

moisture in Concrete and Moisture-sensitive Finishes and Coatings

1 INTRODUCTION

Concrete slabs are the most common flooring system used in a range of buildings including residential and commercial, both low-rise and high-rise. The use of concrete walling in these buildings whether insitu or precast, has also increased significantly in recent times.

While the option of leaving the surface of the concrete floor or wall exposed, either as an off-form or other type of decorative finish is frequently selected, other finishes such as coverings and coatings are often applied to the concrete surface. The successful application of moisture-sensitive finishes (including moisture-sensitive adhesives) requires an understanding of the sources of moisture in concrete, how the moisture content of the concrete changes over time (drying), the factors that affect the rate of drying and how dry the concrete should be prior to installation of the finish. For projects requiring the installation of moisture-sensitive finishes, it is essential that adequate drying time is allowed within the construction schedule.

This data sheet addresses these issues and provides guidance on available test methods to determine the moisture content of concrete and the interpretation of the information to obtain a realistic indication of whether the concrete is dry enough to install various floor and wall finishes.



The successful application of moisture-sensitive finishes (including moisture-sensitive adhesives) requires an understanding of the sources of moisture in concrete.

2 The Nature of Moisture in Concrete

The total amount of moisture contained within the concrete, either as water or water vapour, is known as the moisture content and is generally expressed as a percentage of the mass of the concrete.

Moisture in concrete is present in the capillary pores and smaller gel pores within the concrete matrix. Moisture may exist as either water (when the concrete is wet and the pores are saturated) or as water vapour which provides a level of relative humidity within the concrete material. The amount of water vapour and hence relative humidity within the concrete may vary significantly over time as water vapour moves in or out of the concrete in order to establish an equilibrium with the changing ambient conditions.

Unless the relative humidity of the external environment is particularly low, the relative humidity in concrete will usually remain quite high after the majority of water has evaporated, typically about 75%. This equates to a moisture content of about 2%. When considering moisture-sensitive finishes, it is important to realise that because of the minute nature of the capillaries within concrete in which moisture is held, the concrete can be almost saturated and may still have a moisture content of only about 5% Figure 1. This has implications on what is normally considered a 'dry enough' concrete surface to which to apply moisture-sensitive finishes which is discussed in detail later.

Also from Figure 1, it can be seen that for any given relative humidity, the moisture content of concrete is far less than that of timber. This indicates that timber framing/materials can be placed directly in contact with the concrete as the lower moisture content of the concrete will not affect the timber (moisture content typically 10 to 17%).

Sources of Moisture

The initial source of moisture in concrete is the mixing water that is used at the time of manufacture. Once the concrete is placed, there are numerous other sources of moisture. These include wet curing, exposure to the weather, wet subgrades (in slab-on-ground construction), condensation (either within the concrete or on the surface) and application of mortar tile bedding and other water-based adhesives.

- n Mixing water. Water is added to the concrete during batching to allow hydration of the cement and provide the workability required to place and finish the concrete. Some water will be lost through bleeding and evaporation, and some will be consumed by the hydration process. A small quantity of water will remain following hydration of the cement either in the minute spaces (capillary pores) within the concrete, or within

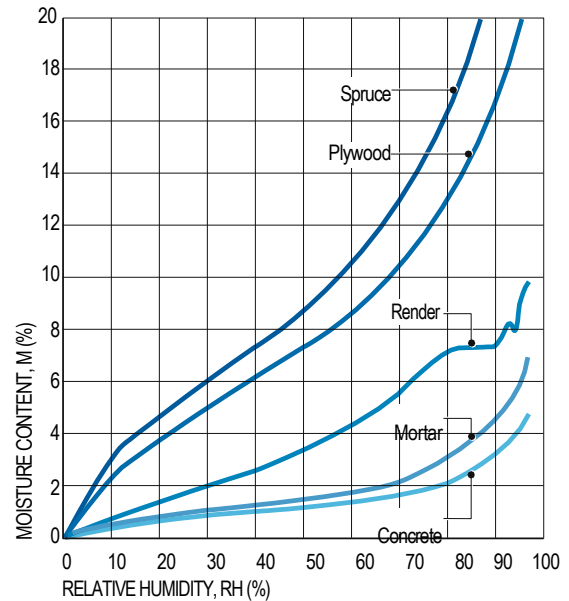


Figure 1: Sorption isotherms for concrete and other building materials (after Straube¹)

the hydration products themselves (gel pores). For low water-cement ratios, all the water in the mix may be consumed during hydration, thus avoiding the necessity for the concrete to dry prior to the application of finishes.

- n Wet curing. Wet curing is generally regarded as the most efficient method of curing concrete to ensure the hydration process continues and hence the design strength and other performance requirements of the concrete are achieved. Wet curing may extend the time required for drying due to saturation of the concrete, rewetting of adjacent elements or creating wet environments (particularly for slab-on-ground work) that provide a source of moisture long after curing has ceased. Where concrete is required to dry out in the least possible time, curing methods that do not introduce further water should be considered.
- n Exposure to the weather. If the drying period of concrete is critical then it should be protected from re-wetting. Rainfall on the concrete slab, infiltration into joints and wetting of subgrades will extend the drying period. For floors, ideally the concrete should not be placed until the building has been enclosed.
- n Wet subgrades. For slab-on-ground work, vapour barriers or damp-proofing membranes complying with the requirements of AS 2870² should be provided to separate the concrete from possible sources of moisture that may delay or prevent the adequate drying of the concrete. If installed correctly and not damaged, they will generally reduce the transmission of

water vapour to a level where it will not cause any problems for moisture-sensitive floor finishes or associated adhesives.

Work by Suprenant and Malish³ indicates that even a 15-mm hole or puncture in the membrane may be sufficient to increase the vapour transmission to the point where localised failure of moisture-sensitive floor finishes or coatings could occur. Use of a damp-proofing membrane (high impact resistance) and granular layer under the membrane are recommended to minimise the risk of damage if moisture-sensitive finishes are planned. Where hydrostatic groundwater pressure is possible, the provision of sub-soil drainage should also be considered to reduce the risk of water reaching the underside of the membrane (and slab).

For concrete walls near ground level, wet subgrades should be isolated from the structure using suitable slab-edge details and damp-proof courses. For further information refer to Slab Edge Dampness and Moisture Ingress⁴.

- n Condensation. The presence of warm moist air against a colder wall or floor surface may result in the condensation of moisture which can be drawn into the building material. Moisture may also condense within the concrete material: known as interstitial condensation. More information on condensation and concrete can be found in Condensation - Design Strategies⁵.
- n Moisture from tile bedding/adhesives/coatings. As these products are generally water based, some moisture will be drawn into the concrete following application. The major concern may not be drying of this moisture, but the effect on pH levels by dissolving alkalis near the surface, which in turn may affect adhesives or applied coatings. Also, the moisture in adhesives may be sufficient to cause the warping of timber flooring, a problem which is often incorrectly attributed to the moisture in the concrete slab. To limit the quantity of water added where moisture-sensitive finishes are used, a minimum 75% solids and 25% water content is generally recommended in adhesives. Typically, the higher the solids content, the more moisture resistant an adhesive will be. Also, as the moisture resistance of different adhesives may vary, it is recommended that the adhesive type not be changed during the course of the work.
- n Cleaning the surface prior to application of finishes. Often an acid, detergent or high-pressure water wash is used to clean the surface of the concrete prior to the application of subsequent surface treatments. Such processes add considerable water to the concrete and unless sufficient drying time can

be allowed, alternate means of cleaning such as abrasive blasting should be considered. Brush blasting produces a surface which has a light sandpaper-like texture and one which is suitable for most surface finishes.

- n Spills, moist environments and cleaning during construction and after installation of the surface finish. During construction, activities involving the use of water should be located away from concrete elements that are in the process of drying. When the concrete (with its applied finish) is in service; the effect of activities involving the use of water on the performance of the finish will depend on the specific application and products used.

3 Moisture Movement over Time (Drying)

Following curing, all the pores within the concrete may initially be filled with water. As the concrete dries, the water evaporates into water vapour and is driven by the difference in vapour pressure (high internal relative humidity compared to that externally) to gradually move towards the surface in order to establish an equilibrium moisture content with the external environment. The rate at which moisture is lost from the surface of the concrete is known as the moisture-vapour emission rate. This rate is unaffected by the slab or wall thickness as it reflects only conditions at the surface of the concrete. However, the thicker the concrete element, the longer it will take for an equilibrium moisture content to be reached between the concrete and the external environment.

Hedenblad⁶ found that the drying time doubled when the slab thickness was increased from 100 to 150 mm, and tripled when increased from 100 to 200 mm. He also found that drying times increased with the age of the concrete. The implications are that if re-wetting or water damage occurs at a later age, the original drying times can not be used as a basis for estimating the additional time required for the concrete to re-dry. Based on this work, if repairs such as grinding to correct flatness tolerances, patching of surface defects or any other procedures that necessitate the use of water are required, these should ideally be completed immediately after curing so that the water added does not affect the drying time. If grinding is required at a later stage, the use of dry grinding processes should be considered.

One of the principle factors affecting the drying of concrete, and the only parameter found to correlate to the drying time, is the water-cement ratio of the concrete: the lower the initial water-cement ratio the shorter the drying time required Figure 2. Thus, if shorter concrete drying times are necessary then reducing the water-cement ratio is recommended. The use of admixtures can assist in reducing the water-cement ratio and maintaining the workability required.

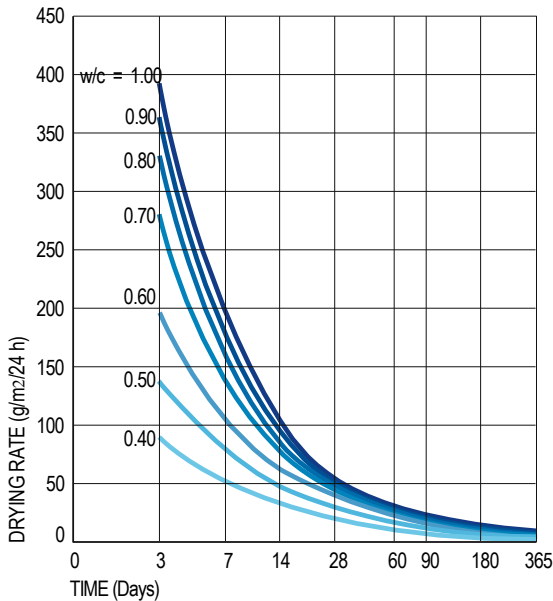


Figure 2: Effect of water-cement ratio on drying time (after Brewer⁸). 100-mm-thick slab, cured for 7 days, drying from one side in a 23°C and 50% relative humidity environment. Time measured from commencement of drying. Units used are consistent with ASTM F1869-04⁹.

Suprenant and Malisch found no benefit in reducing the water-cement ratio below 0.4, as no further reduction in the drying time was obtained. A water-cement ratio of 0.5 will generally allow drying within three months, and slabs with water-cement ratios 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' according to ASTM F710⁷. Note that the use of an approved vapour barrier or damp-proofing membrane for slab-on-ground work should reduce the vapour transmission from the subgrade into the concrete sufficiently for the moisture permeability of the concrete not to be of concern.

Because of the importance of the water-cement ratio on drying times and moisture permeability of the concrete, a lower water-cement ratio (higher concrete strength) may be specified if shorter drying times are required and the surface finish is sensitive to moisture. Note that the lower the water-cement ratio specified the higher the strength of the concrete.

The drying environment will also affect the time required for the concrete to dry. As a lower relative humidity or higher temperature environment will allow faster drying, an air-conditioned space or one which is heated should reduce the drying time. Caution must be exercised if the surface is dried rapidly by the use of equipment such as heaters and blowers due to the increased risk of shrinkage cracking at an early concrete age. Also, while the surface or upper layer of concrete may indicate moisture levels acceptable for the installation of

finishes, the moisture present at greater depths will re-distribute following covering of the surface. Depending on the drying time allowed, this may result in unacceptable moisture levels beneath the finish and hence future problems.

The moisture distribution from the drying of floor slabs is indicated in Figures 3 and 4. The initial relative humidity immediately after curing is 100% as all pores are saturated. As drying occurs either from one side Figure 3 or both sides Figure 4 of the concrete, a drying profile will be established which is dependant on the relative humidity and temperature of the external environment, concrete properties and time. Once a floor covering or other impermeable membrane is applied to the top surface of the slab the moisture within the slab re-distributes to a 'covered' equilibrium. Note that similar moisture profiles will occur in walls, and the drying effect from edges is limited to about the thickness of the concrete.

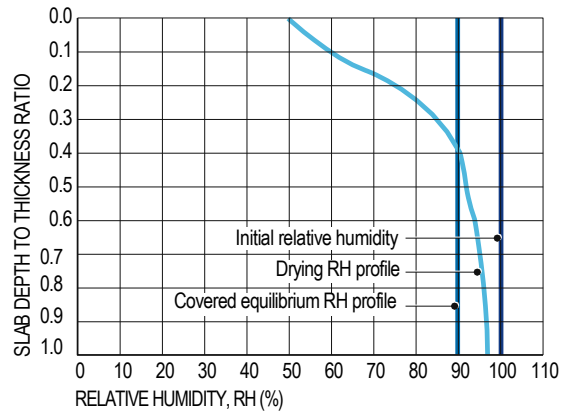


Figure 3: One-sided drying profiles in a slab-on-ground showing the initial drying and covered equilibrium relative humidity profiles (from Hedenblad⁶).

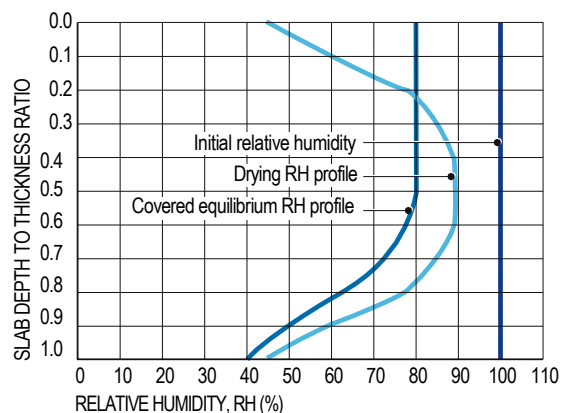


Figure 4: Two-sided drying profiles in an elevated slab showing the initial drying and covered equilibrium relative humidity profiles (Hedenblad⁶).

The majority of moisture-related problems occur as a result of the drying profile that develops. Firstly note from Figure 1 that a 90% relative humidity in the concrete equates to a moisture content of only about 3%. Moisture meters can record relatively low moisture contents within the surface layer of concrete, but pores below may still be saturated. If the surface is covered, the longer-term 'covered' equilibrium moisture content may be unacceptable, especially if re-wetting has occurred. Measuring moisture content at the surface will generally not give an accurate indication of the final moisture content, and whether the concrete is dry enough for the application of a floor finish or coating.

Extended curing times not only delay the commencement of drying, but also produce a less permeable concrete by allowing more hydration products to form. These products reduce the size of capillary pores, and with sufficient curing will lead to capillary discontinuity Table 1. While this will reduce the rate of drying, it may also reduce the vapour emission rate to less than that required for the application of moisture-sensitive finishes. Reducing the moisture permeability is particularly important where moisture-sensitive finishes have been applied to slab-on-ground work where there is no vapour or damp-proofing membrane to control the vapour transmission into the concrete from moisture below the slab.

The application of liquid membrane-forming curing compounds can be beneficial in providing extended curing times and hence reduced permeability as they may take several weeks to degrade and wear off the surface. However, they are generally not recommended where shorter drying times are required for the same reason, ie the delayed commencement of drying. In these situations, curing by covering with plastic sheeting should be considered.

Increasing the concrete strength and using waterproofing additives to either create capillary discontinuity within the concrete or reduce the size/partially block capillaries are also effective methods of reducing the permeability and possibly allow the early application of some finishes and coatings.

Table 1 Curing time required for capillary discontinuity of cement paste (Powers et al¹⁰)

Water-cement ratio by weight	Curing time required for capillary discontinuity
0.40	3 days
0.45	7 days
0.50	14 days
0.60	6 months
0.7	1 year
Over 0.7	Impossible

For walling applications, as the coatings are generally placed on the external face and internal environments are dry, permeability and capillary discontinuity are less of an issue.

The drying profile which develops within the concrete can also cause curling of the slab or wall panel. More information can be found in Curling of Concrete Slabs¹¹. If slab joints are sealed with the slab in a curled condition, the installation of a floor covering that acts as a barrier to moisture movement may allow the moisture to redistribute evenly within the slab. This will reduce (or even largely eliminate) the slab curling caused by the moisture profile. This in turn may result in some of the joint sealant being forced out of the joint and causing a raised line in direct-fixed type floor covering materials such as sheet vinyl. Joint sealants if required should be recessed below the floor surface to allow for such movement.

4 How dry is dry enough?

The important issue with moisture in concrete is not how much water remains in the concrete, but whether it is moving towards or away from the surface. There are a number of methods for estimating the drying time required or determining when the concrete is dry enough for the application of moisture-sensitive finishes or coatings. These range from rule-of-thumb to quantitative tests:

- n Rule-of-thumb. This approach simply allows a drying time of one month for every 25 mm of concrete thickness from completion of curing or since the last re-wetting. Thus, for a 100-mm-thick slab-on-ground drying from one side only, four months would be required. The same thickness in a suspended slab or wall drying from both sides would require only two months. This rule-of-thumb appears to be roughly consistent with the drying times indicated by Figure 2. However, while it may give a reasonable approximation for concrete elements up to 100 mm in thickness, research has found that the drying rate is not linear and varies according to the slab thickness. For thicker elements, and particularly if re-wetting occurs (moisture dries at a lower rate in older concrete) the rule-of-thumb is an inadequate method to estimate the drying period.

- n Water-cement ratio. For water-cement ratios up to 0.5, research work indicates that a period of about three months should provide sufficient drying time for a 100-mm-thick concrete slab drying from one side. Six months is suggested for a 150-mm-thick slab and 12 months for a 200-mm-thick slab. If the slab is able to dry from both sides, these periods can be halved.

n Swedish Concrete Association method. Powers et al¹⁰ give details of a method where a standard drying time, again based on the water-cement ratio, is modified for slab thickness, drying from one or two sides, ambient temperature and humidity, and curing conditions. For a 100-mm-thick slab with 4 weeks of curing, drying to 85% relative humidity from one side, in ambient conditions of 18°C and 60% relative humidity, the process results in a drying time of 116 days. If the slab dries from both sides, the drying time is reduced to 50 days. If the thickness is increased to 150 mm the drying time increases to 232 days, while a thickness of 200 mm results in 319 days drying time. These results are all consistent with the rule-of-thumb and water-cement ratio methods above.

Note that all of the above methods give only estimates of the drying time.

n Vapour emission rate. Rather than trying to estimate the drying time required by the above three methods, an industry guideline following many years of investigation has been adopted in the US. It recommends that moisture-sensitive floor coverings not be laid until the vapour emission rate is in the range of 15 to 25 g/m²/24 h (3 to 5 lbs/1000 ft²/24 h) depending on the type of flooring material Table 2. This is measured using an anhydrous calcium chloride test (see Section 5). Unlike the measurement of surface moisture, the vapour emission rate is an indication of the remaining moisture within the concrete.

Table 2 Moisture vapour emission rate (MVER) required by various floor coverings (Resilient Floor Covering Institute¹²)

MVER	Materials
5 lb/1000 ft ² /24 h (25 g/m ² /24 h)	Vinyl composition tile Felt-backed resilient sheet flooring Porous-backed carpet Linoleum
3 lb/1000 ft ² /24 h (15 g/m ² /24 h)	Solid vinyl sheet flooring Vinyl-backed carpet Nonporous-backed carpet Cork Direct glue-down wood flooring

n Moisture content and/or relative humidity. In Australia, AS/NZS 2455¹³ states that textile floor coverings shall not be laid until the moisture content is not more than 5.5% or the relative humidity level is not more than 70%. Further, that an inspection and assessment is made prior to the laying of such floor coverings and if any conditions exist that will affect the performance of the floor covering, and thus prevent its application, these are to be identified and installation delayed until rectified.

The difficulty with the moisture-content approach is that it generally considers only the surface condition as this is where the moisture content is usually measured. Also, as previously mentioned, the concrete could be almost fully saturated and still have a moisture content less than 5.5%. Thus, while the moisture content may indicate satisfactory conditions, relatively high vapour emission rates may exist (>25 g/m²/24 h) making the installation of moisture-sensitive finishes and coatings inappropriate. Note that there have been many instances where moisture meters have indicated that the moisture content at the surface is less than 5% but problems have been encountered once the floor covering has been installed and when moisture levels within the slab have established an equilibrium moisture content Figure 3.

If the manufacturer's recommendations are more stringent than the 5.5% allowed in the Standard, the impact on the drying time and whether it is achievable should be considered.

In terms of the relative humidity, the concrete is deemed dry enough when the relative humidity is less than or equal to 70%. According to Smith¹⁴ 'experimental evidence has shown that when the moisture has evaporated from the coarse pores of the concrete, the relative humidity falls to 80%. It is reasonable, therefore, to require a relative humidity of 75% or lower before the floor can be considered acceptable for installation of the flooring system.' The relative humidity limit of 70% required by AS/NZS 2455 roughly equates to the US practice of ensuring that the moisture vapour emission rate is less than 15 g/m²/24 h, which has been found by experience to indicate that the concrete is dry enough.

It should be noted that AS/NZS 2455 states that underfloor heating units can be used to dry the concrete floor and should be operated for at least 7 days to assist in lowering the moisture content. However, the concrete may not be dry enough after a relatively short period; particularly for normal concrete work where typically the water-cement ratio could be higher than 0.5.

5 Measuring Moisture and Acceptance Criteria

A range of methods are available to determine whether the moisture in concrete is at an acceptable level for the application of various finishes. The limitations of each test method should be understood if a realistic evaluation of the moisture content is to be obtained.

AS/NZS 2455 contains information on two quantitative test methods for measuring the dryness of concrete: hygrometer and electrical resistance tests.

n Hygrometer test. In this test the instrument is sealed to the concrete surface for 16 hours, the relative humidity of the air between the concrete and instrument is then measured. Alternatively, a hole can be drilled into the concrete, left to stand for 72 hours to allow the air in the hole to achieve equilibrium and a probe then placed into the hole to measure the relative humidity. The concrete is deemed dry enough when the relative humidity is not more than 70%. The hygrometer test is the most widely used method in Europe for determining whether the concrete is dry enough.

n Electrical resistance test. Of the two types of moisture meters available (electrical resistance and impedance), the commonly used ones are of the electrical resistance type. The test involves measuring the electrical conductivity of the concrete between two sensing pins, probes or electrodes in contact with the concrete. The electrical resistance between them indicates the moisture content. Instruments should be calibrated for accuracy in the range of 4% to 9% moisture and be able to measure changes to the nearest 0.5%. As mentioned previously, caution must be exercised as this test method usually indicates only the condition of the surface layer.

If holes are drilled into the concrete, the electrical resistance test may be used to measure moisture content within the slab at greater depths. Some of the factors which may influence the result include the resistance of the aggregates, chlorides in the concrete, reinforcement and condensation on the surface.

The concrete is deemed dry enough when the moisture content is not more than 5.5%.

Other quantitative test methods include:

n Calcium chloride test. This test is used to measure the vapour emission rate from the surface of the concrete and is the most common test method used in the US. While not generally available in Australia, the test procedure is covered in ASTM F1869-04. The test involves placing a cover over a 70-in² (about

210 mm x 210 mm) area of concrete for 60 to 72 hours. Beneath the cover is a 16-g quantity of anhydrous calcium chloride which absorbs any moisture given off by the concrete in the form of vapour. The test kit is weighed before and after the test period, and the moisture vapour emission rate is calculated from the increased weight of the calcium chloride, the test time and surface area under the plastic cover that was sealed to the floor.

The concrete is deemed dry enough when the vapour emission rate is in the range of 15 to 25 g/m²/24 h depending on the type of flooring material Table 2.

n Gravimetric moisture content test. This typically involves taking a full-depth core from the slab using a dry-cut process, drying the sample in an oven until a constant weight is reached and determining the moisture content from the mass of the core and difference between initial and final weights. The use of an appropriate moisture content limit is considered satisfactory with this test as the moisture content measured represents the full thickness of the concrete and not just the surface layer.

Qualitative test methods include those that rely on covering the surface of the concrete with an impermeable material such as a rubber mat, glass or plastic sheet, or by the application of a test area of the covering material itself. Thus they tend to simulate the conditions experienced once the surface becomes covered. These types of tests indicate whether moisture is moving through the slab, and if there is evidence of moisture, that the concrete is typically not ready for moisture-sensitive finishes, coatings or paint. All have similar limitations in not being able to measure moisture beyond the surface layer because of the relatively short time that they are fixed to the concrete, and because of the formation of moisture under the membrane from condensation rather than moisture from within the concrete. While not covered long enough to allow complete redistribution of the moisture within the concrete, experience has proven that they often give a better indication than spot testing a drier surface layer using a moisture meter. Qualitative test methods include:

n Rubber mat test. A 500 mm x 500 mm square is placed on the slab away from windows and doors and left for 24 hours to check for signs of moisture on the underside of the mat or darkening of the concrete, which would indicate the presence of excess moisture. Any effects under the edges of the mat should be ignored unless the edges are sealed.

- n Glass sheet test. A 400 mm x 400 mm square is taped (masking tape) onto the slab in the centre of the room and left for 24 hours. Rather than removing the glass (possibly resulting in rapid drying of moisture), the concrete beneath is inspected for signs of moisture (darkening) through the glass.
- n Plastic sheet test. A 460 mm x 460 mm square 0.1-mm-thick plastic sheet is placed on the concrete and sealed around the edges by taping them down to the concrete. After 16 hours the sheet is removed and the area inspected for evidence of moisture. Variations of this test include the use of a 1 m x 1 m piece of plastic sealed around the edges for 24 hours¹⁵.
- n Test panel. For large projects, a small sample of the flooring material or coating can be glued/applied to the concrete and assessed for satisfactory performance over a suitable period of time. This has the advantage of testing the combination of flooring and adhesive.

Test locations should be distributed evenly in areas where high moisture is suspected, avoiding those areas subjected to sunlight and other direct heat sources. As the moisture content of each batch of concrete may vary, the frequency of testing is often related to the area that can be placed from a single load of concrete. For example, since 5 m³ will cover 50 m² at 100 mm thick, the test frequency could be one test per 50 m².

The timing of tests should be related to the estimated drying time required. For a water-cement ratio up to 0.5 about three months drying time will be required for a 100-mm-thick slab drying from one side only. For this situation, if typical concrete mixes are used, testing within two months of the commencement of drying may be premature as results will typically indicate higher than accepted moisture vapour emission rates. Note that whatever test method is used, the results indicate only what is occurring at the time of measurement.

Acceptance criteria are related to the test method used and may depend on the requirements of various Building Codes, Standards and product manufacturers.

6 Finishes

6.1 Non-moisture-sensitive Finishes

Non-moisture-sensitive finishes such as polished or decorative concrete, cement-based terrazzo and ceramic/stone tiles may be laid while the concrete is still drying provided that an appropriate cementitious bedding or adhesive is used. Note that as some shrinkage of the concrete may still be occurring, the bedding material or adhesive should allow for some movement.

6.2 Moisture-sensitive Finishes

The types of moisture-sensitive finishes that may lead to moisture related problems if sufficient drying time has not been allowed include timber, vinyl, carpet on a rubber underlay, epoxy-based terrazzo tiles and surface coatings.

Where suitable vapour barriers or damp-proofing membranes have not been provided under slabs-on-ground and a continuous source of moisture is expected, moisture-sensitive finishes should not be installed.

Timber flooring

Timber flooring may be affected either by moisture causing swelling and warping of the timber or, if adhesive-fixed to the concrete (typically parquetry), a breakdown in the bond due to high initial moisture contents affecting the water-based adhesive. Note that some adhesives may contain sufficient water to cause moisture-related problems themselves: either swelling of the timber or wetting of the concrete surface which may dissolve alkalis and affect the bond strength of adhesives sensitive to alkaline conditions. Also, timber materials should be removed from plastic packaging and placed in the environment in which they are to be installed for a sufficient time to allow an equilibrium moisture content to be reached prior to laying. Otherwise swelling of the timber due to an increase in the moisture content (from the atmosphere rather than the concrete) may cause problems.

Vinyl sheet flooring

Vinyl sheet flooring with glued seams provides no opportunity for any moisture to dry from the surface of the concrete. Vinyl tiles allow some moisture movement at joints over time but high initial moisture contents in both cases may cause problems with some adhesives. AS/NZS 2455 nominates that 'where the relative humidity of the atmosphere in the building is 75% or more, only adhesives suitable for such conditions shall be used.' Considering the variability of the relative humidity levels within concrete, this requirement could be applicable to the majority of coverings placed on concrete floors.

Suitable adhesives are generally those having at least 75% solids content. Increasing the water content of adhesives typically reduces their strength and increases the quantity of water available to wet the concrete surface or floor covering material. Adhesives used in 'wet' environments for prolonged periods may also re-emulsify, causing failure of the bond.

Carpet

Carpet will allow moisture to pass through and the drying process to continue, with the surface layer generally being sufficiently dry after a short period to have no adverse affects on the carpet material.



Figure 5: Coating used to protect surface, delineate areas and facilitate maintenance

However, some backing materials and underlays (rubber) can provide barriers to the movement of moisture. As the joints in the underlay material are not sealed, moisture will gradually dissipate but the process will be considerably extended, possibly by years. The effect of this on the carpet and consequent dampness issues and odours should be considered.

Coatings Coatings may be applied to concrete surfaces for a variety of reasons including providing colour and/or texture, gloss appearance (polished concrete floors), ease of maintenance (cleaning and disinfecting), protection (aggressive chemicals) and improving properties such as resistance to impact and abrasion Figure 5.

Most coatings if applied to a well-prepared and dry concrete surface and allowed to cure adequately will develop sufficient bond strength to be able to resist water pressure from both hydrostatic and capillary sources of moisture. Typical bond strengths of coatings are usually greater than 1.5 MPa; considerably more than that from, say, a 10-m hydrostatic pressure (0.1 MPa) which would be unlikely for a slab-on-ground, or maximum capillary pressure of about 0.2 MPa.

Moisture-related failures (typically blistering of the surface) tend to be caused by either an inadequate bond forming when the coating is first applied or osmotic blistering. Problems may not be evident immediately, but may occur some months after application. The timing may relate to the difference between achieving a good bond initially and achieving only sufficient adhesion to hold an undisturbed coating in place.

Moisture in the concrete can affect coatings in a number of ways:

- n Preventing the coating from curing properly. If incomplete chemical curing or severely retarded curing of the coating occurs, coatings will typically be easily removed from the substrate and the surface of the coating in contact with the concrete will be soft and/or slightly sticky. Numerous small closely spaced blisters may

also be present. Some coatings may cure in the presence of moisture but develop inadequate bond strength.

- n Exerting a force on the uncured coating that reduces the contact between the coating and concrete that is required to establish a strong bond. If the bond has been affected, the underside of the coating will be hard and the blisters much larger, possibly filled with water. The coating may be removed easily from the surface even where there are no blisters, and the concrete may appear damp where the coating is removed if the original moisture conditions have remained unchanged.
- n Osmotic blistering. The principle behind osmotic blistering is that moisture will flow from areas where the water contains low levels of dissolved salts to areas having higher concentrations in an attempt to reach an equilibrium. Important requirements for the process to occur are a semi-permeable membrane which will allow water movement only (ie no salts), an impermeable coating on the surface which acts as the confining wall of the 'osmotic cell', a concentration of water-soluble material and water Figure 6.

The osmotic pressure that develops under the impermeable coating will exert an upward force on the coating that can easily exceed the bond strength. This results in the formation of a blister as the coating lifts to relieve the pressure. The water may also cause a loss of bond strength and softening of the coating.

Experience has shown that the moisture vapour emission rate should be less than 15 g/m²/24 h (see Section 4) to allow a good bond to be achieved and the moisture content to be low enough for osmotic blistering not to occur. This can be determined either qualitatively by covering the surface with an impermeable membrane, or quantitatively (recommended), by using the calcium chloride or hygrometer test.

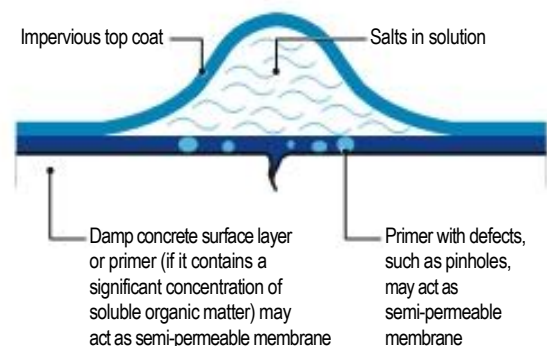


Figure 6: The osmotic blistering process (after Ignoul et al¹⁶)

Table 3 Recommended minimum drying times for concrete before painting (AS/NZS 2311¹⁷)

Surface	Paint type	Drying times (weeks)
Precast and cast in situ concrete Filled concrete blocks	Latex	8
	Alkali-resistant solvent-borne	12*
	Oleoresinous and alkyd	16*
Concrete blocks (unfilled)	Latex	4
Cement render and stucco	Alkali-resistant solvent-borne	6
Concrete bricks and mortar	Oleoresinous and alkyd	12*

* The minimum drying period will depend on the thickness of the concrete and should be increased by four weeks for each 25 mm of thickness above 100 mm. Where two sides of the surface are exposed and well ventilated, then the drying time should be increased by two weeks for each 25 mm of thickness above 100 mm. Where concrete has been wet cured or left exposed during rainy periods, this additional time should be added to the recommended curing time.

The perception that concrete can be painted or coatings applied once the surface appears dry is not valid. The underlying concrete can still be wet and once a coating is applied, the moisture will rapidly reach a new equilibrium beneath the coating. Particularly for impermeable coatings, this could result in the curing of the coating and/or bond strength of the adhesive being affected or osmotic blistering occurring. AS/NZS 2311¹⁷ gives some guidance on the drying times required for various paint types Table 3. Note that drying times are essentially based on a rule-of-thumb approach and caution should be exercised concerning the notes to the table.

The coatings that are susceptible to blistering are those that are quite impermeable to water. Coatings that allow the transmission of water vapour (breathable coatings), reduce the buildup of pressure behind the coating and hence are less susceptible to problems. Unlike those on floor slabs, coatings used on walls are less likely to fail by blistering as the concrete dries quicker (from two sides rather than one side for a slab-on-ground), has fewer sources of moisture that either prolong drying or saturate the concrete behind the coating, no upper concrete zone subject to bleeding and drying during placement is present (ie forming a semi-permeable membrane).

Reducing the risks when applying moisture-sensitive finishes and coatings

Steps to reduce the risk of finish/coating failure (particularly for floors) include:

- n Use concrete with low water-cement ratio and bleed characteristics.
- n Allow adequate time for the concrete to dry.
- n Ensure the moisture vapour emission rate or relative humidity levels are acceptable.
- n Ensure an adequate vapour/damp-proofing membrane is provided beneath slab-on-ground work and a sand bedding is provided to protect the membrane from puncture or other damage during construction.
- n Use breathable coatings if possible.
- n Avoid equipment such as air conditioners, heaters and fans that rapidly dry the surface to enable quicker laying of finishes or application of coatings. These may result in a misleading moisture vapour emission rate and falsely indicate the surface is dry enough to apply the finish or coating.
- n Avoid applying finishes or coatings with the sun on the concrete if possible. This warms the concrete and may increase the water vapour pressure in the capillaries within the concrete.
- n Use fast-setting primers. Some products will establish a good bond before moisture within the concrete redistributes sufficiently to affect the bond.
- n Apply coatings at higher temperatures to promote quicker setting. AS/NZS 2311 recommends that paints should be applied when the temperature is between 10 and 35°C.
- n Ensure products are adequately proportioned and mixed. This will ensure proper setting and hardening, as different concentrations of soluble material in the concrete and coating layer may also cause diffusion of water and osmotic blistering problems.

- n Ensure adequate surface preparation. All laitance, efflorescence, chemical and organic contaminants and dirt should be removed from the surface to achieve good bond strength.
- n Ensure any curing compounds, release agents and form oils, etc have been removed or do not otherwise affect the bond. If these products are present, a suitable primer should be used.
- n Do not wash concrete prior to applying a coating unless sufficient time can be allowed for the surface to dry. Abrasive blasting or other dry processes to prepare the surface are recommended. Water can quickly dissolve salts and create a highly alkaline environment at the concrete surface. For paints containing drying oils this may be harmful due to their susceptibility to saponification.
- n Apply a semi-permeable layer to the concrete surface to reduce the rate of vapour transmission. These are typically latex-modified cementitious products/coatings as the setting and bond are unaffected by the presence of moisture.
- n Use a higher strength concrete that is adequately placed, compacted and cured. Generally strengths greater than 40 MPa will be sufficiently impermeable (due to capillary discontinuity) to reduce the vapour transmission rate through the concrete, and hence vapour emission rate from the surface to an acceptable level. Also, concrete with low permeability provides no catalyst for future osmotic blistering, which is therefore unlikely to occur.
- n Avoid semi-permeable primers and those with non-chemically bonded compounds such as solvents. If using semi-permeable primers, ensure that the surface coating (eg epoxy material) will make the primer layer impermeable.
- n Patch holes and make other repairs early to allow the material used and surrounding concrete to dry adequately.
- n Allow timber coverings sufficient time to achieve an equilibrium moisture content prior to installation.
- n Use adhesives with a minimum 75% solids content.

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