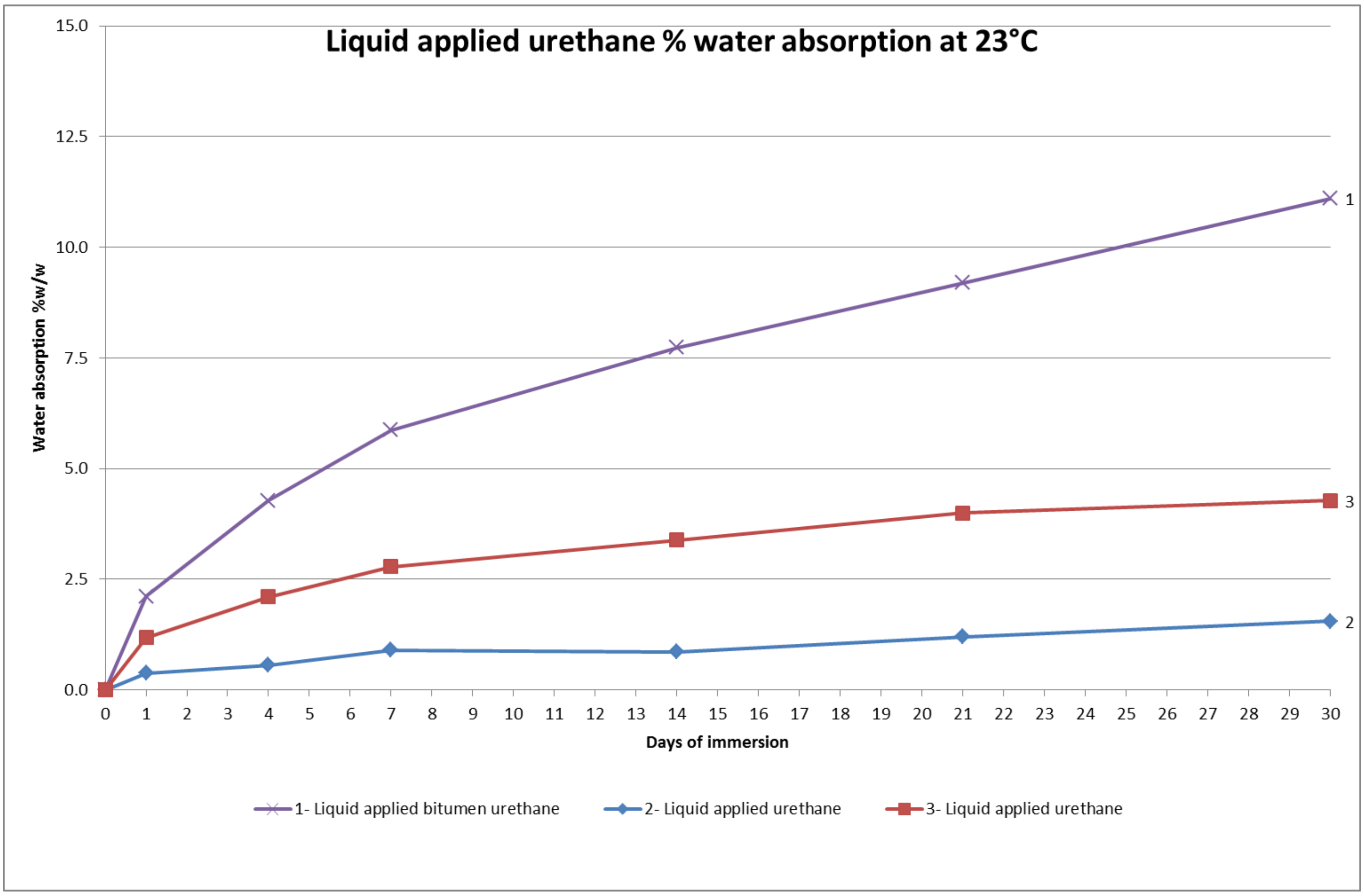

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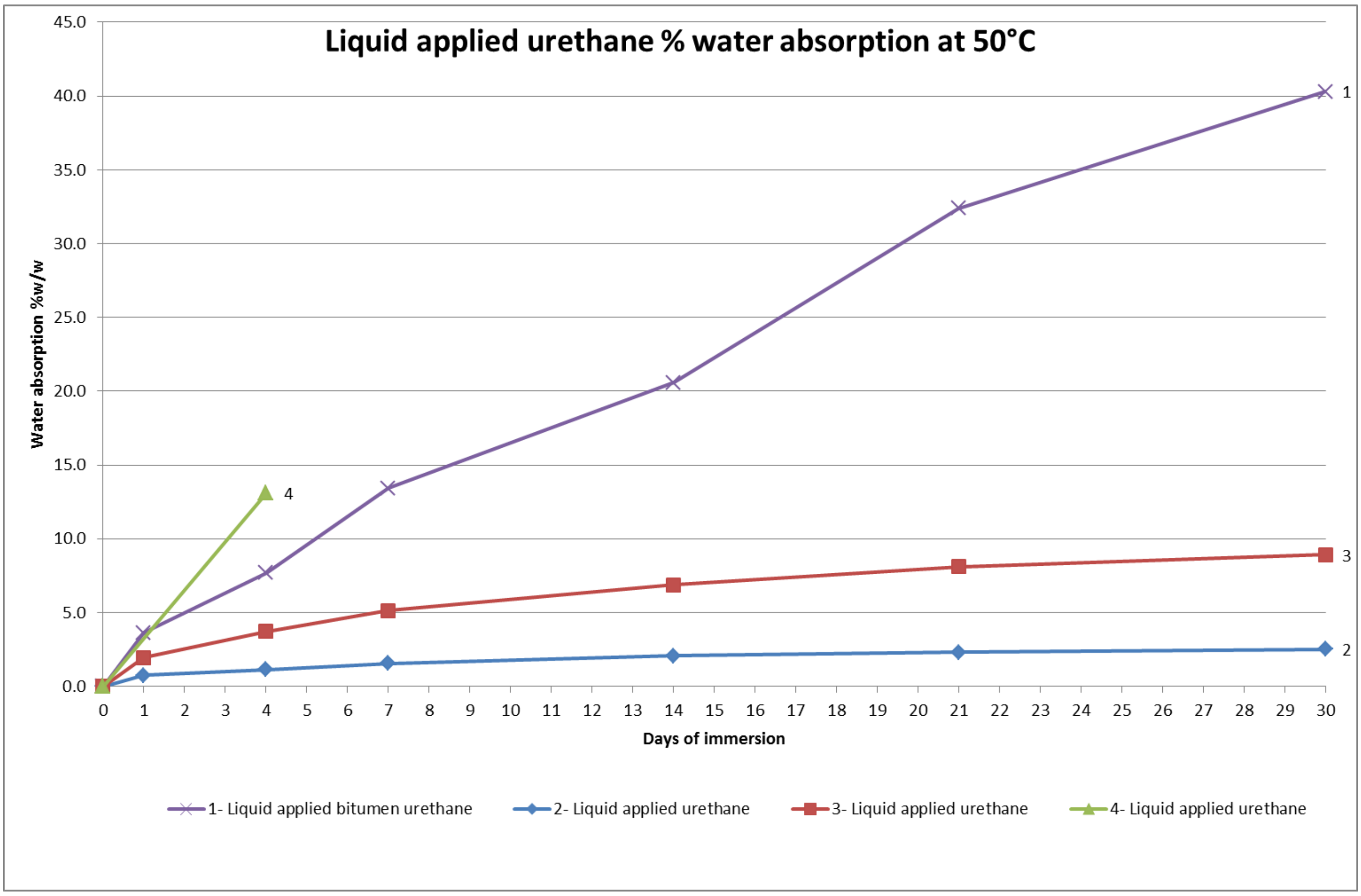

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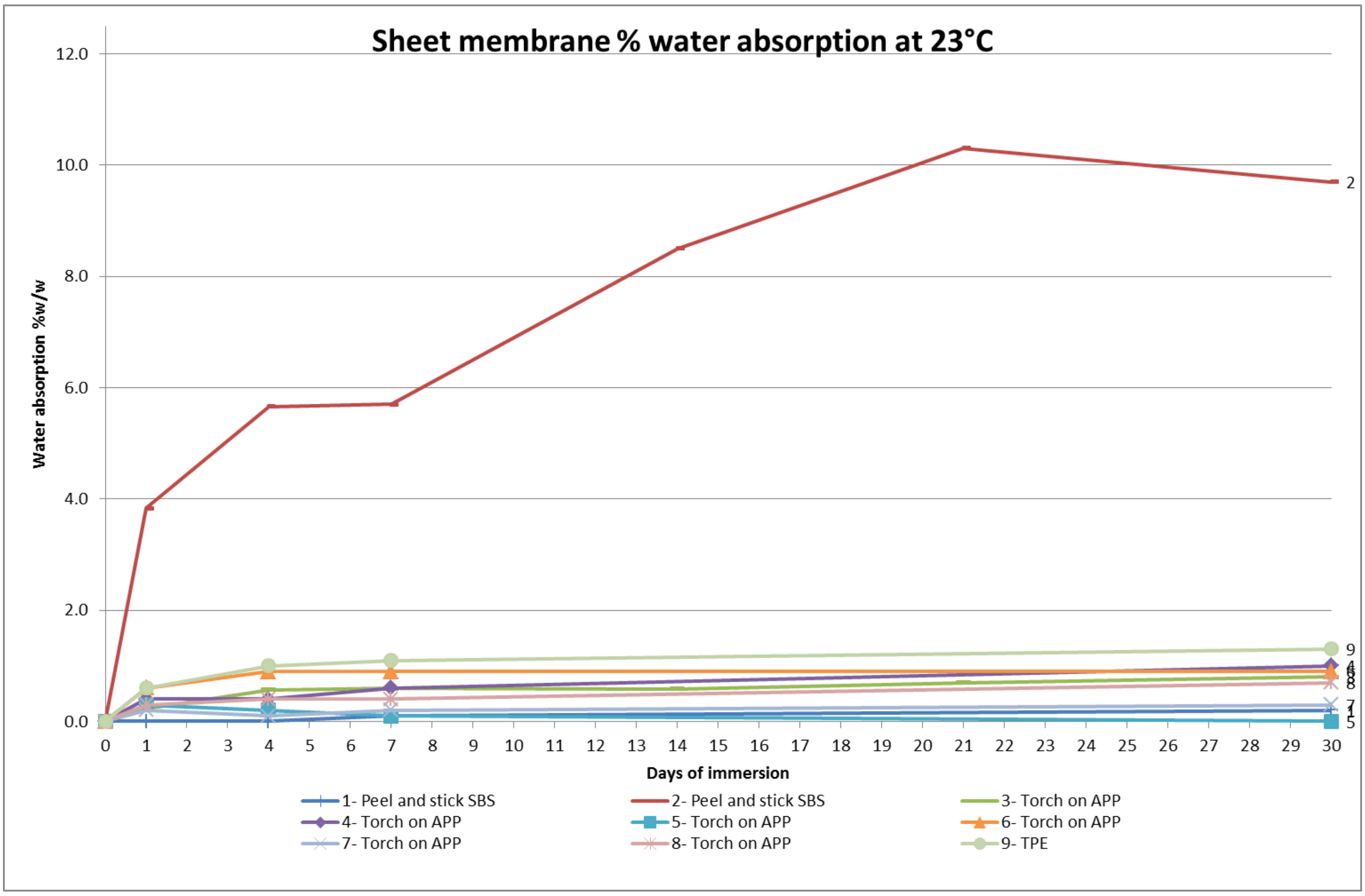

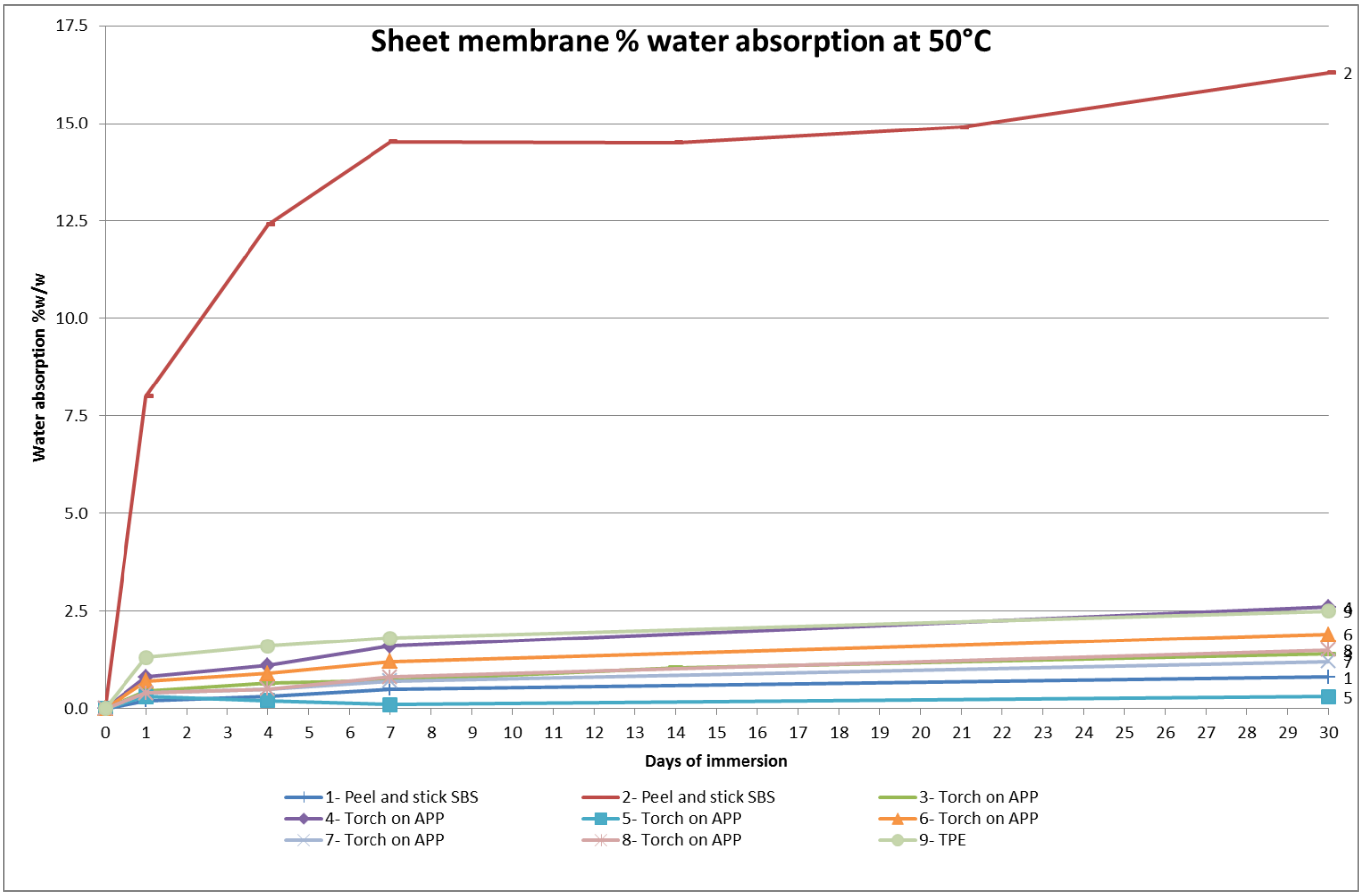

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Conclusions from test data

- We are firmly of the view that the NZ Building Code approach is correct and robust, and that waterproofness of waterproofing building elements is a legally binding obligation on suppliers that must be achieved.
- Consequently *any membrane that serves a waterproofing function should not absorb more that 3% water at equilibrium*. From the data presented, this equilibrium will be effectively established after 7days immersion in water at 50C, if less than 3% water is absorbed.
- At this stage of their development we have not found any liquid applied membranes which could be considered for waterproofing applications.
- In general torch-on or welded seam sheet membranes appear to provide durable performance; but be very afraid if they utilise adhesive based lap joints if these adhesives have not been so tested.
- Welded aluminium or stainless steel shower trays, fitted with O-ring gully traps remain a robust solution.

Other significant influences on waterproofing membrane success or failure

- From this data, it is clear that higher water immersion temperatures increase a membrane's rate of water absorption.
- Water absorption can be a reversible process if heat energy is applied, so periods of drying will reduce water content, if only temporarily.
  Useful improvements to system design are:
  a) Provide an air gap above the membrane, such as through the use of tile jacks. Capillary action will keep a membrane constantly wet when in contact with a wear surface. This severely limits the long standing industry method of direct sticking tiles to waterproofing membranes.
  b) Ensure good falls with no ponding to reduce water contact time.
  c) Choose a membrane with the lowest possible water absorption- ask to see water absorption data for that membrane for at least 7days at 50°C!!!
- Protect membranes from UV light, which generally causes membrane surface breakdown
- Check compatibility of the membrane with all the components that it will be exposed to. Example: Peel and stick membranes on LOSP treated framing timber?

Please do not hesitate to contact us if you require specific advice, and remember:

The quoted price is never the final cost!