WHITE PAPER

Design Considerations for Concrete Durability

Understanding Water Transport Mechanisms in Concrete

By Ted Horan, LEED AP
Concrete Industry Consultant

Abstract: Moisture migration into concrete is the leading cause of concrete degradation worldwide. There are two primary water transport mechanisms in concrete. Considering water's powerful forces and then designing concrete structures to adequately resist the known effects of these two common water transport mechanisms is paramount to achieving durable structures. Designers, contractors, and owners need to thoroughly understand the differences in the mechanisms to ensure the structures they are building provide adequate problem-free service life.

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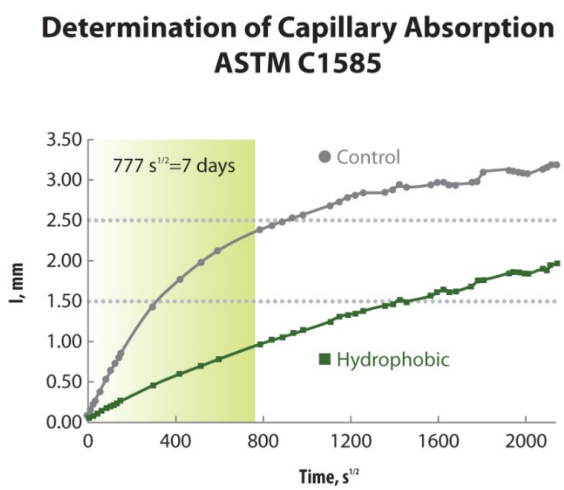
Moisture migration into concrete is the leading cause of concrete degradation worldwide. There are two primary water transport mechanisms in concrete. Considering water's powerful forces and then designing concrete structures to adequately resist the known effects of these two common water transport mechanisms is paramount to achieving durable structures. Designers, contractors, and owners need to thoroughly understand the differences in the mechanisms to ensure the structures they are building provide adequate problem-free service life.

The two mechanisms listed by the magnitude of the challenge they impose are:

1. Capillary absorption or sorptivity
2. Permeability

Ignoring, or more commonly misunderstanding, which of the mechanisms provides the greatest threat to concrete leads to structures that fail to perform long-term and eventually will lead to structural failure.



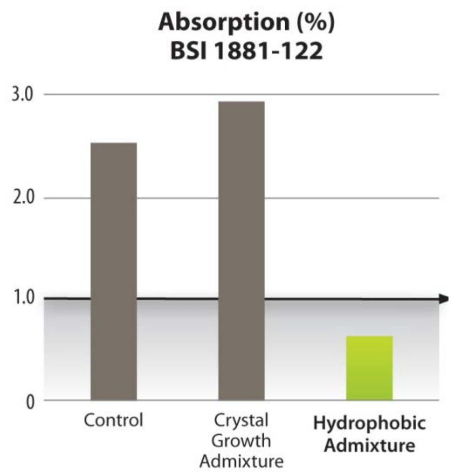
Most degradation processes encountered by concrete require water, dissolved chemicals, and the presence of oxygen. Dissolved salts (chlorides) or other deleterious chemicals can be rapidly transported to the steel reinforcement imbedded in the concrete through the capillary network. The resulting initiation of corrosion causes rebar to expand, breaking up the concrete it is embedded in. Additionally, in cases where water has permeated through a concrete substrate, it may damage building interiors. In each case, the presence of water is detrimental.

Preventing water from freely moving from the outside environment in which the concrete is placed into service to the interior of the concrete matrix is therefore a significant design concern worldwide.

RAPID DELETERIOUS CHEMICAL ABSORPTION THROUGH CAPILLARIES

As mix water required for concrete placement leaves concrete, it leaves behind a porous capillary structure. Capillary absorption is the movement of water through the small pores in concrete in the absence of an externally applied hydraulic head, and is the result of surface interactions between the water and the pore wall. Capillary absorption is the primary transport mechanism for water in concrete structures.

Capillary absorption is so powerful and rapid that it requires no pressure to function and creates far more damage potential than any of the other transport mechanisms. According to a published report written by Dr. Andrew Butler of the Transport Research Laboratory on long-term durability research titled “Capillary Absorption by Concrete” (UK 1998) on 50 mPa/7,250 psi concrete he states, “[t]he speed of capillary absorption is on the order of 10^{-6} m/s – a million times faster than pressure permeability.” He also states “capillary absorption is the primary transport mechanism by which water and chlorides infiltrate concrete” and that “clearly permeability is not a good indicator of resistance to chloride penetration”.

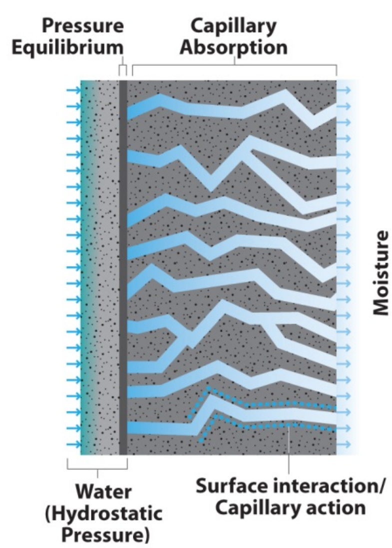


In often repeated studies and experiments, even extremely dense concrete mixes with high compressive strengths, low water cement ratios, and excellent pressure permeability readings rapidly transport water through capillary absorption. To ensure durable concrete it is absolutely essential to adequately address capillary absorption as the designer’s primary duty.

Hydrophobic admixtures dramatically reduce capillary absorption in concrete.

PERMEABILITY

Permeability is the movement of water due to a pressure gradient, such as when concrete is under hydrostatic pressure. Performance under hydrostatic pressure is a simple function of concrete density, or cementitious content. Concrete’s naturally dense matrix, (of even moderate quality mixes) provides an extremely difficult environment to push water through even under high pressure.



The water pressure gradient encountered by a concrete structure is rapidly diminished by the resistance created by its relatively dense matrix. Concrete neutralizes the pressure gradient within the concrete very quickly and then capillary action once again becomes the primary transport mechanism and moves the water further into the structure.

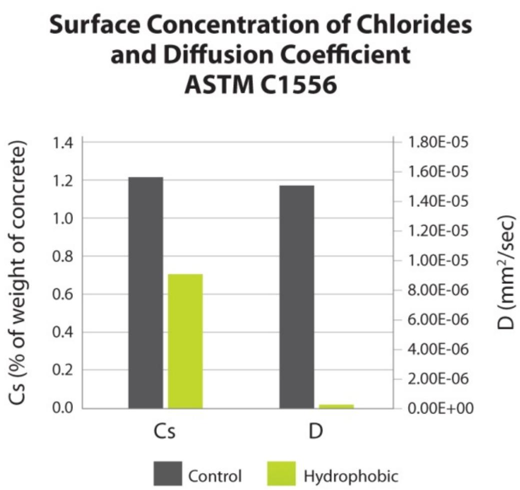
Fortunately, this transport mechanism is the least threatening, and is inexpensive to mitigate. Most designers overcome this challenge economically by simply increasing cementitious content (Portland cement, fly ash, slag, silica fume) or reducing the water/cement ratio to make it more difficult for water to be forced through concrete. Relatively small amounts of cementitious material may be added (for a small additional cost) to dramatically enhance concrete permeability performance.

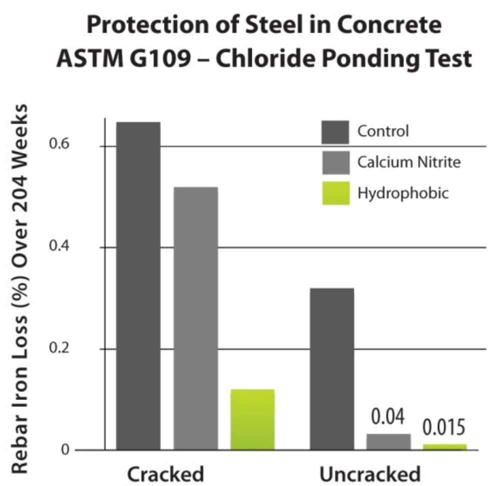
A NOTE ON DIFFUSION

Diffusion measures the slow ingress of chloride ions in saturated concrete.

Although diffusion is not a primary water transport mechanism it an excellent indicator of how deleterious materials can move through concrete structures. Chlorides can penetrate concrete by diffusion, which is the movement of chlorides in solution from an area of high concentration of chlorides to an area of lower concentration.

Chlorides facilitate corrosion of steel reinforcement, which ultimately degrades concrete.





Hydrophobic admixtures reduce both the surface concentration of chlorides in concrete as well as the diffusion coefficient. Also, some hydrophobic admixtures protect steel in both cracked as well as uncracked concrete specimens.

SUMMARY

The primary water transport mechanisms in concrete are capillary absorption and permeability. Capillary absorption is by far the most important mechanism to consider when designing durable structures as it is rapid, occurs in the absence of hydrostatic pressure, and transports water long after water forced into concrete by pressure has reached an internal equilibrium.

Also, as concrete permeability is simply a function of concrete density or cement content, a simple and inexpensive mix design adjustment is made to meet any permeability requirements. Furthermore, because water forced into concrete reaches equilibrium in all concretes, albeit at different depths of penetration, it is not the mechanism that carries water and damaging salts all the way through.

Finally, understanding the movement of chlorides through water in concrete by diffusion is critical to ensuring your structure is protected from degradation.