CREATING MORE VALUE THROUGH WATER-BASED BREATHABLE FLOORING SYSTEMS

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Abstract. Historically technological developments are driven by necessity. Seamless flooring has transitioned through a variety of chemistries and over the past 30 years has improved performance, application process, environmental friendliness and overall value. Developments in water-based technologies are transforming the seamless flooring industry. Systems have been designed for rapid installation, insensitivity to moisture vapor from concrete substrates, lower volatile organic content (VOC) compliance, user friendliness and improved aesthetics. This discussion will provide an overview of the water-based flooring technologies, review the applications, discuss the limitations of the various technologies and compare the overall value compared to traditional epoxy flooring.

INTRODUCTION

Resinous flooring and floor coatings have been used for over a half century. Throughout this period materials of use have evolved allowing for more robust and thicker systems, easier application, lower volatile organic content (VOC), and faster installation.(1, 2) Currently the most widely utilized material used for seamless flooring is high solids epoxy, frequently referred to as 100% solids epoxy. The demand of the market place for faster installations, reduced post-installation issues and more environmentally friendly products has driven the development of water-based technology. These systems provide many of the same performance and aesthetic advantages as the high solids epoxy systems. In addition, the water-based systems are breathable, minimizing issues with moisture vapor transmission (MVT) post installation problems. These "new" systems provide value throughout the supply chain. They are safer to manufacture, more environmentally friendly, easier and/or faster to install, while reducing installation problems.

Why coat concrete?

Concrete is the most commonly utilized construction material in the world. Most commercial and industrial floors are based upon a concrete slab. Concrete provides a supportive surface that can be finished to a slip resistant or polished surface to meet the needs of the use environment. In many applications concrete may not need to be coated. In high traffic environments and in most industrial applications the concrete floor can be protected and last longer if it is coated. Concrete is a relatively weak and porous substrate. Aggressive traffic will wear the surface causing dusting or spalling. The low tensile strength of concrete resulting is chipping and cracking in situations where impact or vibrations frequently occur. The high porosity of concrete allows liquids to enter the concrete slab, potentially weakening the concrete itself. Applications where acidic materials will be exposed to concrete will deteriorate the slab. Concrete is highly alkaline and will react with acidic food stuffs, beverages or chemical acids. (3, 4)

In some cases, concrete is coated to provide additional performance or aesthetic properties. Conductive coatings provide static charge dissipation to protect people and properties from unwanted static discharge. Clean rooms require an environment with little or no dust. A coated floor is easier to clean and will not contribute the airborne particulates. Coatings can also improve the facility light reflectivity or directional indicators with both colored and photoluminescent materials. Finally, although the porosity of concrete provides a relatively slip resistant surface, coating the concrete utilizing aggregate and texture can improve the slip resistance of the surface.

Seamless flooring options

Depending upon the expected performance, the condition of the substrate, and the budget; the concrete can be coating with a variety of different flooring systems. Concrete stains and sealers penetrate the concrete; sealing some of the pores providing improved aesthetics and performance. These penetrating coatings provide no film build and are generally used in light traffic and decorative applications. Thin-mil coatings provide a film build on top of the concrete substrate and generally do not include aggregate other than that used for slip resistant textures. Resin-rich systems are commonly used in aggressive environments. These flooring systems incorporate a blend of aggregates applied as slurry, self-leveling or broadcast process. Resin-rich systems utilizing high solids epoxies are not breathable and can be adversely affected by the movement of moisture from the concrete slab. The highest build systems incorporate more aggregate with the resin and are applied with a trowel. These mortar systems are used to resurface a damaged substrate, address sloped and vertical surfaces, and can include larger aggregate such as marble in thin set terrazzo.

Historical material selection

Coating concrete using solvent containing polymers such as epoxy, polyurethane and polyesters was utilized over fifty years ago to improve and protect the concrete. The material selected was driven by cost, ease of use, and performance. The thickness of application was limited by the solvent and the shrinkage of the floor during the curing process. This led to the development of higher solids materials. Epoxy provided the most cost effective alternative and did not have the high odor of the styrene based polyester and vinyl ester systems. To date, high solids epoxy remains the predominant resin used in the high build seamless flooring industry. In the 1980's, a polyurethane cement system was introduced. This water-based system involves a complicated multi-reaction chemical cure. Most of the water is utilized in the hydration of the cement and thus there is little or no shrinkage. The urethane cement system provides excellent chemical resistant and has been universally adopted by the food and beverage processing industry. Over the last few years, water-based epoxy systems have been introduced. Some of these systems contain cement reflecting the design of the urethane cement systems. Other novel systems contain no cement with equal or better performance properties.

Water-based epoxy evolution

The initial water-based epoxy products introduced were based upon polyamide chemistry. (5) Due to the high viscosity of these materials, nonionic surfactants were added to provide workability. These materials had a short pot life, high color content and slow cure. Applications of these products was limited to primers or thin mil applications. Water-based polyamine adducts were introduced to improve the performance, workability and aesthetics delivered by the polyamides. They had lower color, higher solids, and cured faster. These early water-based products required the addition of cement for thick applications. Attempting to apply these chemistries as a self-leveling system without the use of cement resulted entrapped moisture causing low gloss, soft cure, shrinking and mud cracking. The new water-based technology have solved these issues.

Figure 1. Water-base polyamine adduct epoxy shrinkage cracking.

Limitations of conventional systems

The early water-based epoxies were limited to thin applications and were slow to cure depending upon the temperature and humidity to drive evaporation. Solvent containing chemistries are also limited to thickness of application and their high VOC content is restricting their use. Solvent free chemistries, especially 100% solids epoxy systems, are subject to free amine reaction with water and carbon dioxide resulting in carbamation and surface blush. The most highly visible and most expensive issue with these systems is blistering and delamination. These issues are frequently not experienced several months or years after the installation.

Blister Formation There are a number of theories regarding the cause of blisters in seamless floors. On commonality to all hypothesis is that blisters occur when there is movement of water in the concrete slab. Minimizing the movement of moisture is accomplished by proper exterior grading, utilizing low Perm moisture retarders below the slab, poring low water to cement ratio concrete, proper curing, and installation of the flooring systems at the same environmental conditions in which it will be placed in service. After a impermeable flooring system has been installed on a concrete slab, moisture drive within the concrete is driven by the difference in vapor pressure at the bond line and within the slab. Vapor pressure is a function of temperature and relative humidity. When the slab is "capped" with a seamless flooring system, only the temperature differential will affect the vapor pressure differential. Proper concrete mix design and moisture curing the concrete decreases the permeability of the slab and will reduce the potential channels for moisture movement in liquid and vapor form.

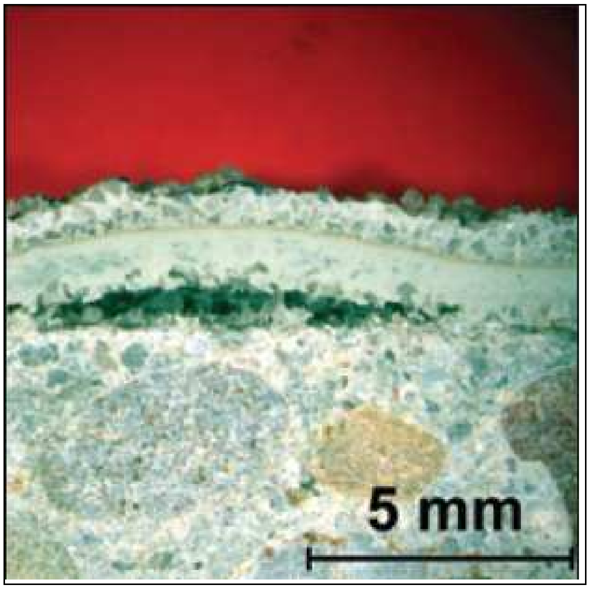

Figure 2. Impermeable epoxy flooring blister.

One theory presented in the late 1990's was termed "osmotic blistering".(6) Unfortunately this is a misuse of the term. Osmosis is the transport of a fluid (in this case water) through a semi permeable membrane, from low concentrations to high concentrations. It had been argued that the concrete slab itself was the semi permeable membrane. In reality, blisters are comprised of a highly alkaline substance and thus the liquid contained within these blisters contains more than water. Concrete is not a semi permeable membrane as all ions can pass through the pore and capillary structure of the slab.

Another school of thought regarding the mechanism of blister formation is based upon the argument that some silica is susceptible to Alkali Silica Reaction (ASR). In the presence of highly alkaline conditions, as seen in floor blisters, some reactive silica will convert to an expansive gel. The gel will create pressure causing delamination and can even lead to concrete cracking. This is not dissimilar to the corrosive affects of rust, where iron is degraded under the proper conditions and expands as the iron is oxidized. In theory, as moisture moves through the concrete, condenses or consolidates at the bond line, the highly alkaline conditions may react with the fine sand (silica) that is at the surface of the concrete. The subsequent ASR "unlocks" the mechanical bond and forces the flooring system to blister.

Yet another theory was recently presented that suggests that the formulation of the resin primer and the flooring system itself may play a role in the formation of blisters. (7) Briefly, the authors present experimental evidence that shows that epoxy formulations containing nonreactive diluents, benzyl alcohol, can actually create discontinuities in the polymer structure leading to pressure points. The capillary pore pressure with a concrete slab has been measured to be as high as 2.9 Bar (42 psi). If this force is focused to a fine pin hole, the pressure would exceed 2,500 pounds per square millimeter. In addition, the formulations containing benzyl alcohol become soft when exposed to highly alkaline conditions.

Regardless of which of these theories or combination of causative affects results in blister formations in impermeable flooring systems, the common element is the movement of water and the accumulation of highly alkaline liquid at the bond line. The blistering problem would not present itself if either one of these factors is eliminated.

Water-based Breathable Technologies

There are several flooring systems on the market today that are based upon water-based chemistry and yield a “breathable” flooring system. As discussed previously, the polyurethane cement systems have proven to be successful for nearly 20 years. Water-base epoxies with cement offer the same advantages and may be more cost effective. Over the past five years, water-based epoxy technology has also been formulated for thick film and troweled systems that contain no cement.(5) Finally, novel water-based polyurethane coating systems are now available as neat coating systems or topcoats for breathable systems.(8)

The newly developed water-based epoxy systems that do not contain cement have solved the issue of shrinking and cure within a 1-2 day period depending upon environmental conditions. The fact that these systems do not shrink as the water leaves the system gives a clue to why they breathe and thus minimize issues related to moisture vapor emmisions. When mixed with a graded aggregate, the water-based epoxy coats the aggregate, the water evaporates and a three dimensional structure remains. When comparing this structure to a typical high solids epoxy, it becomes obvious why they perform differently. The “solid” structure of the high solids system will not allow for the passage of moisture while the open “microporous” structure of the cured water-based system will be breathable. To put this picture in perspective, a molecule of water is 2.8 angstroms in size, that is 1/35,0000 of one millimeter. A pin head is about 2 mm wide.

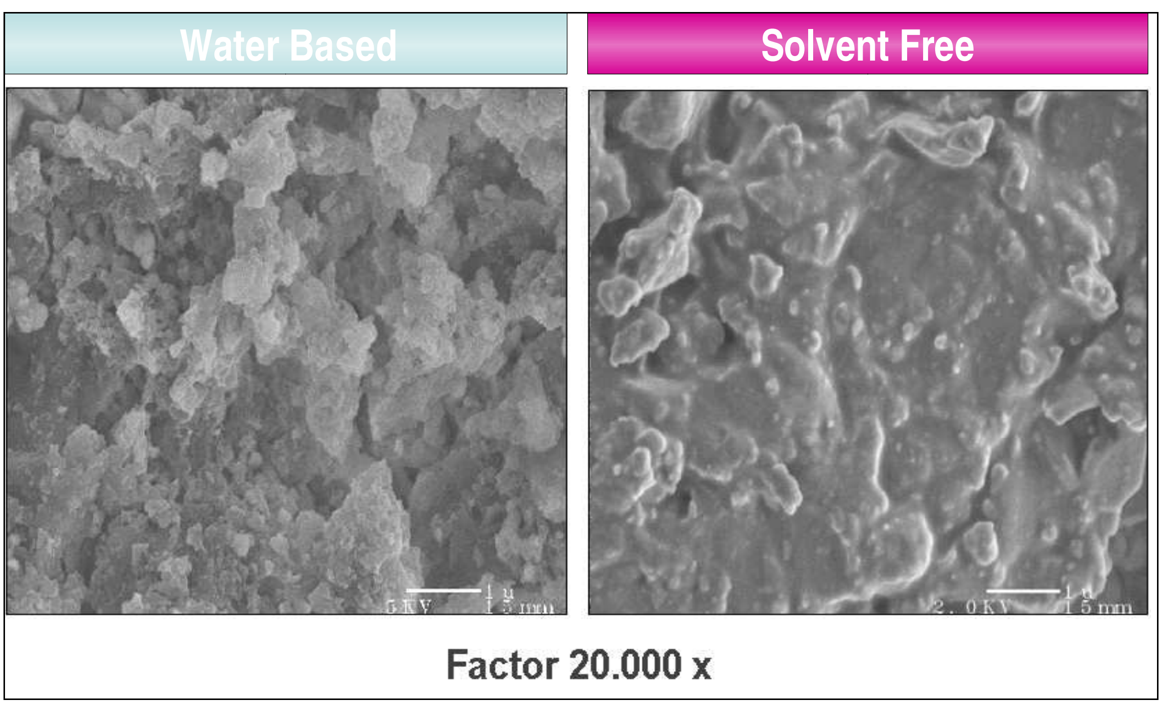

Figure 3. Electron Micrograph of New Water-based Epoxy vs. High Solids Epoxy Systems

Measuring Permeability

Manufacturers are beginning to report the permeance (or permeability) of their products and systems. Typically this is measured using ASTM E96 Standard Test Methods for Water Vapor Transmission of Materials. The ASTM E96 values are not necessarily comparable between products and systems. This test method describes two separate techniques to measure the permeance of a material. One method (Wet Cup Method) uses a water containing cup covered by the test specimen and measures the loss of water in the cup. The second method (Dry Cup Method) uses a desiccant within the cup and measures the gain in weight as moisture passes through the specimen into the cup. Water vapor permeance is the time rate of water vapor transmission through a unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specific temperature and humidity conditions. Permeability is the arithmetic product of permeance and thickness. The samples themselves may vary in thickness and composition. Ideally, the flooring system itself is measured for permeance (g/Pa-s-m) or Perm (inch-pound). Although the test method controls the temperature and humidity during the test, the value derived under these conditions may or may not reflect those under which the system will be used.

Concrete has been reported to have a permeance of between 20 and 30 Perm. In the insulation industy, products are considered to be breathable if their Perm rating is greater than 1. In the flooring industry, however, a floor coating is considered to be breathable in the Perm rating is 3 or higher. (10) The issue is rate. When bonding a "breathable" coating to a concrete surface, can the coating system handle the rate of transmission from the concrete. If a fire hose is connected to a garden hose and the water is allowed to trickle through the fire hose and through the garden hose, there is not issue. Both hose systems can handle the moisture flow. If, on the other hand, the water pressure is maximized through the fire hose, the garden hose will be blown off (disbond) the coupling.

All coatings are permeable, but at what rate? In tank lining applications, the permeability of the coating is reduced through the use of glass or mica flake to avoid blister formation caused by vapor migrating through the coating and condensing at the bond line creating blisters (cold wall effect). The permeance of these tank lining coatings compared with a typical high solids epoxy flooring system results in similar Perm ratings near zero.

Impermeable Resinous Systems

		Glass Flake Filled Novolac (Published)	Mica Filled Polyester (Published)	100% Solids Cycloaliphatic Epoxy System
Water Vapor Transmission	*g/(m^2·s)*	2.09E-07	2.18E-05	6.00E-06
Permeance	*PERMS*	0	0	0
Water Vapor Permeance	*g/(m^2·s·Pa)*	9.15E-11	9.54E-09	5.00E-09

Table 1. ASTM E96 Perm ratings for impermeable coating systems.

When measuring the polyurethane cement systems for permeance we obtain values of 6-7 Perm when tested on top of a concrete paver with a Perm rating of 11. With over 20 years of experience, we know that this value works when placed on a variety of different concrete slabs. These systems have even proven to be successfully installed, with no subsequent moisture issues, over green concrete that had only cured for 3-7 days. Interestingly, the "sealed" system that was coating with a 100% solids epoxy performed as well as the uncoated sample.

WB Urethane Cement

		Paver	Urethane Cement (sealed)	Urethane Cement
Water Vapor Transmission	*g/(m 2 ·s)*	1.44E-03	8.49E-04	8.02E-04
Permeance	*PERMS*	11	6	6
Water Vapor Permeance	*g/(m 2 ·s·Pa)*	6.29E-07	3.71E-07	3.51E-07
L (sample thickness)	*cm*	3.84	4.4	4.2
Permeability, δ	*perm·cm*	2.41E-06	1.63E-06	1.47E-06

Table 2. ASTM E96 Perm ratings for polyurethane cement systems on a paver.

The new water-based epoxy system was tested within three different system designs. The first system was simply a self leveling slurry application. The second system utilized a slurry application followed by a full sand broadcast and sealed with 100% solids epoxy. The last system was a double broadcast using a neat application of water-based epoxy with a decorative quartz broadcast followed by a reapplication of the coating and broadcast quartz. This system was sealed with the same breathable water-based epoxy. The two slurry containing systems produced comparable Perm ratings of 7-8, higher than the polyurethane cement systems. The double broadcast system, however, did not prove to have as high a permeance. One possible explanation for this is that a graded aggregate was not used and the aggregate was placed in the system after it was applied to the floor. It can be concluded that the system design, not just the resin composition is critical to the permeability properties of the system.

WB Epoxy Systems

		Paver	Water-based Epoxy System (published)	Water-based Epoxy (broadcast/sealed)	Water-based Epoxy	Water-based Epoxy Broadcast
Water Vapor Transmission	*g/(m 2 ·s)*	1.44E-03	9.75E-04	1.00E-03	9.47E-04	5.37E-04
Permeance	*PERMS*	11	12	7.6	7.2	4
Water Vapor Permeance	*g/(m 2 ·s·Pa)*	6.29E-07	6.67E-07	4.39E-07	4.14E-07	2.35E-07
L (sample thickness)	*cm*	3.84		4.07	4.04	3.98
Permeability, δ	*perm·cm*	2.41E-06	1.44E-07	1.79E-06	1.67E-06	9.35E-07

Table 3. ASTM E96 Perm rating for new water-based epoxy flooring systems.

The fact that the "sealed" systems, both polyurethane cement and new water-based epoxy systems resulted in high permeance values indicates that these systems can be used under impermeable flooring systems to avoid moisture issues. These breathable systems will work as a remediation system because they are removing the stress from the bond line, preventing potential crystallization and serving as reservoirs for moisture movement. One such example would be the use of these systems under thin set epoxy terrazzo. Most epoxy terrazzo applications incorporate 100% solids epoxy. They are not considered to be breathable and frequently present problems with moisture vapor transmission.

Other Performance Properties of Water-based Systems

Seamless floors are frequently used is wet conditions, areas that require seam cleaning or in process areas where temperatures will fluctuate or thermal shock conditions exist. The water-based epoxy systems provide a natural form of thermal insulation due to the open architecture following cure. The formulation contains no plasticizers, thus unlike most 100% solid epoxies, they will not become soft when exposed to high heat. The polyurethane and epoxy cement containing system also perform well in these environments. Because these systems have similar thermal coefficient of expansion to that of concrete, there is little or no bond line stress when presented with a rapid change in temperature.

High solid epoxy systems are general brittle. Upon heavy impact these system can deform and frequently crack. The water-based epoxy systems, with their microporous structure, will tend to dent when presented with an impact event. The energy of impact is absorbed. The cement containing systems transfer the energy of impact because their physical properties are similar to the underlying substrate.

Table 1 summarizes some of the comparative properties of the water-based breathable technologies. Traditional high solids epoxy systems have served the industry well but are relatively slow to install and have issues with moisture movement in concrete. The Urethane cement systems have addressed both of these weaknesses; they can be installed quickly and have no issues with moisture vapor transmission. The epoxy cement systems also perform like the urethane cements but the system may be slower to cure allowing for a more decorative finish. The new water-based system without cement has better chemical resistance than the cement containing products and performs as well. Finally, the water-based polyurethane coating can be used as a breathable system to a degree and provides all of the advantages of a typical topcoat or coating system.

Technology Comparisons

	Standard Epoxy	Urethane Cement	Epoxy Cement	Water-based Epoxy	Water-based Polyurethane
Permeability	Poor	Excellent	Excellent	Excellent	Good
Abrasion	Excellent	Good	Good	Good	Limited
Impact	Good	Excellent	Excellent	Good	Good
Return to Service	Poor	Excellent	Good	Good	Good
Chemical Resistance	Excellent	Excellent	Good	Excellent	Excellent
Cost	$$	$$$$	$$	$$$	$

Table 4. Flooring System Comparison Chart

Limitations of the water-base technologies Because these technologies contain water, the can freeze. In some cases, if the formulation is not self-emulsifying the emulsions can break and the product will not cure correctly. The microporous nature of the new water-based epoxy systems limits the compressive strength. These systems will dent when placed under high point loads. The cost of the new technologies may be higher than the commodity products currently being used. There may however be a cost trade-off with saving in installation time and post installation issues. In addition, these systems may save scheduling time if placed on green concrete.

Value Proposition

Water-based breathable flooring systems provide value to all parties associated with the flooring installation. In addition to the improved performance and aesthetics of the concrete surface, these technologies eliminate post installation moisture issues. They are VOC compliant and environmentally friendly. They can be easier and faster to install. There is low or no odor during installation, especially if the tools can be cleaned with soap and water. Water-based technology is also safer and “cleaner” to manufacture.

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