

## TN 024 CONCRETE AND MOISTURE SENSITIVE COVERINGS

### 1. INTRODUCTION

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BCRC research indicates that failure of coverings over concrete could become a significant issue due to changing concrete practices unless greater attention is paid to understanding concrete drying and appropriate testing is used to determine if concrete has dried adequately before applying the covering.

“Bubbles” or “blisters” under sheet vinyl floors, deterioration of wooden floors, lifting of coatings and dampness in carpets are all potential problems. BCRC recently investigated one such issue and were alarmed at how changing industry practices and inadequate code provisions are making this a not uncommon occurrence. In the USA it is recognised as a “billion dollar problem”. This technical note outlines the mechanisms that lead to the problem and provides some remedies.

The problem is that water vapour rises from or through the concrete to the concrete surface where it can damage any covering. The simple issue becomes complex because of the number of contributing factors i.e.:

- 1) *Water source.* This may come from water trapped in the concrete (e.g. mix, curing or rain water) or water penetrating through the element (e.g. from ground or high humidity exposure). The key factors are water:cement ratio, membranes under a slab, curing, self desiccation and wetting after construction.
- 2) *Drying rate.* Key factors are the original water:cement ratio of the mix, concrete finishing that seals the concrete surface, ambient relative humidity and temporary coverings that prevent drying.
- 3) *Installation moisture limitations.* The water content within the concrete can be quite high although the surface is sufficiently dry for installation. The effect of rate of drying, sealers and adhesives in relation to slab moisture contents at the time of application need to be considered.
- 4) *Long term moisture limitations.* This is so that the covering does not fail as moisture contents

equilibrate. Important factors are sources of water, factors that affect the bond strength, testing methods and testing criteria that define suitable slab dryness.

- 5) *Moisture measurement.* There are many tests available to determine when the concrete is dry enough but the tests vary in ease of use, repeatability and suitability to the task. The various tests and the significance of the results are discussed.
- 6) *Concrete surface alkalinity.* Many adhesives breakdown in highly alkaline environments. Changes in adhesive types used, the significance of alkalinity and its importance to long term performance must be considered.
- 7) *Osmosis.* The construction should ensure that a semi permeable membrane does not form. Slab finishing methods are critical.

As indicated by the above the basic problem seems relatively simple to define, even though there are disagreements on the exact nature of all the mechanisms. However, integrating the design, construction and covering installation to avoid failure yet meet rapid construction deadlines can be complex.

### STATE OF THE ART

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In order to get an impression of the state of the art in Australia the author contacted various Australian Authorities. A key consideration was to determine if the industry at large was following US or European guidelines rather than the very old Australian Standards. The following are the key points that the floor covering industry raised:

- a) The issue of vinyl adhesive failure is well recognised as a moisture problem in Australia but it is more of an issue in the eastern states on clay soils than it is in WA on sands. This would only be the case where membranes are not used. WA’s dry environment is also likely to play a part
- b) The vinyl manufacturers have recognised that AS 1884 is out of date and have drafted a new standard that is with Australian Standards. This was six years in development

- c) Burnished floors are a consistent problem. This is thought to be due to their locking in moisture that is released later
- d) The knowledge on the issues of floor drying is largely held within the floor covering suppliers. They recognise that the surface box method (AS 1884 Part B) is less reliable than the measurement in a drilled hole method.
- e) Unlike the USA, where the concrete and vinyl industry have journals that have emphasised the issue of vinyl floor and moisture, there are no journals in Australia where the issue of floor drying is discussed.
- f) Low VOC moisture sensitive acrylics were preferred for health and safety reasons and ease of use by floor layers compared to less moisture sensitive epoxy and polyurethane adhesives.

Australian Standards for vinyl floor coverings (AS 1884 (1985) and AS 3553 (1988)) are not superseded but standards are automatically labelled as obsolete after 15 years. Whether obsolete or out of date the standards give inappropriate advice. AS 1884 Clause 2.1.1.2 states *“Before a floor covering is laid on a concrete sub floor... the dryness shall be determined using either a hygrometer or electrical resistance test as described in Appendix A. Dryness shall be considered satisfactory when relative humidity does not exceed 70% (moisture box test on surface) or the moisture content does not exceed 5.5% (electrical resistance test).”* These tests are not generally considered suitable by the industry for testing for dryness of floors.

AS 1884 Clause 3.2c requires that the adhesive be laid in accordance with manufacturers recommendations so that the floor covering adheres permanently to the sub floor. This implies it is the responsibility of the floor covering manufacturer to recommend suitable adhesives and specifications often imply that. However, the emphasis in the US is that this should not be the floor installers responsibility as he has no control over the construction of the concrete. In 2001 the “World Floor Covering Association” (WFCA) published a position paper on moisture testing which was endorsed by many US associations involved with coverings. This states that *“... It is unreasonable to expect a general contractor, concrete contractor or a flooring installer to have sufficient expertise to*

*anticipate and ask the proper questions for evaluation of potential concrete/flooring problems....It is therefore our recommendations that concrete moisture vapour emission testing be performed by qualified independent agencies”.*

Although Australian literature is very limited in comparison to the US some Australian’s in the concrete and floor surfacing industries would have been aware of the US hiatus on floor adhesive failures as there are strong links between the US and Australian in the concrete and floor covering industry sectors. This is evident by the vinyl manufacturers drafting of a new Australian Standard and the CCAA 2007 publication on “Moisture in Concrete”.

The CCAA 2007 document is not a standard but CCAA is a recognised concrete authority in regards provision of technical guidance. This document is quite comprehensive in giving information. However, it does not highlight issues with measuring the water vapour emission rate test in AS 1884.

There do not appear to be any Australian industry journals, concrete or coverings that have highlighted the issue of drying of concrete for moisture sensitive coverings. This may account for why the issues are not well understood by designers, constructors and covering installers.

While information on the moisture problem in Australia is limited the topic has received a lot of attention in the US where it has been labelled a billion dollar problem. The American Concrete Institute (ACI) held a “hot topic” session on concrete moisture in January 2007. It focused on the need for testing and the methods of testing concrete slabs. The ACI’s “Guide for Concrete Slabs that Receive Moisture Sensitive Flooring Materials” was presented. The US has at least two journals that give frequent information on the issues of moisture in slabs.

Between 2003 and 2007 Floor Covering Installer journal had many articles on the issue of proper floor drying, most of them expressing issues with surface humidity testing and advising that the drilled hole humidity tests has significant advantages (Capobianco,2003,2004, 2005, 2006,2007; Olansky 2003, 2003; Grady 2004, Padgett 2005; Tanski 2006, 2006; Tompson 2007). The issue of deep slab moisture retention and eventual equilibration is generally discussed.

Concrete International, the ACI journal that some concrete technologists in Australia are members of, also had many articles on the subject of moisture in slabs and testing (Suprenant 2003, 2003, 2003, Craig 2003,2006;Scurto 2004; Grasley 2006).

Other US Journals Such as Concrete Today, Restoration and Remediation and the Aberdeen Group have also carried several articles.

The Portland Cement Association have a book and DVD on moisture sensitive floors that was first published in 2005 and re-issued in 2008.

From these articles it is clear that the issue associated with concrete drying and testing of moisture contents are well understood in the US and have received a lot of publicity.

There are US standards for most of the drying test methods but they tend to detail how to undertake the test rather than comment on their usefulness.

The state of the art is less clear in Europe as electronic access to journals is not so simple. However, it is clear that in some parts of the industry the significance of moisture content at depth is well known and Nordic codes were based on measurement of moisture at depth since 1995. In the UK however testing is still largely based on RH measurements at the slab surface although the UK test is more rigorous than the AS 1884 test.

## CONSTRUCTION FACTORS

The failure of floor coverings is a complex topic and variations on the same theme as to the theory of failure are proposed by professionals from different industry sectors. The various contributing factors are outlined below.

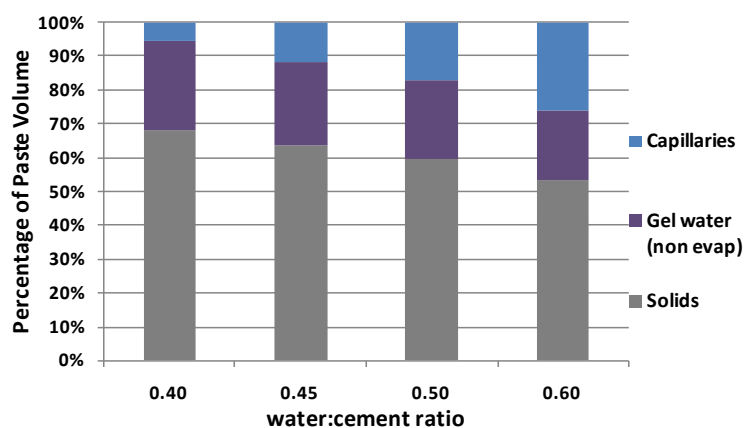
A considerable supply of water can be provided from the ground below a slab on grade. Although slabs can dry from two directions if there is no membrane the risk of moisture availability from below a slab generally means it is simpler to require a membrane. A polythene membrane taped at all joints with care taken not to damage it during construction will provides assurance of no moisture ingress from below.

If no membrane is used then it is vital to provide a capillary break below the slab (eg a crushed rock or gravel layer). In cold climates an insulating layer is

also valuable as it reduces temperature differentials that drive the moisture upwards

The water: cement ratio of concrete is important to the water content and water permeability of concrete. A certain amount of water is required to hydrate the cement and if the quantity of mixing water used is less than that amount then the mixing water could all be consumed in hydration. This occurs at a w/c ratio of approximately 0.38. As the w/c ratio increases above that capillaries form (Figure 1). These capillaries hold the water that must be driven off before laying coverings.

Figure 1 : Increase in Capillary with Increasing w/c Ratio



At a w/c ratio 0.6 capillaries occupy 25% of the paste volume while at a w/c of 0.4 they occupy only 5%. This translates to 10kg/m<sup>2</sup> of water to drive off at a w/c of 0.6 and 2kg/m<sup>2</sup> at a w/c of 0.4. In reality as the water : cement ratio reduces some of the cement stays unhydrated and some free water remains so that even at very low w/c ratios there is some residual water.

Kanare 2005 notes that the capillaries in concrete become discontinuous after 3 days at a w/c ratio of 0.4, at 6 months at a w/c ratio 0.6 and never at a w/c of over 0.7. This significantly affects the water vapour emission rate.

The combination of low water content and low water diffusivity means that the release of water from the surface of a low w/c ratio concrete is considerably lower than that of a high w/c ratio concrete. This is shown in (Figure 2) which is based on US work supporting the calcium chloride surface drying test.

Figure 2 : Rate of Drying for Concrete With Different w/c Ratios

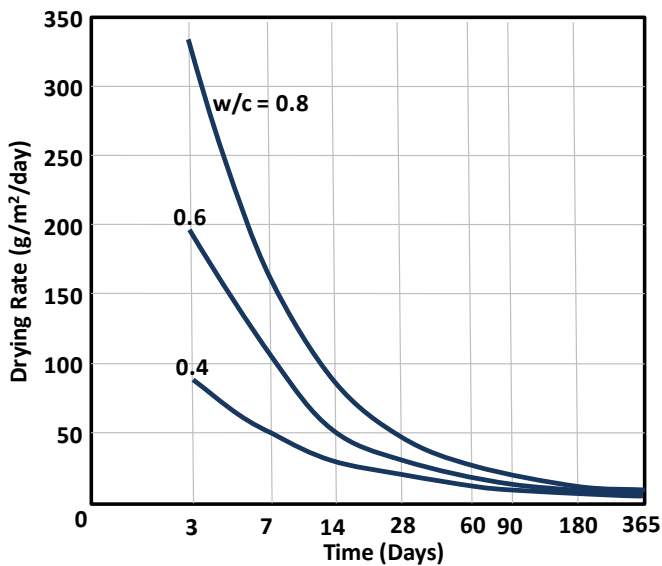


Figure 2 shows that increasing the w/c ratio from 0.4 to 0.6 would increase the drying time significantly. CCAA 2007 quotes ASTM F710 2005 as “.. a water cement ratio of 0.5 will generally allow drying within three months and slabs with a w/c greater than 0.6 will take an exceeding long time to dry and cause adhesives or floor coverings or both to fail due to high moisture permeability” Although Suprenant 2003 notes that w/c ratios lower than 0.4 do not reduce drying times significantly, work in Norway has shown that using silica fume and very low w/c ratios a concrete slab can be dry enough to lay vinyl at 7 days.

Curing of concrete is another critical issue. Suprenant 2003 recommends “ plastic sheeting to cure the concrete for 3 days. This provides a compromise between improving the concrete properties and decreasing the drying time. Many specifiers require water curing for floors... This practice is counter productive for floors that must dry before flooring materials are installed.”

Where concrete is to be left in the open it will be subject to rain water penetration. Conventional assessment of drying time is taken from when the slab is no longer subject to water inundation. However, a further problem arises in that the porosity of the slab reduces with time and hence drying times several months after construction will be higher than drying times immediately after construction.

The drying period only commences once wetting of a slab has stopped. Whist drying is controlled by diffusion of water vapour and is slow, wetting is fast due to capillary action. The sorption of water into concrete is:

$$d = st^{0.5}/v$$

where d = depth (mm)

s = sorptivity (mm/min<sup>0.5</sup>)

t = time (secs)

v = voids ratio

For concrete with a f'c of 32MPa the author estimates the sorptivity would be 0.33mm/min<sup>0.5</sup>. Hence, the time for rain water ponding on a slab to penetrate 125mm and to saturate the concrete would be 28 hours. This could be less time than it takes a rain water puddle to evaporate. Hence, a slab that may have taken months to dry could be totally re-saturated if exposed to one rainstorm or one wash-down.

The manner in which osmosis causes blistering of coatings on steel is well understood. Certain coatings on the inside of a tank acts as a semi-permeable membrane. In typical applications water can pass in both directions through the coating with no pressure build up between the coating and the tank wall (Figure 3a). However, if there is salt contamination between the coating and the tank wall the water will penetrate the coating and the salt will go into solution creating a concentration difference across the coating which then acts as a semi-permeable membrane. This concentration difference leads to water migration through the coating to try and equalise the concentration (Figure 3b). The pressure build up between the coating and steel wall leads to failure of the weaker item, i.e. the coating. Typically blisters form that are filled with water under pressure.

Figure 3 : Osmosis in Linings

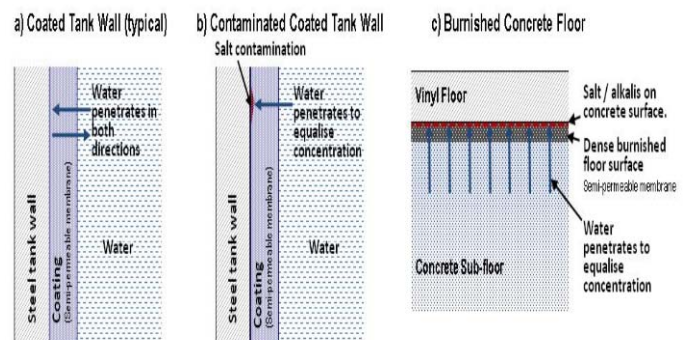
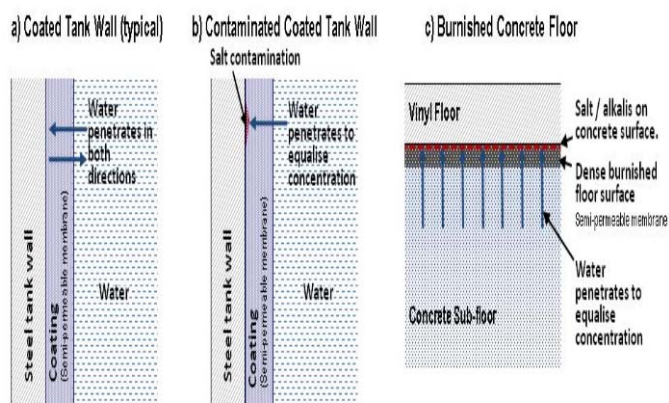


Figure 3c : Osmosis in Concrete



In the context of a burnished concrete floor (Figure 3c) the worked concrete surface acts as the semi permeable layer. Some papers suggest that concrete can not be a semi-permeable membrane as the ions that cause the concentration difference can pass through the concrete pores, eg Murphy 2008. Other papers support concrete becoming the semi-permeable membrane alone, e.g. Ignoul 2008 while others suggest that concrete where the pores are too large can form the semi permeable membrane in conjunction with the adhesive blocking part of the pores.

Table 1 : Comparison of Size of Different Items

	Size nano meters
Sodium ions	0.14
Calcium ions	0.1
Water vapour	0.2
Silane	3-6
Breathable Coating Pore	0.1-50
Concrete Pore	3-100

Table 2 shows that the sodium and calcium ions are much finer than the concrete pores and this is why Murphy 2008 contends that concrete will not act as a semi permeable membrane. However, Siegwart 2002 undertook research on the diffusion of chloride ions using Anaporefilter membranes with known pore diameters. It was found that “*The resistance remains unhindered for a pore size of larger than 4 micron for NaCl and larger than 10 micron for sodium hydroxide. It is not possible to isolate and investigate the influence of one type of ion because a cation is always accompanied by an anion to satisfy the electroneutrality condition.*” This supports the idea of concrete being able to act as a semi-permeable

membrane. Consider a concrete with pores 3-5nm. Water vapour with a size of 0.2nm could pass freely but alkali salts of concrete would not. As burnishing densifies the surface, and steel floats are commonly referred to as “sealing the surface” it is likely that there is at least a film at the surface of a burnished concrete that could act as a semi permeable membrane.

Keane 2005 reports that Tanaka 1995 used cement paste discs to show that osmotic pressures in excess of 0.8MPa could be built up and lower water cement ratios developed higher pressures and transmitted more water. This is strong confirmation that osmotic pressures with burnished floors are likely.

Calcium hydroxide and soluble alkali hydrates act as the salts. Any water ponding at the concrete surface (eg water curing or exposure to rain water) will tend to increase the leaching of hydroxides from the concrete to the surface so that there is a higher risk of salts being present in the surface of the burnished layer.

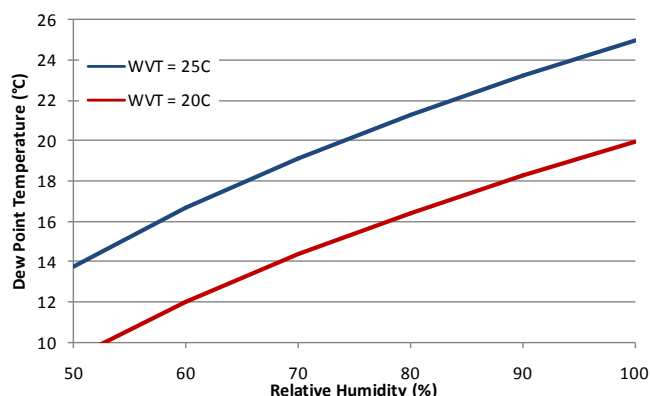
The hardened surface of burnished floors therefore has four significant factors leading to the failure of floor coverings:

- reduced ability of the concrete to dry leaving a high base moisture content
- formation of a high resistivity surface layer that will cause capacitance and resistance meters to give false low moisture contents. RH box tests will also give misleading results
- reduced ability of adhesives to penetrate and bond to the concrete thereby reducing the ability to resist water vapour or osmotic pressure
- formation of a semi permeable membrane leading to osmotic pressure

Condensation of water is the change of water from its gaseous phase to its liquid phase. It occurs when the vapour is cooled to its dew point. If the humidity in concrete pores is 70% and the concrete is at a temperature of 25°C then if over night the concrete temperature falls below the dew point temperature of 19°C then the water vapour will condense on the pore walls. The dew point temperature is dependent on the temperature of the vapour and the humidity and the temperature of the condensing surface. The Dew Point Temperature is shown versus Relative Humidity for initial temperatures of 20°C and 25°C in Figure 4.

This shows that as the RH at the top surface of the concrete increases due to equilibration the likelihood of water condensing on the vinyl increases as the Dew Point Temperature increases with RH. However condensation will only occur if the temperature at the concrete surface drops. At 90% RH the temperature would only need to drop by 2°C for condensation to occur.

**Figure 4 : Dew Point Temperature for Concrete at the BRF**



Taking into account the above general concrete specifications where moisture sensitive coverings are to be used might comprise:

- 1) 40MPa concrete with a maximum w/c ratio of 0.45
- 2) no burnishing or hard trowelling of the surface
- 3) final pass bull float to open the concrete surface
- 4) cure under polythene for 3 days and then allow to dry
- 5) prevent the ingress of rain or wash down water after curing
- 6) prevent condensation by preventing large temperature changes and ensuring the equilibrium RH of the concrete is sufficiently low before sealing

Silica fume can be incorporated into the mix to reduce the pore size distribution and hence vapour emission rates. Although this has been used successfully to give early drying times in Scandinavia there are reports of poor bonding of finishes where silica fume is used precisely because of the closed pore structure and hence its use should only follow successful bonding trials.

## OPERATIONAL ASPECTS

The drying time depends very much on the relative humidity of the air but once an impermeable covering is laid the operating RH is of no significance.

Condensation can occur in concrete when temperatures drop overnight leading to an increased moisture content. However, if the concrete is in a building with strict temperature control condensation within the concrete or under the vinyl is unlikely.

Water vapour pressure is dependant on the temperature and at 22°C is 2.6MPa. Where concrete is exposed to sunlight the floor temperature would increase. At 30°C the vapour pressure would be 4.2MPa. Considering the adhesive bond strength with no degradation is likely to be 1.0-2.5MPa the vapour pressure would be sufficient to lift impermeable coverings.

## DRYING TIMES

Many scientific papers deal with concrete drying including Mills 1985, Legros 1992, Hedenblad 1997, Andrade 1999, Johannesson 2009, West 2005, Leivo 2008 and Picandet 2008, Rantala 2008, Slanina 2009. This is not an exhaustive list but shows that there has been considerable research into the topic of concrete drying.

Leivo 2008 discusses a steady state model for slab drying which is applicable to slabs with no membrane under the slab. Unfortunately the simple model is of no use for most Australian structures as membranes interfere with the steady state. Interestingly Leivo notes that membranes are negative for drying as they limit drying to one face. In Western Australian conditions where the soil is well drained sand the absence of a waterproofing membrane could be positive provided a capillary suppressant layer is used. Of less significance is the discussion on the benefit of an insulating layer between the slab and soil.

Mills 1985 studied the mechanism of water vapour diffusion through concrete and found that it is strongly related to porosity. This accounts for the step increase when silica fume (and other fine fillers) are used in concrete (see Hednblad 2007 below).

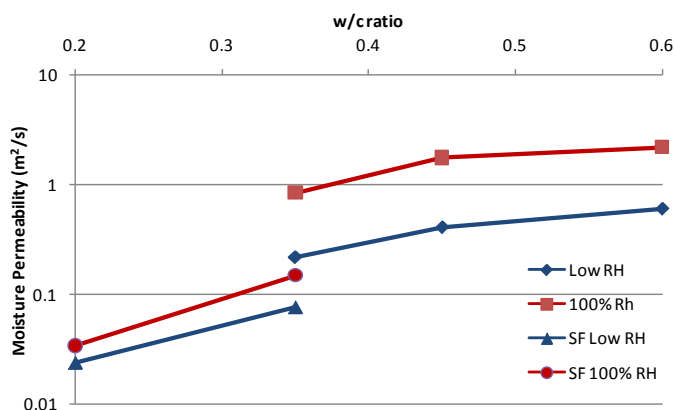
Picandet 2006 provides a method of measuring the water permeability and water vapour diffusivity of concrete and provides data for normal and high strength concrete. He shows that the water vapour

diffusion coefficient increases exponentially once the water content reaches 10-12% and that the high strength concrete has a diffusivity 10 times less than the normal concrete. This is similar to Hedenblad 2007.

Johannesson 2009 reviews various drying models and notes that the allowance for sorption hysteresis is important. He presents a model that includes liquid and vapour flow and sorption hysteresis. He notes that vapour diffusivity decreases when the liquid water content increases due to blocking but is not able to measure this or apply a mathematical theory. Hence the modelling slips into providing a subjective algorithm verified by experimental outcome. The complexity of the model which relies on fitting to actual data and the lack of hard data makes this model unsuitable for general use.

Hedenblad 2007 focuses on a model to predict the moisture permeability based on the relative humidity in the concrete pores. In doing so he provides data on the effect of w/c ratio and moisture permeability (Figure 5).

**Figure 5 : Relationship Between Moisture Permeability and w/c Ratio and Humidity**



One of the issues with simple models such as Leivo 2008 is that they do not adequately cater for the influence of humidity in the pores on the permeability. As can be seen this can have an order of magnitude significance on the permeability and hence drying rate. This also explains why concrete dries more rapidly during its early life than it does subsequently. The importance of w/c ratio and mix ingredients is also highly significant. A reduction in permeability from 0.6 to 0.2 and the inclusion of silica fumes has a two orders of magnitude effect. Depending on the extent of burnishing the surface layer of the burnished floor could have permeability

at the lower end of the moisture permeability shown in Figure 5. This would lead to much longer drying times than the literature indicates for a 125mm thick slab.

Martin 1983 is one of the few Australian reports of slab moisture and floor coverings. It provides a summary of Nilsson's data for estimating drying time based on a 60 day drying period for standard conditions. This provides a very useful and simple way of gauging the drying time of concrete

West 2005 undertook considerable research of the moisture movement in concrete floors slabs during drying and after application of vinyl tiles. This research was one of the main considerations in the ASTM recommendation for measuring the moisture content at depth rather than the US's historical norm of measuring the humidity at the concrete surface.

Dr West's research on drying times used a finite element approach to drying rates however a linear model was also developed and found to give a reasonable approximation to the finite element approach. In the authors private communication with Dr West, Dr West noted that:

- It is relatively easy to dry the surface of the concrete but leave considerable moisture at depth. Hence, techniques to assess the time to floor laying based on surface moisture alone are not appropriate. A more reliable approach is to measure the RH at depth in a small chamber. This is the basis of the ASTM.
- Forced drying dries the surface quickly but leaves considerable moisture at depth. Slower drying to achieve the same surface concrete RH leaves a lower residual moisture content at depth. Although the standard gives the required RH as 75% at 40% depth for a slab on grade this may still be too high if forced drying is used as it will leave a higher moisture content at depth than when natural drying is used. When forced drying is used it is recommended that the RH at 40% slab depth is no greater than 65%.
- The value of 75% RH at the concrete surface as being the safe RH is based on manufacturer's experience. In general this has been found to be a suitable RH to lay vinyl at without ensuing problems. In reality the safe surface RH is typically around 80% but could be much higher.

d) Moisture suppressants are being marketed that enable a higher moisture content to be tolerated.

Rantala 2008 undertook similar FE analysis to West 2005 but it was supported with experiments on slabs. For one slab “The linoleum floor was applied on the slab surface 68 days after casting. At that time the RH at the surface was 53% and at 40% slab depth was 83%. Within 10 days the RH at the top of the slab had reached 78% and after 72 days equilibrium had been reached with a slab RH of 82%.” This proves the point of taking RH measurements at 40% of the slab depth to give information on the long term RH. He also notes “The hardening process itself dries out the concrete due to self desiccation in hydration.” However he also points out “Drying a massive ground slab is a long process and may last, depending on the type of concrete and prevailing drying conditions, several years or even a decade”.

## ADHESIVES

The adhesive is a very critical item in the success of floor covering installation as discussed below.

A polymer obtains its properties from the monomer residues along the backbone of a long chain molecule. The solubility of a long chain molecule may be soluble (eg ethylene oxide) or insoluble (eg Styrene). The influence of moisture and pH on the breakdown of vinyl adhesives is reasonably well understood by chemical engineers but not by the flooring or concrete industry. The breakdown is principally due to alkali hydrolysis and remulsification.

Dickens (undated) notes that the rate of breakdown of an adhesive is higher if absorbs the alkali liquids. This occurs when the adhesive contain hygroscopic materials (eg surfactants and clays) and the breakdown is accelerated when the linkages are particularly subject to alkali attack, eg acrylic modified with high vinyl acetate content. He reports three general mechanisms that cause breakdown:

- 1) Degradation occurs at crosslinks to expose water soluble backbone chains
- 2) Hydrolysis creates water soluble molecules
- 3) Hydrolysis of liable bonds causes breakdown from the backbones forming water soluble molecules

Hence adhesive may be water soluble in any event but water insoluble adhesive may breakdown under

the action of hydroxide ions and then become water soluble.

Anderberg 2008 report on the effect of pH on adhesives. *“The standard adhesive bonds contains poly(butyl acrylate-co-2-ethylhexyl acrylate) in which butyl and 2ethylhexyl groups are attached to a backbone of acrylate groups. If hydrolysis breaks the ester bond the butyl and 2ethylhexyl groups are split off and released as volatile butanol and 2ethylhexanol.”*

Other adhesives that are often thought to be less reactive contain poly(ethylene-co-vinyl acetate). Hydrolyses still occurs but the groups that are splits off form an acetate ion in the concretes alkaline environment that does not give the volatile’s odour. *“The low emitting adhesive is thus not alkali resistant as people in the construction industry sometimes believe”.*

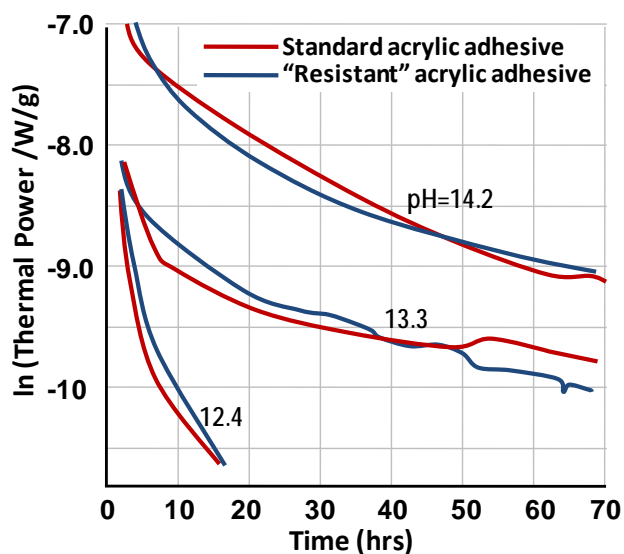
In both cases the acids that are formed by the reaction are immediately neutralised and this produces heat that can be monitored by calorimetry. Figure 6 shows the results on 2 acrylic adhesives and shows the very strong influence of pH on the hydrolysis of both adhesives. Over time the reactions slow. This is a function of the availability of hydroxyl ions at the concrete surface and not the RH. The hydroxide ions are consumed in the reaction and new ions need to arrive to continue the hydrolysis. Anderberg notes *“If one sees an influence of RH on the rate of alkaline hydrolysis .... this is probably because water is needed for the diffusion of hydroxide ions to the reaction sites”.*

Chino 2009 reported on the emissions from one SBR, one acrylic/SBR blend and four acrylic adhesives. In the SBR there were no VOC emissions and in the adhesive with a blend of acrylic and SBR the VOC emissions were delayed, presumably because the rubber latex acted as a barrier between the alkalis and the acrylic. However the VOC emissions rate eventually increased to match the other adhesives.

The importance of pH is underlined in cement substrates where the surface may have very high hydroxide levels due to capillary rise during hydration or in older concrete may be low due to carbonation. The carbonation will also help to seal the surface and reduce water migration.



Figure 6 : Measured Thermal Output due to Hydrolysis of Adhesives



The wet concrete will have a pH of around 13. However after a few months reaction of the calcium hydroxide and carbon dioxide in the concrete will reduce the pH to below 10. Some specifications require that the surface of the concrete be tested for pH to ensure that the adhesive is not immediately subject to a high alkaline environment. However the adhesive also contains water and this will be absorbed by the concrete. Suprenant 2003 tested floor surfaces before and after wetting and found that some adhesives would lead to quite high uptakes of water into the concrete surface thereby releasing hydroxide ions at depth that diffused back to the surface so that the concrete pH increased from 9 to 11.5 in a few minutes.

In specifying the adhesive it is important to recognise the adhesives susceptibility to alkali hydrolysis, re-emulsification and its water content.

A common method of enabling the laying of vinyl floors on slabs that are wet is to apply a water vapour suppressant on the floor on the basis that blocking the moisture will solve the problem. Whilst these can suppress water vapour the mechanism that solves the problem may be the blocking of the delivery of hydroxides.

Kanare 2007 notes that the best vapour suppressants under sheet vinyl are "high cross linked density, 100% solids two part epoxies and that these can have vapour transmission rates of 10mg/hr/m<sup>2</sup> when applied in 12-15mil thickness."

## TESTS FOR CONCRETE DRYING

There are a number of publications that provide reasonably detailed assessments of tests for drying of concrete eg Kanare 2005 and details of the test methods are not repeated here. However a general discussion of the test methods is given below.

Most Australian specification calls for testing of the concrete for drying in accordance with the hygrometer test in AS 1884 Appendix A. In this test a dial hygrometer in a vapour tight mounting housed in a well insulated box is sealed to the concrete surface. The principle of the test is that during the test period the box traps water vapour evaporating from the slab surface. The increasing humidity in the box leads to a reduction in the slabs water vapour transmission rate until such time as equilibrium is reached. However, AS 1884 does not stipulate testing until stable readings are obtained. It requires only that the box be in place for 16hrs before taking the first reading. This may be an oversight. A similar test in BS8203 1996 requires that the hygrometer be sealed under an insulated impermeable box for 72 hrs to allow the RH to equilibrate and then readings are taken at 24 hour intervals until two consecutive readings are obtained that are the same. This is then the equilibrium moisture content. Readings taken at 16hrs could miss rising moisture from deeper in the slab that will take some time to rise.

Even the more rigorous BS8203 test is considered to have short comings as equilibrium could be reached with high moisture contents at depth that would ultimately equilibrate to give high moisture contents.

Beale, 2009 undertook an assessment "to evaluate commonly available methods for determining the moisture content in concrete slabs" on projects in Western Australia. The methods included the calcium chloride test but as the conversion from US to metric was incorrect this led to questionable conclusions in regards the various test methods related to it. The research also left out tests methods that are readily available in WA on the basis of their cost. Hence the report has not been used as a basis for assessment of the tests in WA. However a notable point was the difficult in sealing the RH box to the concrete surface with non water based adhesives. Where lack of sealing was obtained the results were particularly affected by the ambient conditions. This may be why BS8203 requires sealing with a defined gasket.

AS 1884 Appendix A notes “*accuracy and repeatability are not high but practical experience with the methods has enabled users to establish the suitability of the floor for laying resilient sheet*” and “*The concrete slab shall be considered to provide sufficiently dry conditions for satisfactory laying of the floor covering if the relative humidity does not exceed 70%.*” No qualification are made in regards the slab thickness, concrete mix or surface nature of the slab.

Hedenblad’s drying analysis indicated that for a slab with a membrane if RH probes were isolated at a point at 40% of the slab depth then the equilibrium RH would be approximately equivalent to the ultimate RH of the slab after moisture had equilibrated. For walls or slabs drying from 2 sides the appropriate depth is 20% of the wall or slab thickness. This was the basis for the Nordtest NT Build 439 test method where a 16mm hole is drilled, the surface of the hole to 40% of slab depth is sealed off by a sleeve and the equilibrium RH is measured. The system ensures that the moisture contents on application of the adhesive and ultimately will be suitable for the adhesive.

Although other tests such as MVER, impedance probes, resistance probes, plastic sheet test and mat test can all be used as tests to indicate when to start the RH of drilled holes test they are not suitable to give results for laying of a floor covering where moisture deep in the slab may be an issue. Only the drilled hole RH test is suitable for that.

NT Build 439 was adopted as ASTM F 2170 in 2002 and since then the IntelliRock logging probe has been designed around ASTM F 2170. A 19mm hole is drilled, a sleeve is set and the RH probe and built in logger inserted. The RH results can be down loaded at any time to show the rate of decrease of RH with time. Loggers can include an automated equilibrium assessment. These probes make it simple to establish the equilibrium RH at any depth and to give feedback on the rate of change of RH. There are several RH probes that can be used in holes and read manually but Keane 2005 notes that there is an advantage using logging probes.

## **CONCLUSIONS**

The mechanisms of the failure of moisture sensitive floors has not been clearly given in any of the papers or articles reviewed. Different papers from different

industry sectors give part of the story. The following are considered to be the key factors:

- 1) Initially water in the concrete slab is derived from mixing water. W/C ratios of 0.6 and higher are not uncommon. These high w/c ratios will leave a high water content and water vapour diffusion rate. A w/c ratio of 0.40 to 0.45 is most appropriate.
- 2) Wet curing should be avoided. Concrete is likely to be sufficiently strong and durable with curing under polythene for 3 days, particularly if 40MPa concrete had been specified.
- 3) The magnitude of the drying task is generally not understood. Facts that should be kept in mind include:
  - a. Increasing the w/c ratio from 0.4 to 0.6 gives a five fold increase in the water that must be dried out if the capillaries are saturated by water curing.
  - b. For a concrete with a 0.6 w/c ratio the drying rate must reduce from the initial massive rate of 200 gm/m<sup>2</sup>/day to a relatively miniscule acceptable rate of 3 gm/m<sup>2</sup>/day.
  - c. Reducing the drying rate by forced drying only dries the surface of concrete and will do nothing about the water deep in the slab.
- 4) Burnishing creates a high density, strong, low permeability surface layer. The very point of burnishing is to achieve these things. However burnishing is likely to reduce the drying rate significantly, the glassy finish reduces bond performance of adhesives and it could create a semi-permeable membrane leading to osmotic failure.
- 5) The type of adhesive to resist water and alkalis is very important.
- 6) The AS 1884 RH Box test is hopelessly flawed. The BS8203 RH box test at least gives a stabilised RH value. However even the BS8203 test is not recommended as a determinant of the floors long term moisture state as water may be locked deep in the concrete.
- 7) The only test for moisture that is considered suitable for final evaluation of concrete dryness is the ASTM F 2170 test.
- 8) Logging IntelliRock RH probes are beneficial where equilibrium RH is required, either in a

drilled hole or in a box, as these give a clear indication of the changing nature of the RH and when equilibrium is reached as well as giving a record of measurement.

The introduction of burnished floors at the same time as the introduction of acrylic adhesives which are prone to re-emulsification at a time when Australian standards for drying are not properly resolved has the potentials to introduce many problems in the industry.

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