Prevention of Moisture Related Disbondment of Non-Permeable Flooring Systems

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Abstract

This paper will describe how to prevent moisture related disbondment of non-permeable flooring systems on concrete substrates. The paper also introduces the basics of how concrete is produced and cured. The key factors affecting permeability and porosity are examined, as well as their relationship to moisture related failures of seamless, non-breathable flooring products. Guidelines for construction and mix design are offered in order to prevent such problems. Recommendations for remedial actions are also provided.

Introduction

In order to understand how to successfully keep non-permeable, seamless systems bonded to concrete, it is important to understand the basics of concrete's composition.

Concrete is the resultant product of mixing Portland cement, water, graded aggregates, pozzolans and air. The only chemical reaction that occurs is between water and the various silicates that are present in Portland cement. Portland cement is made by grinding calcareous material, such as limestone or shell, with an argillaceous (clayish) material such as clay, shale or blast furnace slag. These two finely ground materials are heated in a giant rotary furnace to the point where they begin to fuse. The resulting product is called a clinker. The clinker is cooled and reground to a fine powder to form Portland cement. While the clinker is being ground, small amounts of additional ingredients are added to produce the various types of cement. Cements are defined in accordance with ASTM C-150, and are comprised of the following types:

TYPE I	*Standard setting*
TYPE IF	*Standard setting with fly ash*
TYPE II	*Slow setting (low tri-calcium aluminate,)*
TYPE III	*Fast setting*
TYPE IV & V	*Slow setting sulfate resistant*
TYPE K	*Shrinkage compensating*
TYPE "__"a	*____________ setting with air entrainment*

When cement is mixed with water, the resultant product is referred to as Paste. This is the substance that binds all other ingredients together. This paste is created by the hydration of cement particles. The reaction of water actually deteriorates the particle and causes it to swell. This gel is the addition of water to calcium silicate to form calcium silicate hydrate, and the reaction of calcium oxide with water to form calcium hydroxide. At this point, the cement is in its plastic state. Putting mechanical energy into the system will break the gels. Early in the hydration process, the gel structure will completely recover. Cement begins its set when the hydration products swell around the dissolving cement particle and are close enough to touch a neighboring gel mass. The spaces within gel masses are called gel voids or pores, and tend to be unconnected. Capillary voids will be formed where there are no gel masses. These tend to be interconnected and result from excess water in the mix. The -importance of this point will be examined in more detail later.

Pozzolans are primarily fine grade silicas of pyrogenic origin which can reduce cost and change setting time, density, porosity, water demand and strength.

Air is an important element in concrete, and is added purposefully via air entrainment admixtures, or through installation i.e., the mixing and placing process. Air obviously provides inexpensive volume, but also improves workability and freeze/thaw stability.

It is interesting to note that the quality i.e., durability of concrete, has been going in the wrong direction in the last 20 years. Shilstone and Shilstone, authors of many articles[1] and lectures at ACI, believe the reasons for this are as follows:

- A reduction in academic programs offered in architectural and engineering programs; An over emphasis of measurable values, such as 28 day compressive strength. By itse1f~ this does not mean much in terms of performance.
- A view towards up front cost and schedules (speed) which negate a view towards value.
- Ignorance of historical information concerning quality concrete still serviceable after decades of use.
- The view of most contractors that they will meet specs, rather than a team approach to providing value and meeting owners needs.

In light of these factors, it is incumbent upon the manufacturers and installers of non-permeable flooring systems not only to understand their substrate, but to work on the front end to prevent problems. This begins with a fundamental understanding of the primary factors that cause failure of these systems. Specifically, this paper will deal with the permeability and porosity of concrete, and the effects of moisture movement through it. But, before we begin this investigation, let's recognize that the vast majority of concrete slabs on or above grade are suitable for accepting non-permeable flooring systems. The problem job, however, is usually the one that gets the most attention and, therefore, hurts the industry. Problems can also be costly to repair and can wipe out a year's profit if not addressed properly. For these reasons, it is important to know enough about the substrate to prevent problems.

The Composition

It is clear that, by definition, a high density concrete will have lower amounts of air space. Therefore, in order to minimize "space" in concrete, it would generally seem safe to assume that the higher the density, the lower the permeability. However, it is somewhat more complicated than that. The real issue is whether or not the "spaces" are connected and can provide an uninterrupted path through the concrete to the surface. Recall the two hydration products of the curing process. Only the capillary pores are connected. The single greatest cause of capillary pores is an excess of water. *(see Figure 1).*

Effects of W/C Ratio on Gel Mass Density

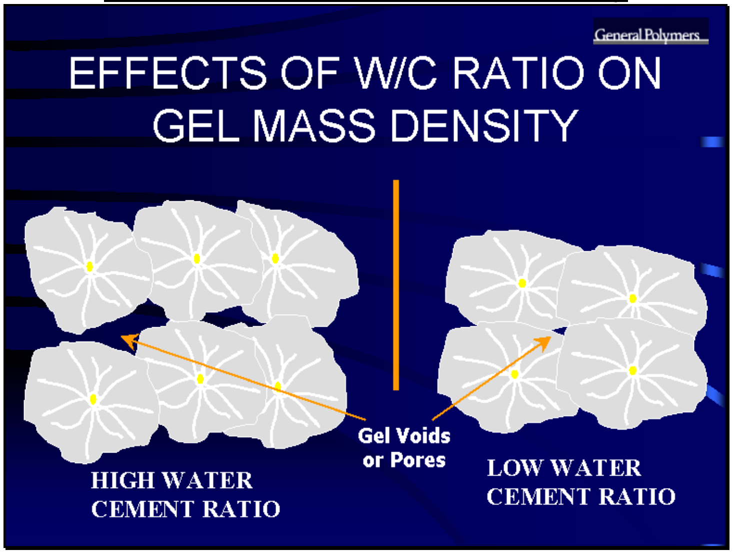

Figure 1.

Excess water will cause the gel masses to be spaced further apart. As a result, there is less contact between the gel masses and, after the water evaporates, a hollow pore is left. Additionally, water in the gel particles held either by chemical reaction or adsorbed to the surface of the calcium silicate hydrates, require extremely high temperatures to remove. Temperatures in excess of 1000°C are required to remove chemically reacted water, and temperatures around 100°C will remove most adsorbed water. Chemically reacted and absorbed water are formed in the gel masses. Therefore, it is safe to say that only water in capillary voids can play a role in creating moisture vapor problems. The best way to reduce capillary pores and, therefore, permeability, is to keep the water/cement ratio low. *(See Figure* 2)[2].

Permeability as a Function of W/C Ratio

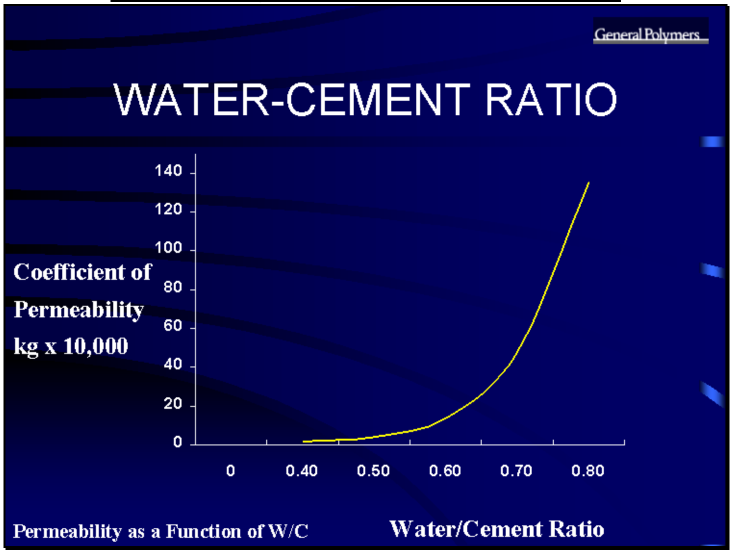

Figure 2.

The distance between the gel masses of hydrated cement will also have a dramatic effect on the 28 day compressive strength. Again, this distance is greater with higher amounts of water.

Figure 3 demonstrates the dramatic effect that the water/cement ratio has on 28 day compressive strength[3]. Doubling the water/cement ratio from .4 to .8 will drop the compressive strength from ~ 6,000 psi to 2,200 psi. Low strength is a tip-off that the water/cement ratio may be too high.

<u>Strength as a Function of W/C Ratio in Non-Air Entrained Concrete</u>

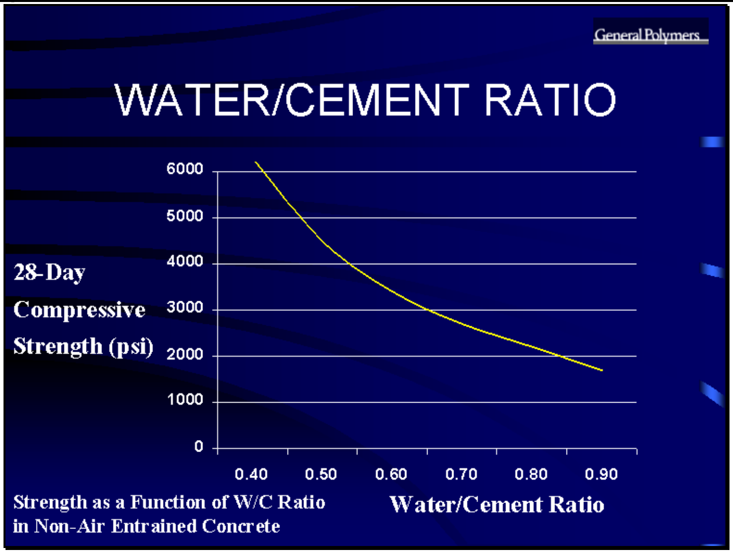

Figure 3.

A high water cement ratio also increases the amount of shrinkage cracking that occurs. As water leaves the capillaries (as vapor), capillary pressure will cause the opposite sides of the pore to contract. As these forces build, the concrete <u>paste</u> will crack unless sufficient cure and strength development has occurred to counter these forces.[4] In general, the aggregate does not contribute to shrinkage cracks. The only place a crack can occur, beside the paste, is at the paste-aggregate interface *(see Figure 4.)*

<u>Shrinkage Cracking</u>

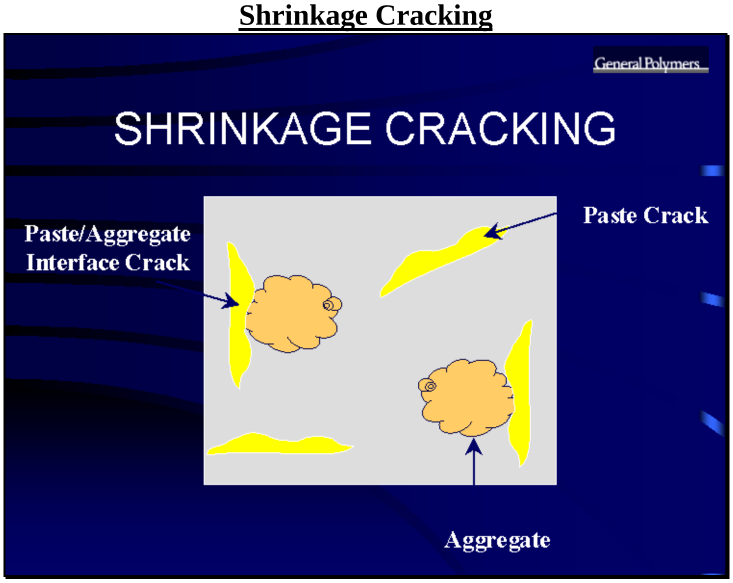

Figure 4.

Therefore, higher loading of aggregate will help to minimize shrinkage cracks, as this reduces the total quantity of paste per given volume of concrete. More importantly, the correct grading of aggregate must be utilized. Consider that if only large aggregate is used, the paste-filled space between aggregate will be large. This creates the largest possible volume for stress, resulting in the highest probability of stress cracks occurring. To reduce the size of this volume, two factors are important. The first is to use of lowest amount of water The reason for this is explained by the fact that water per given weight takes up more volume than cement. This is shown graphically in Figures 5 & 6.[5]

C/W in Cement Paste

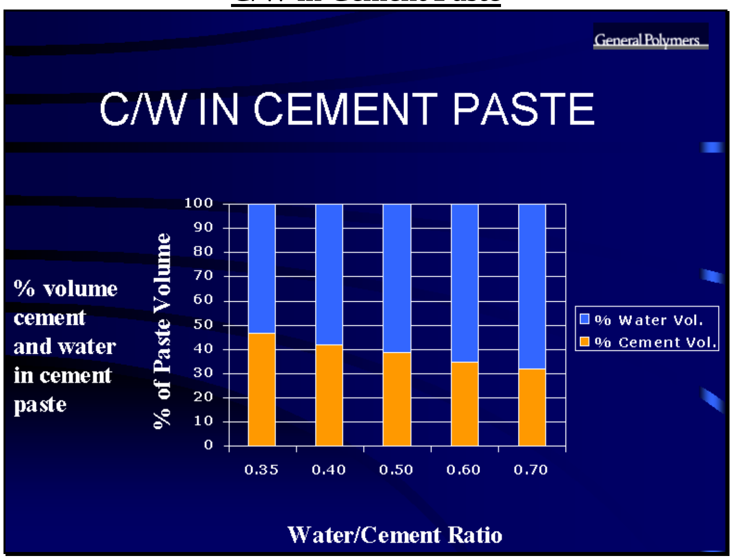

Figure 5.

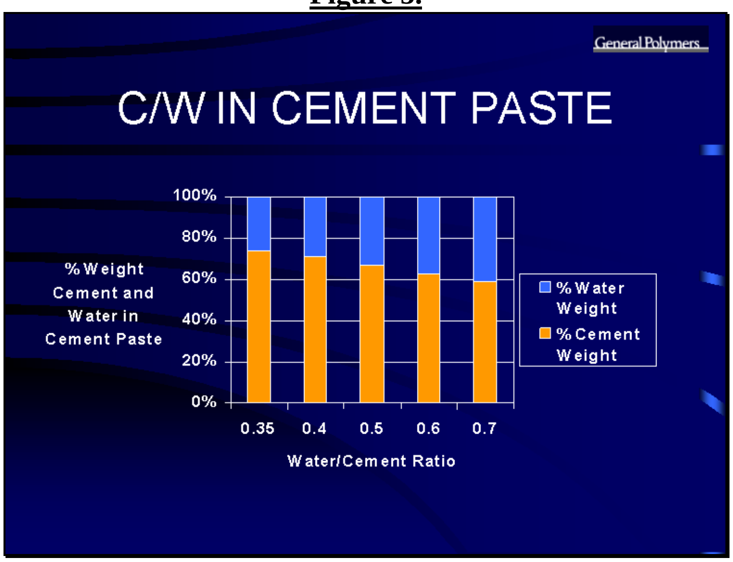

Figure 6.

Of course, this "volume" must be taken up by additional aggregate as total cement and water are reduced. The second factor is the use of well-graded aggregate. By using a well-graded aggregate, the various size particles will compact tightly, minimizing the concentration of paste in a given volume of concrete. Mr. James Shilstone has published several articles outlining the advantages of well-graded aggregates.[6] He points out the importance of incorporating an intermediate aggregate between the fine and coarse aggregate. His optimum gradation targets 12% passing between consecutive sieve sizes, and not greater than 15% as a specified limit *(see Figures 7).* The details of well graded aggregate requirements as specified in ASTM C33. The shape of the aggregate is also important. Rounded or cubic aggregate will pack more efficiently than elongated aggregate, and should be used preferentially.

<u>Aggregate Packing of Well Graded Aggregate</u>

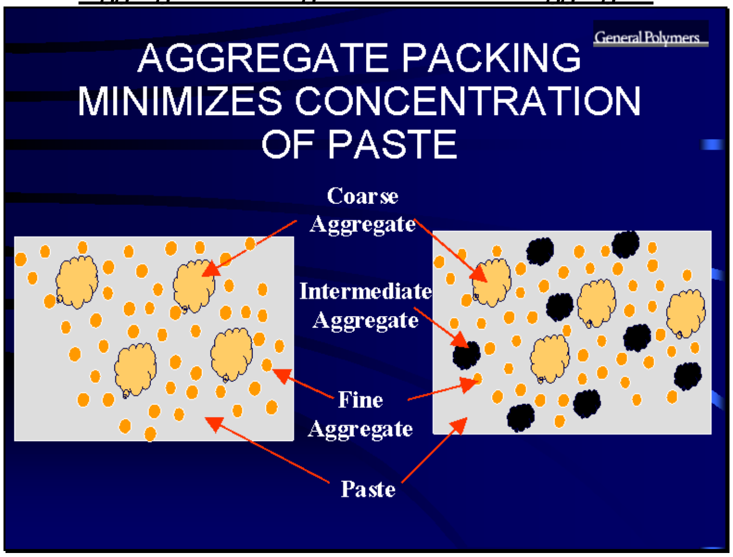

Figure 7.

Rheology, or the *way* in which a material flows, is important in insuring that all the aggregate particles are wet out. This helps minimize the amount of paste agglomeration and, therefore, decreases shrinkage. The incorporation of air helps workability and improves freeze thaw stability. While this will decrease density, the air bubbles serve to break capillary action as the diameter of the air bubbles is significantly greater than that of the capillary pores. This can be demonstrated by considering the way in which water readily moves into a paper towel, but will not move up a straw without some more significant external force. Entrained air tends to exist in discreet bubbles and may actually help to minimize movement of moisture via capillary voids. This should, therefore, minimize the amount of moisture which can reach the surface of a concrete slab.

In order to achieve 5000 psi, total air entrained should not exceed 6 ½%. Details are established in ACI's Building Code 318/31 SR-3 1, Chapter 4, Section 4.2.1.

<u>The Finish</u>

The key to a successful finish for acceptance of a non-permeable flooring system is to provide minimum disruption to the even distribution of paste and aggregate. Compaction is important, but it should be kept to a minimum to prevent bringing too much paste to the surface, Too severe a finish of any kind will bring water and paste to the surface. This will be the weakest, most porous and crack-ridden portion of the concrete. These reasons have everything to do with a high water/cement ratio, and high paste concentration.

The best finish is a light steel trowel finish, as this will provide for the least amount of paste brought to the surface. Any other type of finish will require more significant surface preparation.

<u>The Cure Cycle</u>

Most technical specifications and most manufacturers' literature, call for a minimum 28 day curing period prior to the application of polymer based coatings and toppings. The technical - basis for this recommendation is the relationship between time and the cement hydration process, which is directly related to compressive strength development, and is measurable. Plain concrete is proportioned to develop 80% of its design strength in 7 days, and 100% of its design strength in not more than 28 days (concrete containing fly ash is 56 days). This measurement tells us that the cement used in mixing the concrete has, for the most part, completed the hydration process although hydration will continue for years to a lesser degree. This measurement does not, however, define for us the relationship of the aged concrete to the remaining excess moisture content.

It is interesting to note that cement requires no more than 25% of its weight in water to frilly hydrate, i.e., a water/cement ratio of 0.25. With this amount of water, the concrete would be totally unworkable for anything other than dry-packing. For this reason, additional water is added to the mix to make it more useful. This excess water is referred to as *water of workability* or *water of convenience*. A typical 3,500 psi mix design with standard air entraining and water reducing admixtures, might have a cement content of 470 lbs. per cubic yard and a water demand of~188 pounds, or 22.6 gallons (water weighs 8.33 pounds/gallon), to achieve a required water/cement ratio of.40. This mix design would then have an excess water/cement ratio in the amount of .15 (.40-25). By multiplying the excess water/cement ratio (.15) by the weight of cement (470#), we arrive at a calculation of 70.5# or 8.5 gallons of excess water that will not be consumed by the hydration process. This excess water must be allowed to escape, while maintaining adequate moisture (curing), for the hydration process. Much of the excess water will escape through capillary action, i.e., bleeding, while the concrete is in its plastic state during consolidation and finishing operations. These capillary escape routes are the cause of concrete's high porosity and resulting permeability.

Proper curing of concrete to attain the desired physical properties, requires that moisture in the hardened concrete be maintained for a minimum of 3 to 7 days, depending on temperature, humidity, type of cement and type of' admixtures used. A good rule of thumb is to cure concrete until it has reached 80% of its design strength. This allows the concrete to develop sufficient strength to counter the forces of shrinkage that cause cracking. There are several acceptable methods of curing concrete and may be referred to in ACI 308-86 and ACI 302.1 R-89. Some of those methods are listed below

- Ponding water
- Moisture retaining sheet membrane
- Soaker hoses
- Liquid membrane curing compounds
- Wet burlap

Of greatest interest and concern to our industry, is the use of liquid membrane curing compounds which leave a film and/or residue on the surface which must be removed by mechanical means, i.e., sandblasting, shot blasting, scarification, etc. prior to the application of a bonded system. Most suppliers will make recommendations concerning these kinds of products In general, they should not be used due to potential for bond interference.

Without question, the most durable and fully hydrated cement is necessary for marine applications. A new specification for marine concrete will be published this year. In part, the spec will read that a 7 day water cure is required, and failure to comply will result in grounds for total rejection and replacement. We should subscribe to nothing less if we want to insure the highest quality substrate.

Understanding the Problem

We now have an understanding of why and how we should minimize the amount of unnecessary water and, therefore, capillary voids and shrinkage cracks in concrete. It is also apparent that it is not possible to eliminate moisture from concrete. It is possible, however, to control its movement if we understand how moisture moves from concrete to the environment.

Lets first understand the terms that are used to describe moisture related problems. Hydrostatic pressure is defined as a force exerted by a column or head of water. The force is calculated by the weight of water per square inch. This is equal to .43 psi per foot of height in the column of water. The force required to cause disbondment of any non-permeable flooring system will be the lesser of the tensile strength of concrete or the adhesive bond strength to the concrete. If the bond strength of a system is 300 psi, then the column of water necessary to cause disbondment must be over 697 feet. Clearly, this is only possible in a below grade slab. Therefore, for on/or above grade slabs, hydrostatic pressure is not an issue in disbondment of non-permeable flooring systems.

Capillarity is best described as a fluid pulled through a fine opening or pore. The liquid is driven by differences in temperature and dryness. Capillarity is quite specific to liquids, and **is** dependent upon its surface tension and the size of the pore. The smaller the radius of the pore, the faster a liquid of a given surface tension will move through the pore. It is also harder to remove water from a smaller pore. Note that this, by definition, is an intra-concrete phenomenon of a liquid (water), and therefore is not responsible for delivering moisture out of slab. If, however, the slab is sitting in a pool of water, capillary action will increase the water content of the slab. Keep this in mind when sub-grade preparation is discussed.

It can readily be seen that neither hydrostatic pressure nor capillary action can be the major contributors to failure (disbondment) of non-permeable flooring systems. How then does moisture leave an on or above grade concrete slab? Invariably, it is in the form of moisture vapor.

Moisture vapor will always move to an environment of lower temperature and lower relative humidity based upon the differential in vapor pressure. Once this is understood, strategies to minimize the events can be addressed.

Construction of Sub-Grade

Recall that moisture moves readily through small capillaries, but not so readily through large capillaries. This simple fact provides adequate information on how to prepare for acceptance of an on grade slab. Providing drainage means eliminating capillaries capable of delivering water to the slab. Nothing replaces prevention of water problems better than keeping water away from the sub-grade.

The sub-grade specification should require an engineer's inspection and acceptance prior to installation of the slab. The slab grade should be examined to determine if there are any soft or uncompacted areas, as well as presence of unevenness in the surface. The grade should also be inspected. The best way to verify the uniformity of compaction is by observing the sub-grade during proof rolling. Any irregularities caused by rolling should be viewed as a signal of potential future problems. These areas should be recompacted before slab placement.[7]

The use of vapor barriers creates an interesting situation for installation. The reason for placing a vapor barrier is to prevent excess moisture from migrating into the slab. This will also prevent moisture from exiting the slab during cure, thereby causing a differential in water retention from the bottom to the top of the slab. This may lead to an increase in shrinkage cracks. The best solution is to install a vapor bather and wet cure the slab for 7 days. This will insure sufficient strength generation to offset the faster drying at the surface. Of course, attention to water/cement ratio, aggregate grading and rheology cannot be ignored.

The recommended sub-grade would include 4" of crushed rock, 2" of sand and a vapor barrier. If additional sand is added on top of the vapor barrier, it should be coarse and dry prior to installation of the concrete. It is important to note that the spaces between granules in crushed rock are large enough to eliminate capillary flow, which makes this layer especially important in preventing the delivery of additional moisture to the slab. In general, the finer the particle size, the greater the probability of capillary moisture movement.

Another alternative is to create a *between slab membrane* based on epoxy or urethane elastomers. This may be expensive, but is perhaps the surest way to eliminate sub-grade moisture problems.

Of course, all exterior below grade concrete should be treated with positive side waterproofing, and all joints and flashing around the perimeter should be sealed.

Surface Preparation and Installation

There are significantly greater floor failures due to surface preparation and installation errors than moisture vapor transmission. Poor surface preparation and ignoring guidelines for installation conditions can be problems in and of themselves, but also lead to increased problems with moisture vapor disbondment.

Let's first consider surface preparation. It is now clearly understood that the surface of finished concrete is paste rich, and, therefore, the weakest part of the concrete. Additionally, water's evaporation during the drying stage may draw impurities from the slab and leave them on the surface (efflorescence) to later act as disbonding agents. While there are many ways to prepare a surface, by far the optimum method is to remove this layer by mechanical means. There are no shortcuts. In addition to providing a bonding surface free of the capillary pore-rich paste, the surface area is dramatically increased, which provides increased surface area for bonding, and a physical interlocking of the cured topping and the concrete. The recommended profile for non-permeable flooring systems are as follows:

Topping Thickness	**Substrate Profile**
1/8"	20-25 mils
1/2" 1/4"	30-40 rnils
1/4" 1/2"	40-60 mils

Now that an adequate surface has been prepared, conditions of installation must be addressed. The manufacturers' recommendations for temperature and humidity should be followed. It is generally accepted, however, that installation temperatures should be 5°F above the dew point. The dew point is the temperature at which moisture will condense on a surface. Moisture can affect the cure, adhesion and ability to accept a second coat of many resinous systems.(*Table 1*)

Dew Point Chart

General Polymers

DEW POINT CHART

SURFACE TEMPERATURE AT WHICH CONDENSATION OCCURS

AMBIENT AIR TEMPERATURE - FAHRENHEIT

Relative Humidity	20	30	40	50	60	70	80	90	100	110	120
90%	18	28	37	47	57	67	77	87	97	107	117
85%	17	26	36	45	55	65	75	84	95	104	113
80%	16	25	34	44	54	63	73	82	93	102	110
75%	15	24	33	42	52	62	71	80	91	100	108
70%	13	22	31	40	50	60	68	78	88	96	105
65%	12	20	29	38	47	57	66	76	85	93	103
60%	11	19	27	36	45	55	64	73	83	92	101
55%	9	17	25	34	43	53	61	70	80	89	98
50%	6	15	23	31	40	50	59	67	77	86	94
45%	4	13	21	29	37	47	56	64	73	52	91
40%	1	11	18	26	35	43	52	61	69	78	87
35%	-2	8	16	23	31	40	48	57	65	74	83
30%	-6	4	13	20	28	36	44	52	61	69	77

Table 1.

Most manufacturers will also state that a temperature of 50°-60°F minimum is necessary for installation. Note that this does not address anything except the temperature necessary to drive the reaction. A more insidious issue can cause problems and later disbondment even if these conditions are met. Recall that moisture vapor moves from low to high temperatures, and high to low humidities. Therefore, if a system is installed in new construction at conditions of 5O°-6O~F and high humidity, i.e. winter or fall rains, then whatever moisture is in the concrete will not move and create an immediate problem. It may, however, be compelled to move when the structure is completed and temperatures rise and humidity drops. This can explain why it may take months for moisture vapor to present a problem.

The best way to predict this occurrence is to test for moisture vapor transmission under usage conditions with a Calcium Chloride test kit. This means a heat source should be provided to simulate use conditions at the test site to predict the amount of moisture vapor movement when conditions change. If the level is 5 pounds per 1,000 sq.ft. per 24 hours by the calcium chloride test, then external heating and ventilation must be provided to those areas prior to installation of the first layer, i.e., primer or membrane. Once the concrete is completely sealed with this first layer; it will not be possible for moisture to re-enter the slab from the environment above the slab. Assuming that the slab is installed with a functioning vapor barrier membrane, the possibility of future problems are dramatically reduced.

Use of a liquid primer and/or membrane is recommended in all cases. The reason is that the more fluid a product and the lower its surface tension, the better wetting agent it will be. This has the dual effect of improving penetration and adhesion, and sealing the slab from moisture re-entering the concrete when the external heat source is removed.

Problem Prevention due to Moisture Vapor Transmission

To review, the factors we must address to prevent moisture vapor transmission problems are composition of the concrete, the finishing of the concrete, the cure conditions and - surface preparation.

Concrete specifications should include the following to maximize the probability of successful bonding of non-permeable floor coverings:

	Water/cement ratio should be	< 0.45
	Aggregate must be well graded, to minimize total water and cement (paste)	ASTM C33
•	Compressive strength, minimum	5000 psi
	Elimination of all $CaCl_2$ & NaCI	0%
	Concrete Density	140 lbs/ft^3
	Slump (Rheology)	< 4”
-	Air	<6.5%

The preferred placement which should always be specified is compaction and a light steel trowel finish to minimize the disruption of the paste and aggregate distribution. Remember that the paste on the surface has the highest water/cement ratio and, therefore, will be the weakest part of the concrete.

Cure conditions should be clearly stated in any specification for concrete to accept non-permeable durable go below 50°F (10°C) or above 90°F (32°C),

The sub-grade design should provide for adequate drainage, should include 4 crushed rock, 2” of sand and a vapor barrier. The coarse aggregate draining system will eliminate capillary action that may deliver moisture to the bottom of the slab.

The correct floor preparation is to insure complete removal of the top paste layer via mechanical means, i.e., shotblasting.

Installation must be done at or close to use conditions to insure that moisture vapor does not become an issue at a later date. Temperature should be between 50°F and 90°F, and at least 5°F above the dew point

Dealing with Existing Problems

There may be call to install a non-permeable flooring system on existing slabs with known moisture problems. In this case, the first issue is to gather as much information as possible as to the construction and past history of the slab. This must include a moisture test with calcium chloride. This test should always be conducted after shotblasting. The level of moisture will dictate how to remedy the problems.

Options include a variety of chemistries all designed to penetrate the existing pores, decrease the permeability and inhibit the path of moisture through the slab. These include potassium silicates, siloxanes, gel forming polymers and high solvent containing resinous systems. After installing these systems, moisture tests should be conducted again to determine the level of improvement. The net change in moisture vapor transmission is only meaningful if temperature and humidity above the test areas are the same for both before and after tests. Field tests have demonstrated that a 30% to 50% reduction in moisture vapor transmission is possible using these techniques. This is often significant enough to allow successful installation of non-permeable flooring systems. Consult with your supplier of non-permeable floor coverings for specific recommendations.

Should a non-permeable flooring system fail, it may be necessary to understand the causes of the disbondment. Fundamental information should be gathered concerning the concrete slab. That information should include:

- Estimated age of the concrete;
- Specified water/cement ratio;
- Current conditions of paste, surface and overall;
- Presence of admixtures (especially CaCI2);
- Presence of any sealer or curing compound;
- Current vapor emission level;
- Intended use of the floor;
- Interior environmental conditions; and
- Environmental conditions during installation.

Additionally, key questions concerning the existing floor covering must be addressed. These are as follows:

- •What is the condition of the existing floor covering? -
- •How long has the floor covering been in use?
- •When were problems (irrespective of how slight) first noticed?
- •Is there any noticeable discoloration?
- •Is there any noticeable odor?
- •Is there any visible moisture?
- •What was the age of the concrete when the flooring was installed?
- What were the environmental conditions during installation?
- Did the damage appear to be seasonal?

- Have any determinations been made to ascertain whether the problem is condensation or vapor emissions?

The answers to these key questions will provide the basic information concerning how to diagnose the cause of the problem. The flooring manufacturer may be helpful in resolving problems concerning their floor coverings.

Conclusions

It is readily apparent that the best way to eliminate moisture vapor transmission problems is to prevent them by creating a concrete slab which will have minimum shrinkage and capillary pores. This is done by carefully controlling the concrete mix design with special attention paid to minimizing total water, keeping the water/cement low and using well graded aggregate. Not only will this provide the least permeability, but also provide the most durable concrete. Attention to a well drained sub-slab system is essential to minimizing future water problems. Additionally, minimal disruption of the even distribution of paste and well graded aggregate during compaction and finishing will provide the most sound substrate with minimal surface removal prior to application. The manufacturers' recommendations concerning installation should always be followed. Best results can be obtained by installing at or close to the actual use conditions of the flooring system. There are remedial methods available to reduce moisture vapor transmission, but they are not as effective as doing it right the first time.

***NOTE**.:*There are several other potential sources of problems that can lead to disbondment and failure of a non-permeable flooring system. These include sulfate attack, alkali-silica reactions and chloride induced corrosion of reinforcing steel. These issues may affect the longevity of a flooring system, and are beyond this scope of this paper.

[1]"High Performance Concrete Mixtures for Durability", "Concrete Mixture Optimization", **ACI Seminar**. October. 1991

[2] Ken Hoover and Tullic Stokes: "*Making Cents" out of the Water-Cement Ratio*", **Concrete International**, May, 1995.

[3] Ibid.

[4] An eloquent mathematical description of shrinkage events can be found in Chapter 6 of "**Teaching the Materials, Science, Engineering and Field Aspects of Concrete**", 1993, NSF-ACBM Center.

[5] Ken Hoover and Tullic Stokes: "*Making Cents" out of the Water-Cement Ratio*", **Concrete International**, May, 1995.

[6] "*Concrete Mixture Optimization*", Concrete International, June 1990.

[7] *"Understanding Problems With Industrial Floor Slabs".* **Concrete Repair Bulletin**, March/April, 1995.