

2-Part Epoxy Coatings & Osmotic Blisters

A problem with 2-part epoxy sealants as a strategy
for mitigating elevated MVER in concrete

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Developing a safe, effective solution to mitigating for elevated MVER in concrete floors is a monumental problem for formulators servicing the construction industry. There are a wide variety of published articles addressing different perspectives on the source of moisture in concrete and its movement, yet developing an answer to the problem has been a long difficult process of trial and error. Several early attempts at resolving the issue did not take into consideration the full extent and complexities associated with the physics of moisture and its movement within the concrete slab.

Initial strategies for MVER mitigation utilized published data circa WWII (airbase runway construction) in which sodium and/or potassium silicates were used to impregnate the concrete slab in the hopes of hardening the top carbonate layer through gel formation. Several articles are available concerning the pitfalls of this strategy.

A second generation strategy involves the use of 2-part epoxy "impermeable" sealants. This system utilizes epoxy chemistry to create a low to no perm sealant layer, isolating the concrete surface and allowing for the creation of a new bonding substrate commonly referenced by flooring contractors as a forming a "Cap". The adhesive bond is created with conventional water-based adhesives over a polymer modified cementitious skim functioning as an adsorbent surface layer or "blotter layer". The impermeable epoxy sealant, as a strategy, negates the argument for "cause and effect" related to moisture source and emission. The sealant strategy relies upon isolating the slab permanently from the adhesive bond line. The following is a general discussion of some of the inherent problems related with this solution.

The Problem with the "Impermeable Sealant"

The amazing thing about osmotic blistering is most people in construction know very little about it. Yet the phenomena has been a billion dollar problem in the boating industry for over 30 years.

Osmotic Blisters in Boat Hulls, a Comparative

To understand some of the physical/chemical dynamics involved in some "impermeable" concrete sealant failures let's look at an analogous situation that has taken place within the boating industry pertaining to failures of Gel-kote (epoxy laminate) boat hulls. As early as 1987 the cause and effect relationship of water permeation was understood and documented by a University of Rhode Island study of Thomas Rocket and Vincent Rose, "The Causes of Boat Hull Blisters" -

In simple terms, water penetrates the exterior Gel-kote both as water vapor and as liquid water. Water is particularly good at this due to the small size of the H₂O molecule. The gelkote is a rather poor barrier against water penetration and becomes **hygroscopic** when constantly immersed. The glass fiber component of the Gel-kote assists in acting as a form of capillary tunnel to transport water molecules to the interior epoxy laminate. Once penetration within the Gel-kote layer occurs the water goes into chemical solution with components defined as "water soluble materials" (or WSMs). Further migration of this

more concentrated solution takes place until this supernatant solution encounters the interior epoxy laminate. This physical process is referred to as osmotic permeation. The specific components of WSMs can be quite broad and include a multitude of organic species including phthalic acids, glycols, styrenes and materials left unreacted from the hardening process. The “take away” is that functionally the varied components have the same net effect by creating a solution of increased concentration at the laminate boundary layer. What happens next is a corrosive chemical reaction related to osmotic permeation called **hydrolysis**.

Virtually all conventionally built polyester fiberglass boat hulls that are continually immersed in water will exhibit osmotic related damage and show signs of hydrolytic deterioration of the interior laminates after 5 to 10 years of immersion. These signs include "sediment piles" where hydrolysis fluid is entering the hull, increased visible interior moisture content, reduced resin and glass fiber clarity, reduced resin hardness as well as the obvious and well documented blisters.

Hydrolysis: A chemical process of decomposition involving the attack of a chemical bond and addition of the elements of water (Webster's). When used in reference to the osmotic blister phenomena, the bonds being broken are the crosslink molecules of the cured epoxy resin. Hydrolysis will increase the next concentration of fluid at the boundary layer attracting moisture of less concentration.

Hygroscopic: An adjective referring to a material which absorbs water readily. Talc or clay is an extremely hygroscopic filler used in conventional polyester auto body putty, cheap flooring adhesive and accounts for the rapid deterioration of this material when exposed to elevated pH.

Boat Hulls Compared to the Epoxy Sealed Concrete Slab

The comparative analogy of fiberglass boat hulls and concrete treated with an impermeable epoxy sealant is surprising:

- Gel-kote is a semipermeable layer with limited porosity upon cure analogous to cured concrete.
- Gel-kote can contain glass fibers that facilitates capillary activity promoting the movement of moisture and moisture vapor through the layer analogous to many “channeling” theories on how moisture will move through a concrete slab by capillary action promoted by large aggregate and other fill materials.
- The interface between cured resin and Gel-kote is a boundary layer where WSM nutrient water impacts the impermeable epoxy laminate. The Gel-kote/epoxy laminate boundary layer is analogous to the concrete/epoxy sealant bond line.

Additional Anecdotal Evidence

Blistering of synthetic-organic or epoxy floor protective coatings continue to be a major and costly concern that has been related to the flow of moisture vapor through the porous concrete. This flow can occur as a result of:

- 1) **Hydrostatic Pressures or Hydrostatic Head** - hydrostatic pressures are found when a slab on grade is below the water table. Rarely occurs.
- 2) **Capillary Action** - capillary action occurs where a moisture source, in contact with the underside of the slab, migrates by filling voids facilitated by properties of surface tension.
- 3) **Moisture Vapor Emission** - moisture vapor emission develops as a result of higher humidity within the slab relative to the humidity above the slab, driven by chemical gradient and facilitated by surface evaporation.

Although all contribute to the moisture flow through the slab, none by itself or combined produces enough force to lift a well-adhered epoxy floor formulation. Epoxy flooring formulations provide an effective, “impermeable” seal to block moisture flow. This is their claim to fame, as well, this is also their Achilles heel.

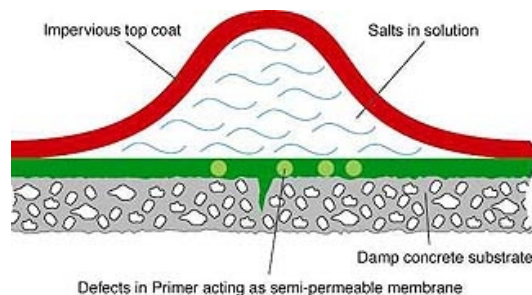
Osmotic pressure can produce forces that are several orders of magnitude higher than hydrostatic forces observed in un-coated concrete. **Osmosis** is defined as the spontaneous flow of a liquid through a semipermeable membrane, from a dilute solution to a more concentrated solution. As a result, the liquid volume of the initially more concentrated solution increases until the hydrostatic pressure generated is in equilibrium with the osmotic pressure. The pressure generated by osmosis can greatly exceed other forces in concrete and ultimately result in delamination of the floor coating. Three requirements must be fulfilled for osmosis to take place:

- 1) Presence of water (liquid and/or vapor)
- 2) Presence of salts or water-soluble (hygroscopic) organics, (*Side Note: I wonder about that sodium/potassium silicate strategy first mentioned*)
- 3) Presence of a semi-permeable membrane, (concrete slab)

All these conditions are typically found on and within concrete.

In order to prepare the concrete slab for epoxy film coatings it has been common practice to employ shot blast and high pressure water jetting to remove soluble salts that are readily available through several routes (salt water, ground water, de-icing or acid etching). However, their complete removal is virtually impossible. Concrete can “act” as a semi-permeable membrane itself, or better stated, a semi-permeable membrane is created when a coating (i.e., 2-part epoxy) is applied. This is particularly evident when epoxy is mistakenly applied to damp concrete where water (gathered in the pores) prevents sufficient bond. When all three factors mentioned previously combine there exists a high probability of osmotic activity occurring that can eventually lead to blister formation.

So what about these blisters? Well, blisters form when the flow of water into the laminate boundary exceeds the flow of hydrolysis fluid back out. It is that simple, FLOW IN EXCEEDS FLOW OUT. To understand technically what happens, we have to understand osmosis and osmotic theory.



Osmosis and Concrete Coating Failures

As stated earlier, when two fluids are separated by a semi-permeable membrane and one is more concentrated than the other, the more concentrated will draw the less concentrated solution through the membrane until the two are of equal concentration. The force that does the "drawing" is called "osmotic force" and it can be substantial. So how does this relate to blister failures of

epoxy film coats and how about 2-part epoxies used to mitigate moisture and reduce MVER?

Here comes the twist in the story. What we have described so far is actually two distinct chemical/physical processes that lead to failure. We now understand the first process, osmosis, but it's more likely the second chemical process is more significant to actual failures?

Contradicting earlier theories, the **damage** from osmosis is not caused by excessive water permeation to the boundary layer of concrete substrate and sealant. Osmotic activity is only act 2 of a 2 act scene. Act 1 is the process of hydrolysis, which can in itself create "WSM"! Corrosive hydrolytic attack can destroy chemical bonds within the sealant film resulting in a loss of film integrity. With the loss of film integrity, a likely pocket may form, fill with high concentrate fluid (**supernatant**), osmotic forces initiate and osmotic pressure expands the cavity through an influx of lower concentrate water. This process is normally slow, but the natural presence of alkalis and the inherent hydrolytic effect are omnipresent.

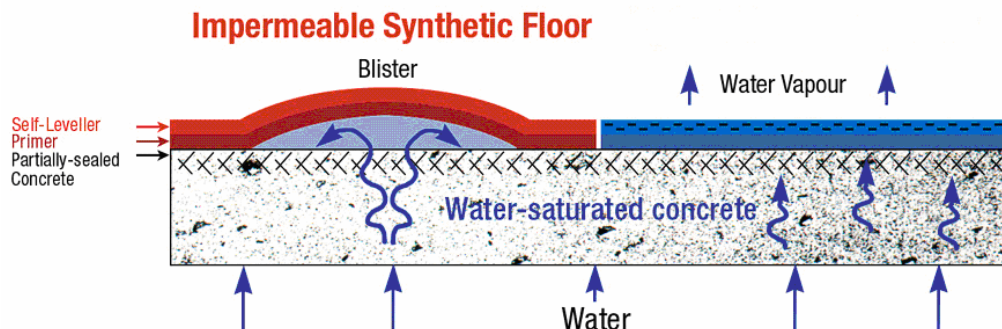
So to recap, in order for osmotic blistering to occur, three (3) things are required:

1. A semi-permeable membrane, (arguably concrete is not a perfect example but sufficient for this discussion).
2. A concentration of water-soluble material (WSMs), which can be anything from the resin ingredients in the epoxy coating, to constituents resulting from hydrolysis, to materials from acid etching, to "unreacted paste", to sodium/potassium silicates. All providing a source for WSM and creation of high concentrate water at the boundary layer.
3. Water - even when we think concrete is dry, it still contains up to 5 percent of free water by weight and on average is measures roughly 70% *insitu* RH (*insitu* = contained within).

What can you do to reduce the chances of osmotic blistering?

- If possible, minimize the amount of soluble salts in the concrete design mix. Mentioned in the actual fine print of most epoxy mitigation system warranties.
- Let the concrete dry for at least two months and/or ensure a fully functional water vapor barrier is underneath the slab when placed.
- Avoid acid etching as a surface preparation technique.
- Don't wash the concrete or apply with detergent.
- Take care to use a floor sweeping material that will not contaminate the surface.
- Ensure that the epoxy coating resin constituents are accurately proportioned and mixed.
- Shot blast the floor.

Obviously some of those options aren't viable when it comes to timely construction. Worse yet, most of the extreme cases of osmotic blistering will occur even if these suggestions are followed.



Case Studies of Osmotic Blistering

Hong Kong International Airport

The 600,000-square-foot baggage handling area lies 14 feet below sea level and is fully saturated with salt water. Contractors were called in as they were close to finishing the facility and realized that a conventional epoxy coating system would not function over such a fully saturated slab. The answer was the use of a “permeable” resin/kaolin/Portland cement-modified polymer coating. The strategy keyed upon the creation of a dense matrix that could resist hydrostatic pressure delamination and yet allow a reduced or restricted passage of water vapor. Simply put, ALLOW THE DAMP SUBSTRATE TO BREATHE. Dissipate the water vapor through the coating eliminating the potential for an osmotic event and subsequent surface blistering.

Since the application in Hong Kong, the coating system has performed perfectly.

Northeastern Municipal Water Treatment Filter Tanks

Two separate cases of epoxy coating failure on one project; the original failure and the failure of the repair:

Original Coating

1. The first coating application developed liquid filled osmotic blisters. Upon analysis high concentrations of chloride, sulfate, nitrate, bromide and phosphate were recorded. The concentration of water soluble salts detected in the blister liquid was sufficiently high to result in the development of osmotic blisters.

The source of the water soluble salts appeared to be the concrete itself. The concrete was acid etched in preparation for the coating. The presence of chlorides may indicate inadequate rinsing after acid etching. Sulfates present may have resulted from sulfur trioxide, a typical ingredient in the manufacturing of cement. However, the sources of nitrates, bromides and phosphates were unknown. They may have been contaminants in the water that was used to mix the concrete slurry or contaminants in the aggregate used to prepare the concrete. It was unlikely that these contaminants resulted from dirt and debris accumulation on the walls, deposited during construction.

Repair Coating

2. The repair coating system failed by another regrettable process error. The original surface was not fully removed. Most of the surface on the concrete walls still contained the original coating system, therefore functioning as a barrier between the contaminants on the concrete substrate and the repair coat. The repair system failed by peeling and/or loss of bond. An analysis of the dis-bonded coating from the filter tank revealed that the converter had not mixed sufficiently the polyamide component of the epoxy coating system. As a result, the coating system was unable to effectively cure, and dis-bonded after being subjected to maintenance.

PME Laboratory Dhahran, Saudi Arabia

A study commissioned by the laboratory was conducted by the Center for Engineering Research, King Fahd University of Petroleum in order to determine the cause of epoxy blister formation within the ESD floor coating of the PME lab. Petrological Analysis of the concrete core samples retrieved from the slab showed carbonation and salt concentration within the surface layer. Additional test confirmed the presence of inordinately high levels of silicate, sulfate and other miscellaneous cations.

Cations, Silicate and Hydroxide

The concrete cores from blister locations exhibited similar depth profiles with respect to water soluble components. The sodium and potassium values were found as expected higher at the surface, while calcium and hydroxide values were lower. Sodium and potassium values varied with depth in the range of 1535 to 227 mg/Kg and 1920 to 507mg/Kg of concrete respectively. Calcium and hydroxide values varied with depth in the range of 3180 to 8460 mg/Kg (159 to 423 meq/Kg) and 3916 to 7683 mg/Kg (230 to 452meq/Kg) of concrete respectively. The calcium and hydroxide equivalent values (meq/Kg) were nearly identical which was indicative of calcium hydroxide salt. The water soluble silicate concentrations were also high at the surface of the concrete specimens due most probably to **silica filler as a primer** (see; sodium/potassium silicate use as first generation mitigation strategy) on the concrete slab before application of the epoxy coating. The silicate values varied in the range of 95 to 59 mg/Kg of concrete with depth.

Blister Fluid

The results of inorganic analysis of fluid samples showed that the fluid samples obtained from the blisters contained very high concentrations of Na' and K' in the ranges of 12,700 to 16700 and 16,000 to 25,900 mg/L respectively. The calcium content in the blister fluids was low. The chloride concentration in the fluids was also found low compared to sulfate values and ranged between 351 to 774 mg/L, whereas the sulfate content of the fluids was high in the range of 2400 to 6130 mg/L indicating that sulfate salts in the concrete were more soluble in the high pH fluid than chloride salts. **Silicate levels recorded were incredibly high** and ranged 4,000mg/L to 19,700 mg/L which by comparison was over 200 times that of the surface layer when tested. The pH of the fluid samples was recorded highly alkaline and close to 14 as measured (see; hydrolysis).

Carbonation of Concrete

The results showed that the surface layer of the floor slab had carbonated to a depth of about 10 mm. This was confirmed by phenolphthalein and carbon dioxide tests, and supported by lower pH and water soluble calcium content in the surface layer compared to the bulk of the core specimens.

Concrete carbonation begins at the outset of the original cast. Calcium hydroxide which is produced during hydration (often understood as drying) of cement with water reacts with carbon dioxide in the atmosphere to form calcium carbonate. Carbonation reduces the pH of the pore solution due to neutralization of calcium hydroxide at the surface (this is why we grind in ASTM F710 and F1869). Carbonation rates depend on the quality and mix design of the concrete as well as environmental parameters.

Moisture Vapor Emission

This part of the study was conducted outside of standard ASTM protocol and moisture vapor emission was not measured according to any conventional standards. Obviously the physical presence of the osmotic blisters provides empirical evidence of moisture. The researches did develop a curious internal test which gave a nice comparative study providing a validity to the elevated MVER claim, although again outside accepted standards. The evidence pointed to the presence of a sub-slab source (broken water pipe) for moisture.

Conclusions

Concrete by virtue of being porous is analogous to a semi-permeable membrane (albeit, not

perfect) once sealed with an impermeable coating. Application of sealant for moisture mitigation sets in motion the physical/chemical potential to support an osmotic event. Particularly, if differentials in WSM concentration find time to develop at the concrete boundary layer with sealant. The three factors necessary for osmosis are moisture, WSM and an impermeable film.

In summation we can conclude:

1. Concrete treated with silica hardening agents for moisture control may supply the necessary WSM required for osmotic activity.
2. Application of an impermeable sealant for moisture control may set in motion the creation of a semi-permeable membrane condition necessary for osmotic activity.

The anecdotal evidence suggest that the application of a moisture vapor retarding system that allows the permeation of moisture to a controlled degree may be the best strategy. In fact, borrowing the language often associated with the silica products, densification of the concrete slab could best achieve this restricted flow especially if it did not involve saturation with a possible water soluble constituent. Obviously, allowing permeation also presents moisture at the adhesive bond line. In order to maintain the integrity of the adhesive with the presence of elevated MVER a review of accepted adhesive chemistry and formulation is required.

What Becomes Apparent

Creation of a system which brings a water insoluble densification of the concrete would allow the natural **controlled** venting of moisture from the slab to within tolerance of an innovative moisture resistant adhesive formulation.

In cases of resilient rubber or vinyl sheet the densification would restrict the moisture emission, insuring the integrity of the bond. Understanding the incompressible properties of water (see; Einstein & MVER) is to understand that it's impossible for water to build pressure unless; an osmotic condition as described occurs or, hydrostatic conditions exists in which the installation is below the level of the actual moisture source. Since densification is permeable to a controlled degree, osmosis can not occur (see; 3 rules for osmosis, pg 3) and hydrostatic conditions a rare and within the scope of design.