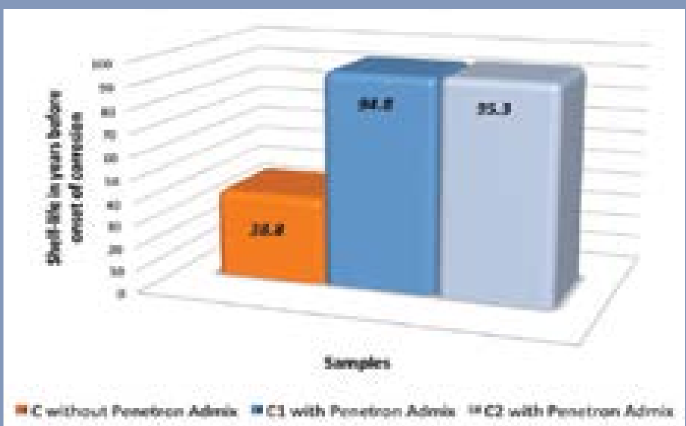
PENETRON®

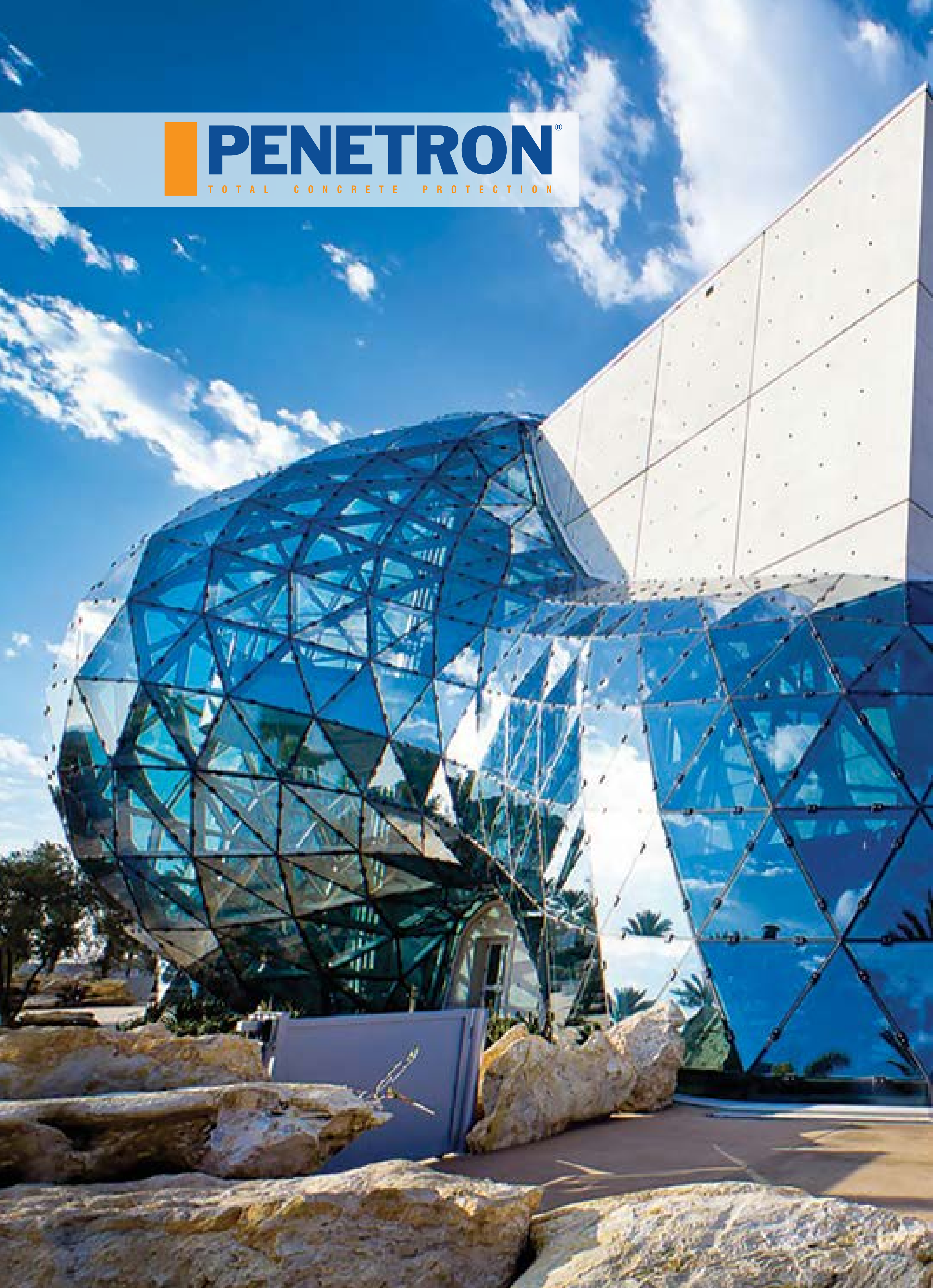
TOTAL CONCRETE PROTECTION

DURABILITY OF CONCRETE

PENETRON ADMIX®: adds 60 years to the life cycle of concrete in corrosive environment (study by ACI for crystal growth admixtures)



- **Permanent Waterproofing**
- **Anti-Corrosion Protection**
- **Strength Improvement**
- **Resistance to Chemical Stress**


PENETRON®
TOTAL CONCRETE PROTECTION

Durability of Concrete

CONCRETE

IS THE SECOND MOST CONSUMED PRODUCT ON EARTH AFTER WATER

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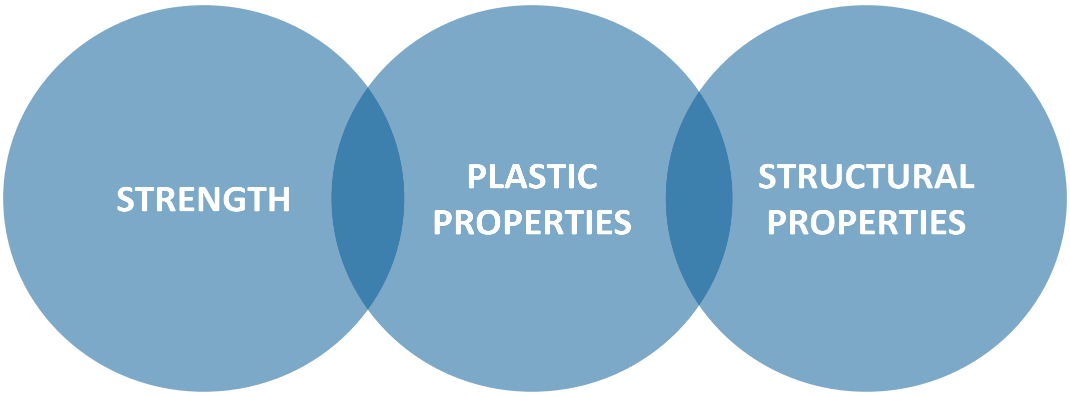
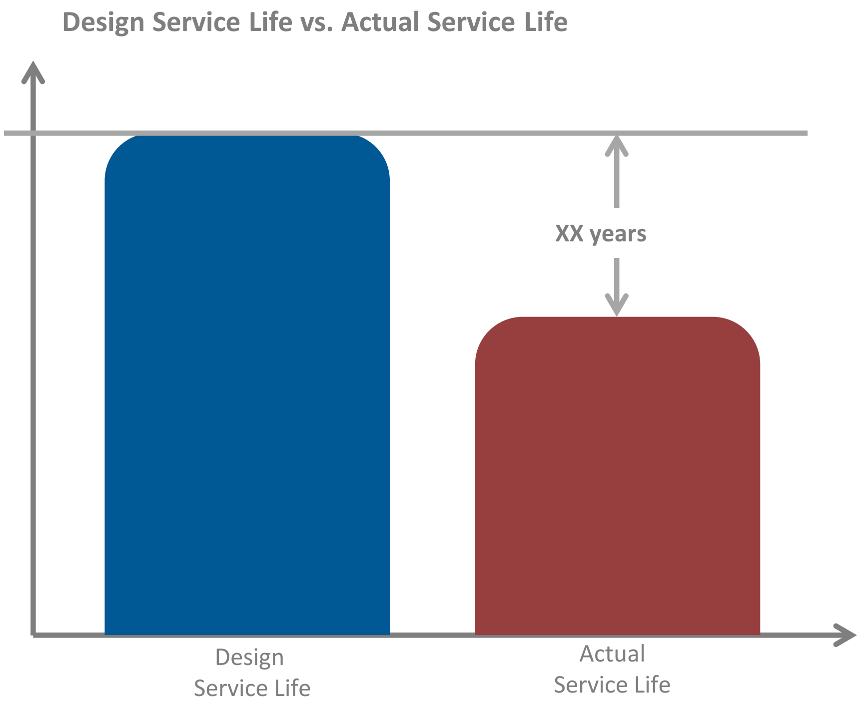
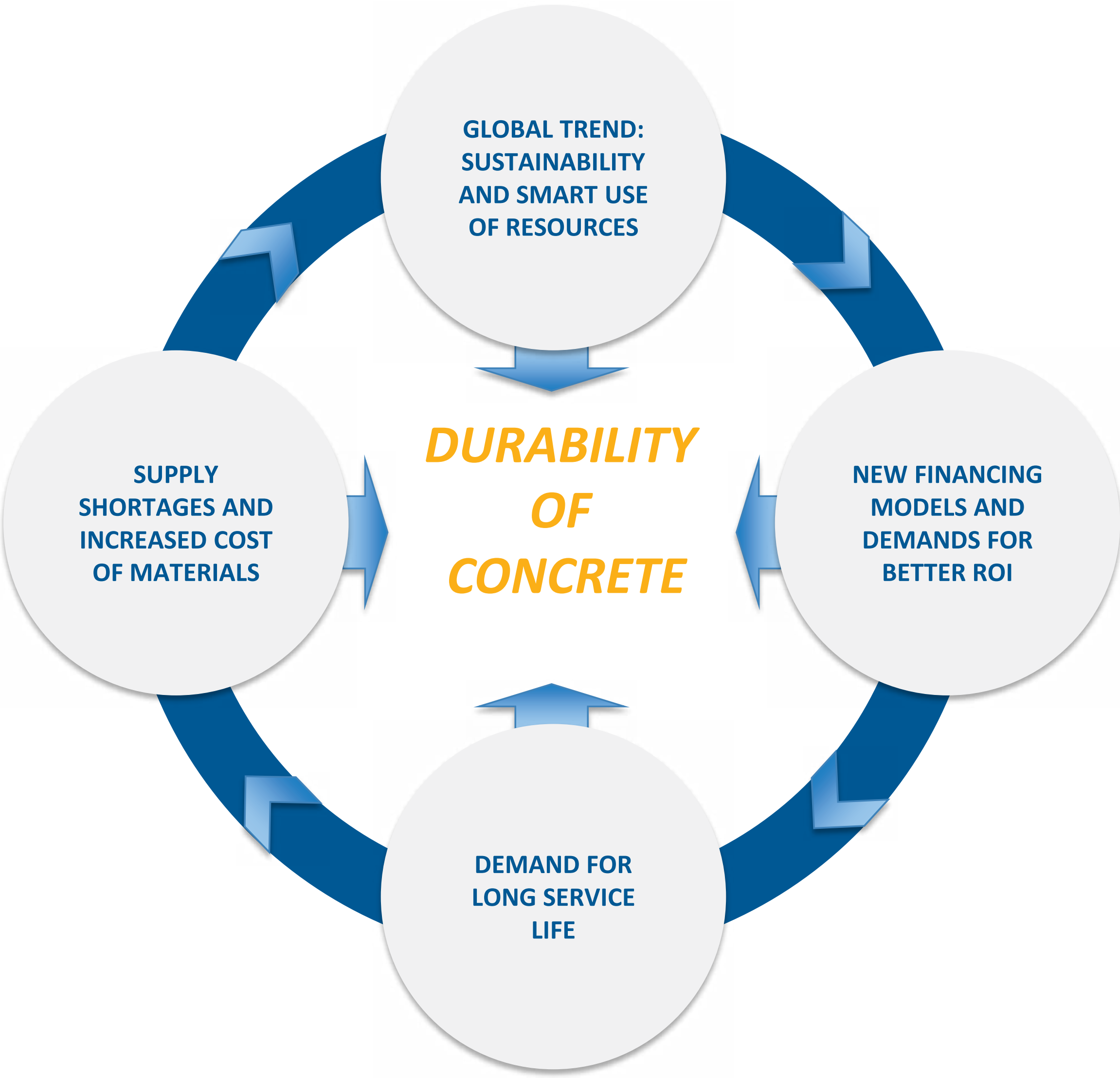


Attractive and stable structures

…and structures that can withstand high hydrostatic pressure

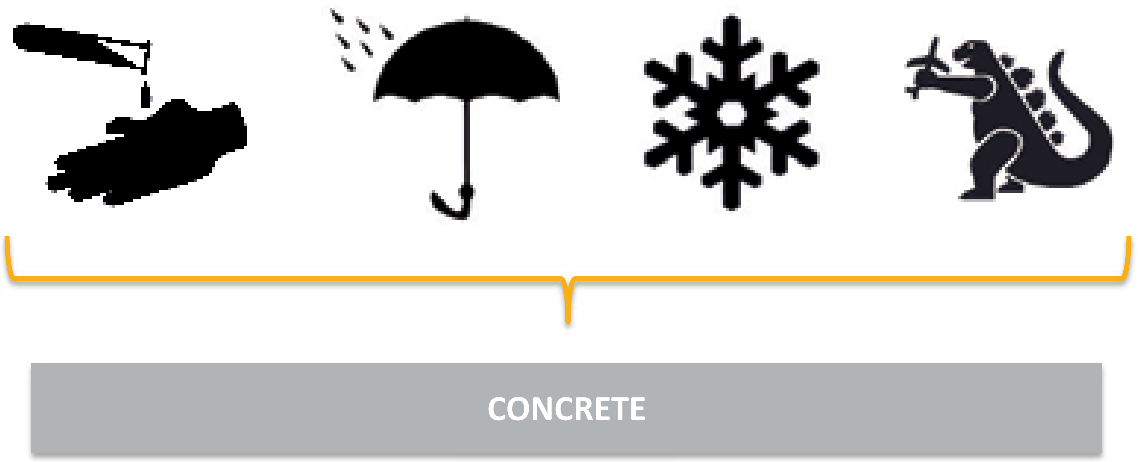
Design life vs. actual service life



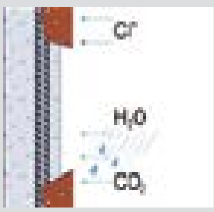
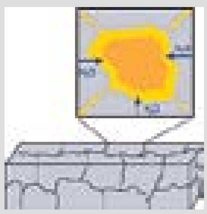
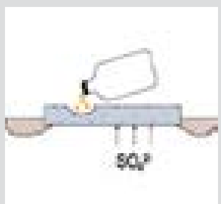

GLOBAL TREND: SUSTAINABILITY AND SMART USE OF RESOURCES
SUPPLY SHORTAGES AND INCREASED COST OF MATERIALS
DURABILITY OF CONCRETE
NEW FINANCING MODELS AND DEMANDS FOR BETTER ROI
DEMAND FOR LONG SERVICE LIFE

What is concrete durability?

"Durability of hydraulic cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment." *(ACI 201.2R-10)*

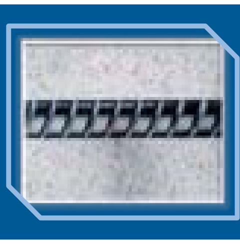


The main reasons for concrete deterioration

CORROSION OF REINFORCEMENT STEEL	FREEZING AND THAWING	CHEMICAL REACTIONS OF THE AGGREGATE (ASR/AAR)	CHEMICAL ATTACK
			

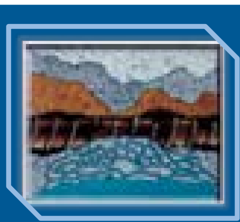
CORROSION

Strong in compression but weak in tension, concrete requires the use of reinforcement steel to stop it from disintegrating under pressure



However, through cracks, voids and pores, concrete allows **water** to penetrate and deliver corrosive chemicals that eventually attack the steel designed to strengthen it.

Once corrosion starts, it is difficult to determine the extent of the damage as it can occur anywhere along the network of steel reinforcement.



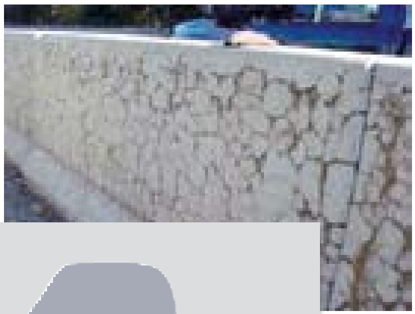
FREEZING AND THAWING

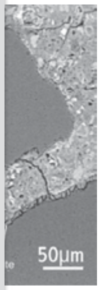
Under freezing conditions, **water** trapped inside concrete turns to ice and expands, creating cracks

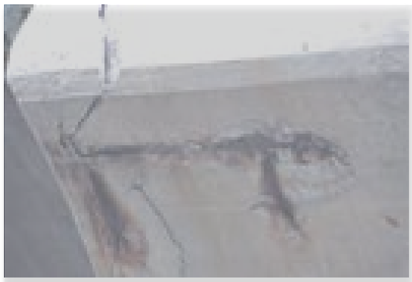
When the ice melts, the water travels yet deeper into the concrete, where the same freeze/thaw cycle is repeated

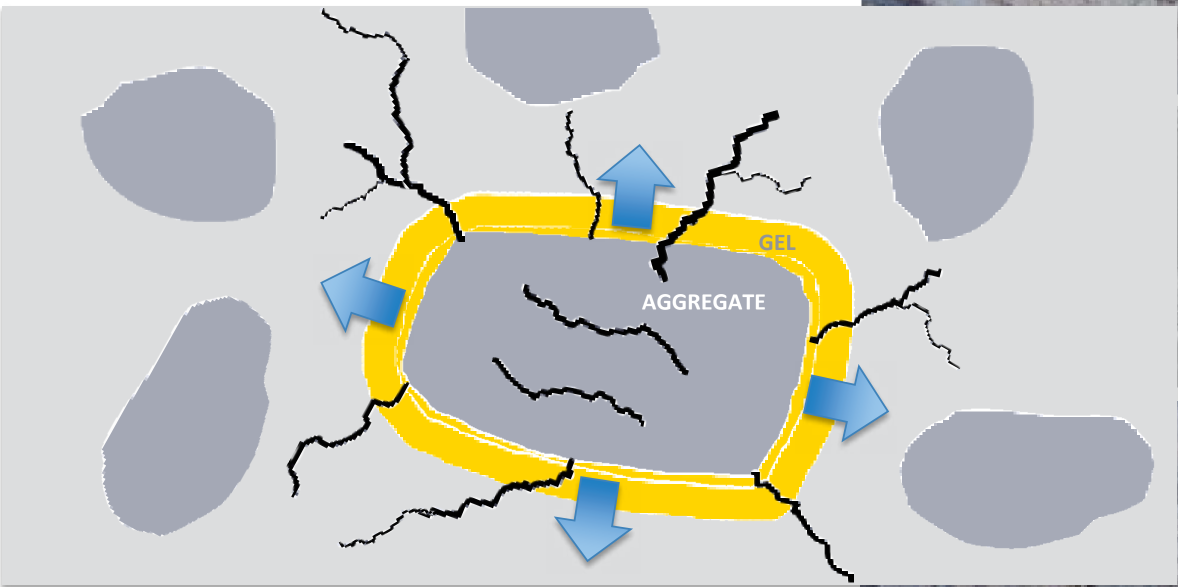
The use of road salts and other deicing chemicals only worsen the problem by introducing aggressive chemicals into the concrete

ALKALI-AGGREGATE REACTIONS (ASR/AAR)

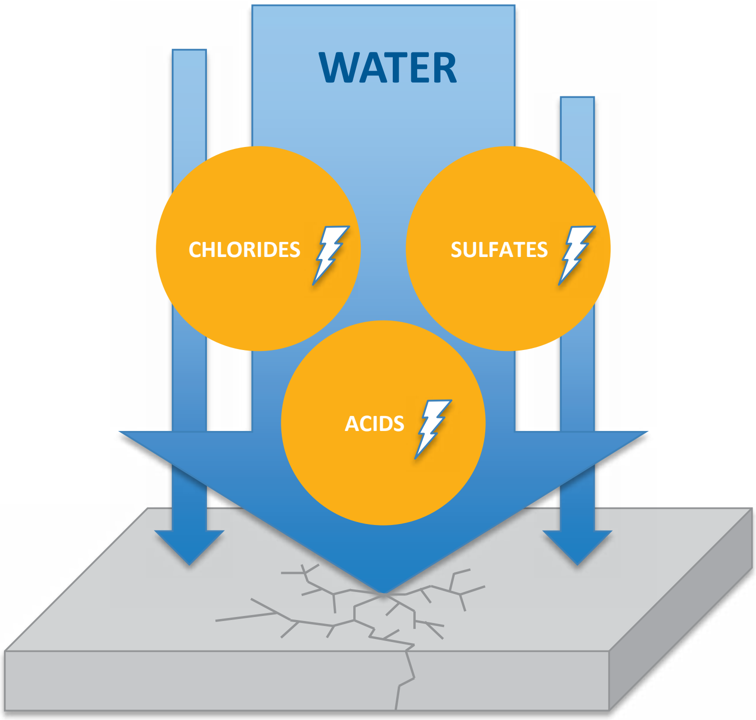


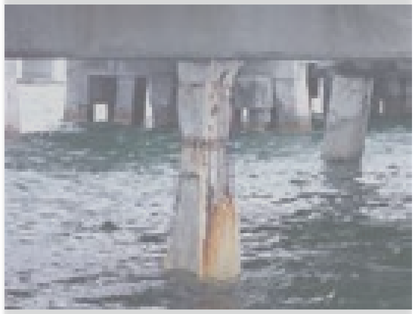






CHEMICAL ATTACK



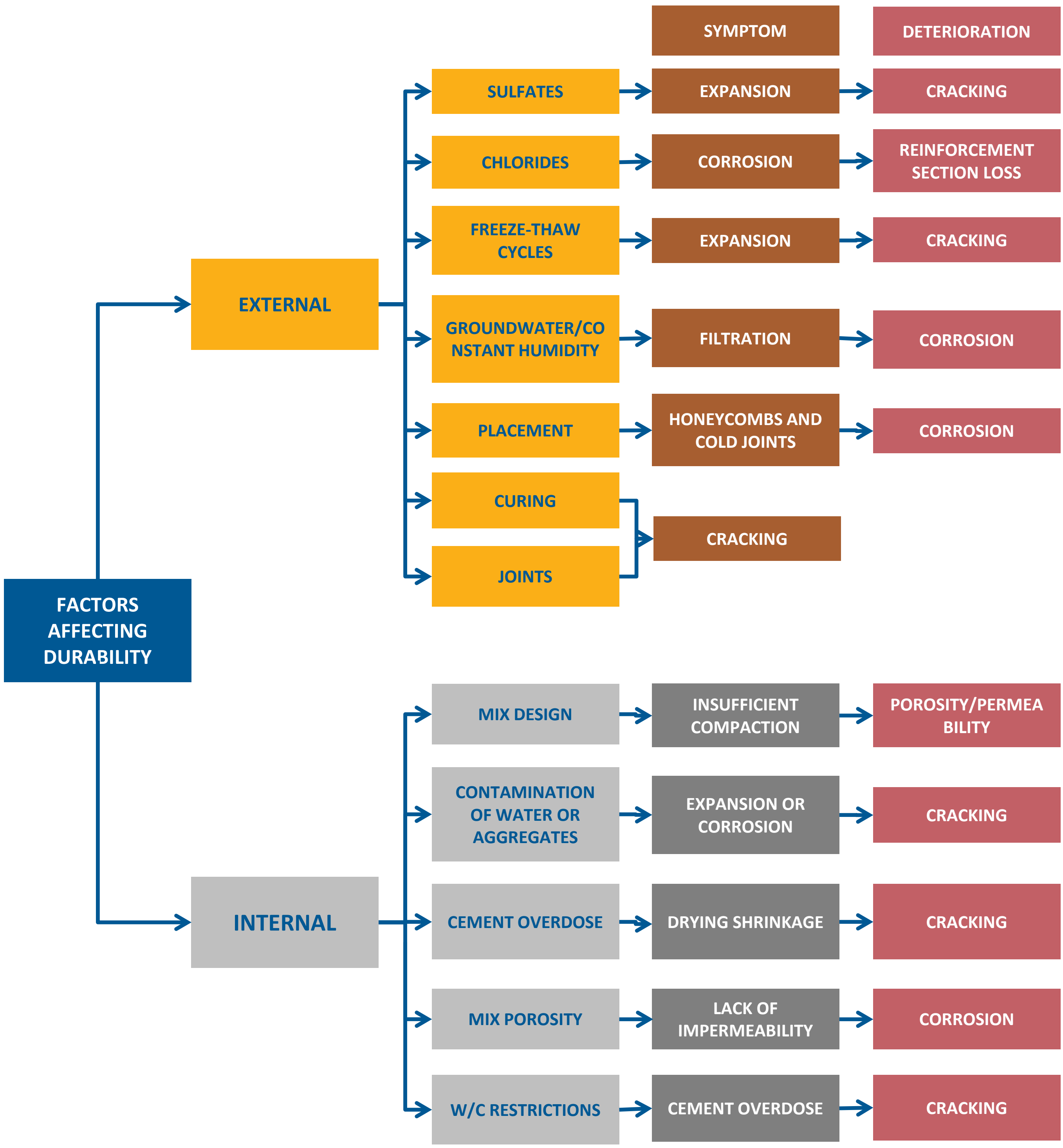


THE ROOT CAUSE OF CONCRETE DETERIORATION

WATER

INCREASE
IN CONCRETE DURABILITY/
SERVICE LIFE

Threats to durability
(internal vs. external)



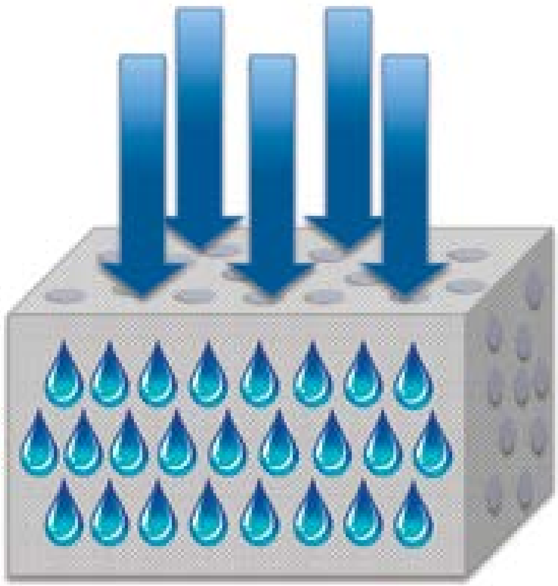
PERMEABILITY

Rate of flow of a fluid into a porous solid

Average Concrete is very porous due to shrinkage cracks, voids and capillaries

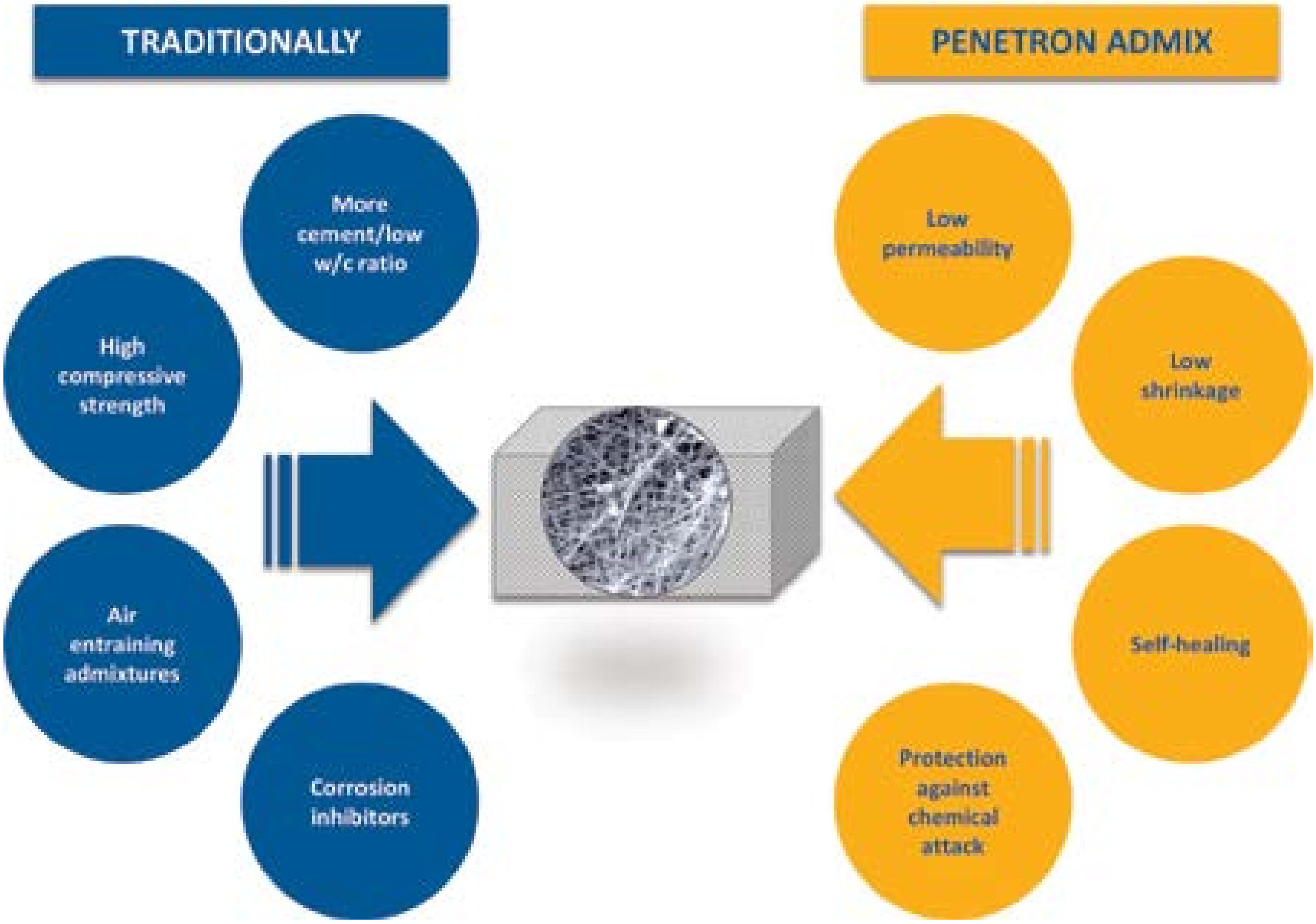
The better connected these voids are, the more permeable the concrete is and the easier it is for waterborne contaminants to enter the concrete.

REDUCTION OF PERMEABILITY



REDUCTION OF PERMEABILITY = INCREASE IN DURABILITY

ACHIEVING CONCRETE DURABILITY



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AMERICAN CONCRETE INSTITUTE REPORTS (ACI) ON CHEMICAL ADMIXTURES FOR CONCRETE

PENETRON INTERNATIONAL ANALYSIS

PENETRON®
TOTAL CONCRETE PROTECTION

ACI 212.3R-10

Report on Chemical Admixtures for Concrete

Reported by ACI Committee 212

American Concrete Institute®

ADMIXTURES, THEIR CHARACTERISTICS, AND USAGE

Admixture type	Effects and benefits	Materials
Air-entraining (ASTM C260 and AASHTO M154)	Improve durability in freezing and thawing, deicer, sulfate, and alkali-reactive environments. Improve workability.	Salts of wood resins, some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, tall oils and gum rosin salts, alkylbenzene sulfonates, salts of sulfonated hydrocarbons.
Accelerating (ASTM C494/C494M and AASHTO M194, Type C or E)	Accelerate setting and early-strength development.	Calcium chloride (ASTM D98 and AASHTO M144), triethanolamine, sodium thiocyanate, sodium/calcium formate, sodium/calcium nitrite, calcium nitrate, aluminates, silicates.
Water-reducing (ASTM C494/C494M and AASHTO M194, Type A)	Reduce water content at least 5%.	Lignosulfonic acids and their salts. Hydroxylated carboxylic acids and their salts. Polysaccharides, melamine polycondensation products, naphthalene polycondensation products, and polycarboxylates.
Water-reducing and set-retarding (ASTM C494/C494M and AASHTO M194, Type D)	Reduce water content at least 5%. Delay set time.	See water reducer, Type A (retarding component is added).
High-range water-reducing (ASTM C494/C494M and AASHTO M194, Type F or G)	Reduce water content by at least 12 to 40%, increase slump, decrease placing time, increase flowability of concrete, used in self-consolidating concrete (SCC).	Melamine sulfonate polycondensation products, naphthalene sulfonate polycondensation products, and polycarboxylates.
Mid-range water-reducing (ASTM C494/C494M, Type A)	Reduce water content by between 5% and 10% without retardation of initial set.	Lignosulfonic acids and their salts. Polycarboxylates.
Extended set control (hydration control) (ASTM C494/C494M, Type B or D)	Used to stop or severely retard the cement hydration process. Often used in wash water and in returned concrete for reuse, and can provide medium- to long-term set retardation for long hauls. Retain slump life in a more consistent manner than normal retarding admixtures.	Carboxylic acids. Phosphorus-containing organic acid salts.
Shrinkage-reducing	Reduce drying shrinkage. Reductions of 30 to 50% can be achieved.	Polyoxyalkylene alkyl ether. Propylene glycol.
Corrosion-inhibiting (ASTM C1582/C1582M)	Significantly reduce the rate of steel corrosion and extend the time for onset of corrosion.	Amine carboxylates aminoester organic emulsion, calcium nitrite, organic alkyidicarboxylic. Chromates, phosphates, hypophosphites, alkalis, and fluorides.
Lithium admixtures to reduce deleterious expansions from alkali-silica reaction	Minimize deleterious expansions from alkali-silica reaction.	Lithium nitrate, lithium carbonate, lithium hydroxide, and lithium nitrite.
Permeability-reducing admixture: non-hydrostatic conditions (PRAN)	Water-repellent surface, reduced water absorption.	Long-chain fatty acid derivatives (stearic, oleic, caprylic capric), soaps and oils (tallows, soya-based), petroleum derivatives (mineral oil, paraffin, bitumen emulsions), and fine particle fillers (silicates, bentonite, talc).
Permeability-reducing admixture: hydrostatic conditions (PRAH)	Reduced permeability, increased resistance to water penetration under pressure.	Crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer).
Bonding	Increase bond strength.	Polyvinyl chloride, polyvinyl acetate, acrylics, and butadiene-styrene copolymers.
Coloring	Colored concrete.	Carbon black, iron oxide, phthalocyanine, raw burnt umber, chromium oxide, and titanium dioxide.
Flocculating	Increase interparticle attraction to allow paste to behave as one large flock.	Vinyl acetate-maleic anhydride copolymer.
Fungicidal, cermicidal, insecticidal	Inhibit or control bacterial, fungal, and insecticidal growth.	Polyhalogenated phenols, emulsion, and copper compounds.
Rheology/viscosity-modifying	Modify the rheological properties of plastic concrete.	Polyethylene oxides, cellulose ethers (HEC, HPMC), alginates (from seaweed), natural and synthetic gums, and polyacrylamides or polyvinyl alcohol.
Air-detraining	Reduce air in concrete mixtures, cement slurries, and other cementing applications.	Tributyl phosphate, dibutyl phosphate, dibutylphthalate, polydimethylsiloxane, dodecyl (lauryl) alcohol, octyl alcohol, poly-propylene glycols, water-soluble esters of carbonic and boric acids, and lower sulfonate oils.

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CHAPTER 15—PERMEABILITY-REDUCING ADMIXTURES

15.1—Introduction

While it is generally accepted that well-proportioned and properly cured concrete produced using a low *w/cm* will result in a finished product with good durability and low permeability, no concrete structure is absolutely waterproof or "bottle tight" (Perkins 1986). Concrete is a porous material, and water can penetrate concrete through pores and microcracks due to capillary absorption (often referred to as wicking) or due to hydrostatic pressure. 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. The permeability of concrete is the movement of water due to a pressure gradient, such as water in contact with a concrete structure installed underground. In some cases, porosity may be exacerbated by external factors such as incomplete consolidation and curing, which may ultimately

- Hydrophobic or water-repellent chemicals are the largest group and include materials based on soaps and long-chain fatty acid derivatives, vegetable oils (tallows, soya-based materials, and greases), and petroleum (mineral oil, paraffin waxes, and bitumen emulsions). These materials provide a water-repellent layer along pores in the concrete, but the pores remain physically open;
- Finely divided solids include materials such as inert and chemically active fillers (talc, bentonite, silicious powders, clay, hydrocarbon resins, and coal tar pitches) and chemically active fillers (lime, silicates, and colloidal silica). Fine solids act as densifiers and physically restrict the passage of water through the pores. Some authors include SCMs in this category as well; and
- Crystalline materials consist of proprietary active chemicals provided in a carrier of cement and sand. The hydrophilic nature of these materials causes them to increase the density of calcium silicate hydrate (CHS) and/or generate pore-blocking deposits that resist water penetration.

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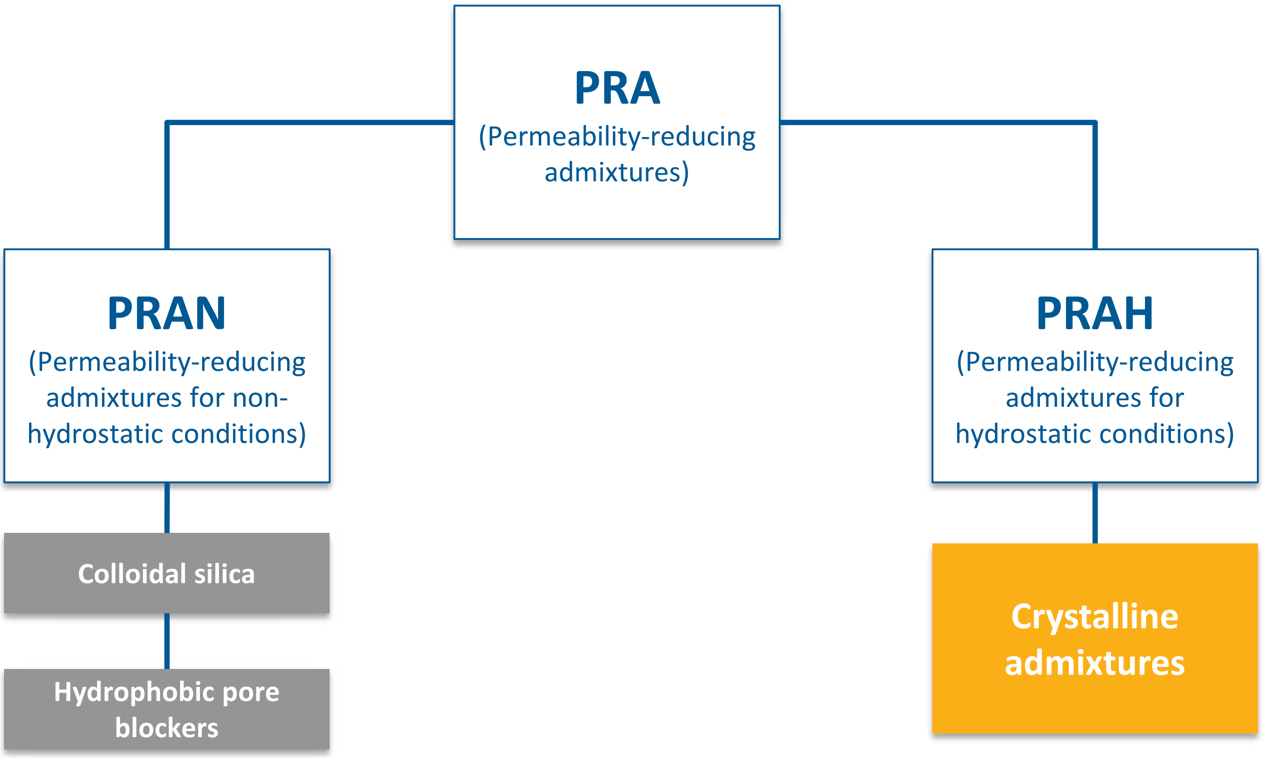
“ **In addition, a class of materials referred to as permeability-reducing admixtures (PRAs) has been developed to improve concrete durability through controlling water and moisture movement** (Roy and Northwood 1999) **as well as by reducing chloride ion ingress** (Munn et al. 2003) **and permeability** (Munn et al. 2005). ”



Only crystalline admixtures can be categorized as true PRAH

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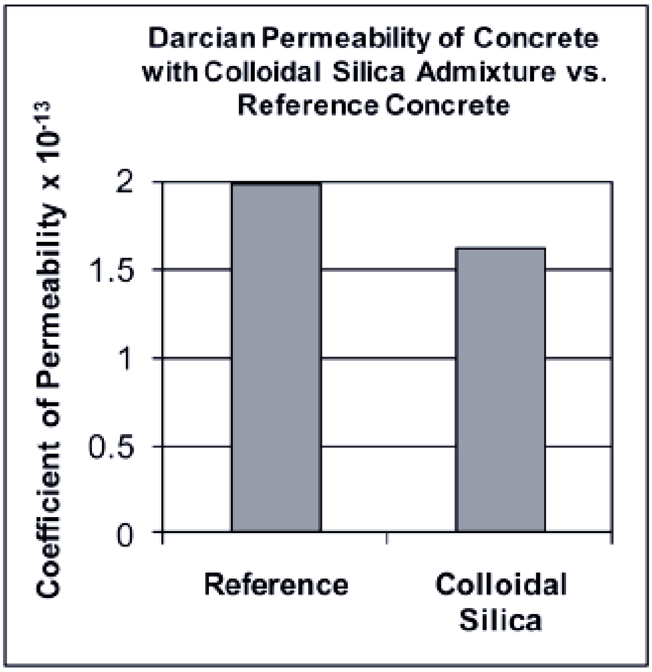

Fig 15.5—Reduction in permeability of concrete using PRAs. Tested using modified BS EN 12390-8. Pressure = 150 psi (1.0 MPa). Time = 96 hours

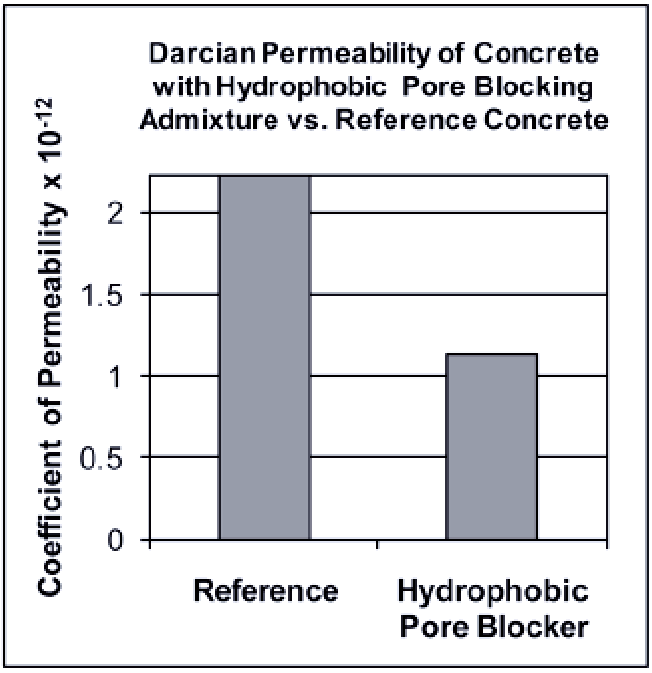

Fig 15.5—Reduction in permeability of concrete using PRAs. Tested using modified BS EN 12390-8. Pressure = 150 psi (1.0 MPa). Time = 96 hours

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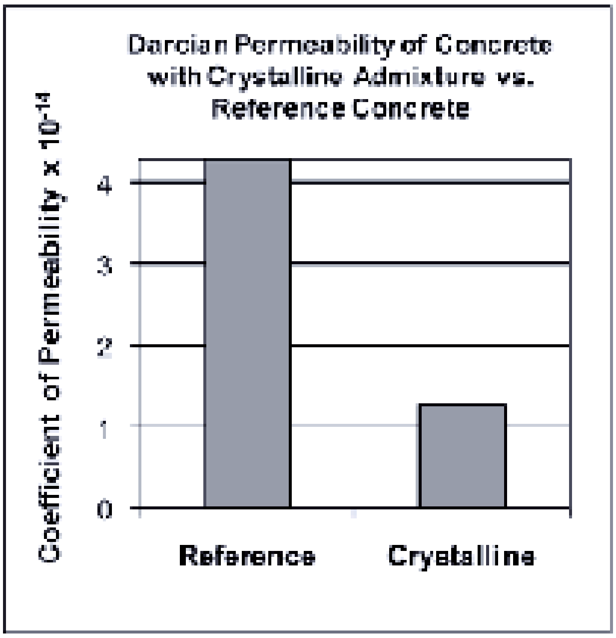

Fig 15.5—Reduction in permeability of concrete using PRAs. Tested using modified BS EN 12390-8. Pressure = 150 psi (1.0 MPa). Time = 96 hours

Report on Chemical Admixtures for Concrete (ACI 212.3R-10)

Table 15.1—Reduction in permeability of concrete using PRAs

Admixture type	Coefficient of permeability of reference concrete	Coefficient of permeability of test concrete	Percent reduction in permeability
Crystalline	4.29×10^{-14}	1.28×10^{-14}	70
Colloidal silica	1.98×10^{-13}	1.61×10^{-13}	19
Hydrophobic pore blocker	2.23×10^{-12}	1.14×10^{-12}	49

Crystalline admixtures are recommended to reduce concrete permeability and increase the durability of concrete.

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ADVANCED WATERPROOFING & PROTECTION SYSTEMS

Looking at the ACI 212.3R-10 Report on "Chemical Admixtures for Concrete"

The "Report on Chemical Admixtures for Concrete" published by the American Concrete Institute (ACI 212.3R-10 / January 2011) includes a chapter on permeability-reducing admixtures (PRAs). These PRAs (Permeability Reducing Admixtures) include a wide range of admixtures than can be used to reduce permeability in concrete. More specifically, it describes two PRA categories:

- **Permeability-Reducing Admixture for Non-hydrostatic conditions (PRAN)** – previously referred to as a "damp proofing admixture," where resistance to water under pressure is very limited and not suitable for concrete exposed to water under pressure

- **Permeability-Reducing Admixture for Hydrostatic conditions (PRAH)** – or a "waterproofing admixture" that is sufficiently stable to resist water under pressure and is used for watertight construction for tanks, foundations, and containment structures, etc.

In general, the performance of a permeability reducing admixtures depends on whether it is a PRAN or PRAH.

PRANs consist of either hydrophobic or water-repellent chemicals (soaps and long-chain fatty acid derivatives, vegetable oils and petroleum), finely divided solids (talc, bentonite, silicious powders, clay, hydrocarbon resins, and coal tar pitches) or chemically active fillers (lime, silicates, and colloidal silica). They are most widely used for damp proofing protection under non-hydrostatic conditions.

PRAHs include finely divided solids (such as colloidal silica), hydrophobic pore blockers and crystalline admixtures. However, finely divided solids, including colloidal silica, are typically used under non-hydrostatic conditions and only some of the polymer materials can be categorized as PRAHs. Hydrophobic pore-blocking materials are used only under non-hydrostatic conditions. Crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer) are only used in hydrostatic conditions.

Crystalline admixtures resist water penetration against hydrostatic pressure and have proven to be the most effective PRAH products with clear advantages over hydrophobic materials based on other mechanisms or polymer coalescence, or other fillers in terms of sealing cracks, long-term effectiveness, enhanced durability of the concrete structure, etc. Finally, they are able to bridge cracks formed by thermal or mechanical movement. Only crystalline admixtures can be classified as true PRAHs products. As described in the table on page 2 of the ACI 212.3R-10 document on admixtures ("Admixtures, their characteristics & usage"), only crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer) can be used in hydrostatic conditions.

Advantages of a PRAH

The proprietary active ingredients in a crystalline PRAH react with water and cement particles in the concrete to increase the density of calcium silicate hydrate (CHS) and/or generate pore-blocking deposits in the existing micro-cracks and capillaries to resist water penetration. As hairline cracks form over the life of the concrete, crystalline admixtures continue to activate in the presence of moisture, sealing additional gaps.

As noted in the ACI report: “To resist hydrostatic pressure, PRAHs employ a pore-blocking mechanism from crystalline growth, polymer coalescence, or other filler, although the ability to withstand hydrostatic pressure will depend on how completely the pores are blocked and the stability of the deposits under pressure. The distinction should be made based on the admixture’s demonstrated ability to reduce water penetration under the expected service conditions.” The pore-blocking mechanism is based on proprietary active chemicals blended with a mixture of cement and sand.

Because PRAHs based on polymer coalescence or other filler s are unable to withstand high hydrostatic pressure, they cannot be considered “true” PRAH admixtures. The pore-blocking mechanism in crystalline-based PRAHs is based on proprietary active chemicals blended with a mixture of cement and sand, which respond permanently and comprehensively to moisture and changes even when exposed to high hydrostatic pressure.

Unlike hydrophobic materials – such as the PRAN products discussed above – crystalline admixtures are hydrophilic. The crystalline deposits develop throughout the concrete, becoming a permanent part of the concrete mass when exposed to water. PRAHs make external water proofing membranes redundant, even for concrete under high hydrostatic pressure.

PENETRON® PRAH Technology: Testing Under High Hydrostatic Conditions

Similar to the general process described for crystalline PRAH admixtures above, the active ingredients in PENETRON ADMIX® react with the by-products of cement hydration in the presence of water in fresh and hardened concrete structures. These reactions extend hydration and form additional calcium silicate hydrate molecules along with insoluble crystals throughout the concrete matrix. These insoluble formations precipitate within the natural pores and capillaries of the concrete mix to dramatically reduce the permeability of the concrete.

When PENETRON ADMIX® is added to concrete during batching, the resulting crystalline lattice also permanently seals hair line cracks as they develop over the lifetime of the concrete.

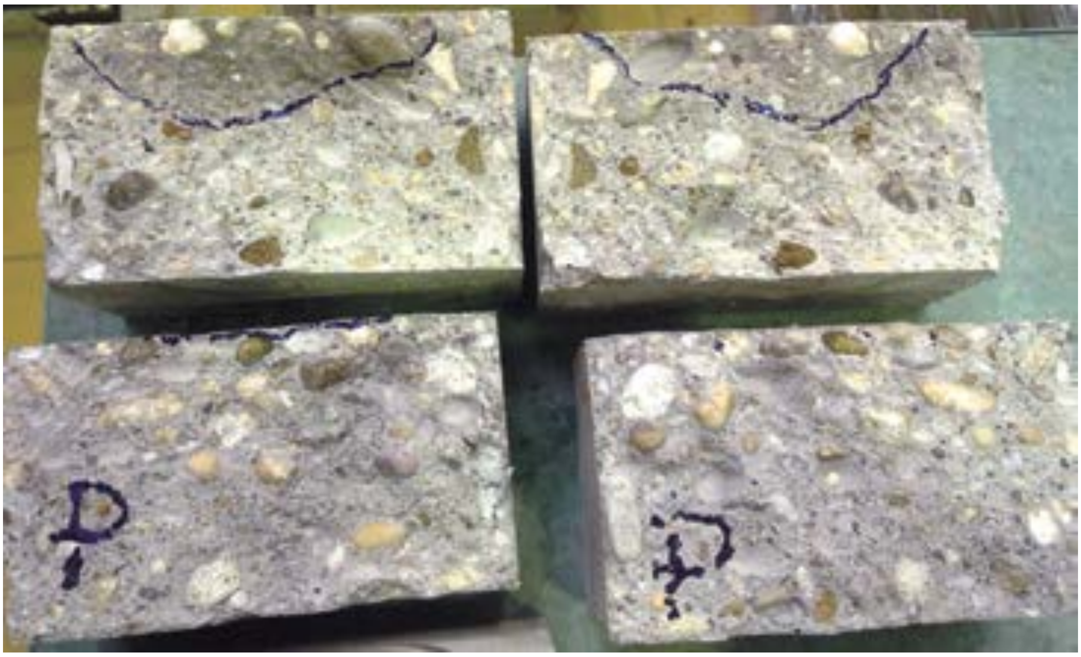
PENETRON products have been extensively tested in the laboratory under high hydrostatic conditions (including ASTM D5084, NBR 10.787/94, USAE CRD C48, BS EN 12390-8 and DIN 1048-5 Water Permeability). In these tests, the resulting crystalline lattice effectively reduces the permeability of the concrete samples when compared to the control samples; leakage in the treated concrete was eliminated, even when exposed to high hydrostatic test conditions.

The following examples show the improvements from the permeability-reducing reactions of PENETRON ADMIX® under high hydrostatic conditions.

Testing Water Penetration Under Pressure – NBR 10.787/94
101.5 psi (700 kPa) Head Pressure

After being exposed to a pressure of 101.5 psi (234.1 ft of head pressure) for four weeks, the PENETRON crystalline reaction had almost completely reduced concrete permeability and eliminated all leakage.

MSZ EN 12390-8:2009 (DIN 1048)



Samples treated with PENETRON ADMIX® (mar ked with a P) and two control samples are shown. All samples were exposed to a head pressure of 72.5 psi (500 kPa) for 72 hours. This photo was taken immediately after splitting the samples in half to measure the depth of water penetration. The PENETRON ADMIX® samples exhibited a 94.4% reduction in water penetration compared to the control samples.

Recent PENETRON® PRAH Projects

PENETRON®'s permeability reducing technology has been proven in demanding high hydrostatic conditions in the field with the highest success. Several recent projects highlight the effectiveness of PENETRON permeability reducing admixtures in high hydrostatic service conditions:

- *South Cobb Tunnel Lift Station* near Atlanta, GA
- *Tower Street Reservoir* – an eight-million gallon water holding tank in Harrisonburg, VA
- *National Road Bikeway Tunnel* near St. Clairsville, OH
- *Singapore Airport / Terminal 3*, Singapore
- *Gardens by the Bay*, Marina Bay, Singapore
- *Corredor Duarte*, Santo Domingo, Dominican Republic
- *Chennai International Airport*, India

South Cobb Tunnel Lift Station
This structure is a 212 ft (65 m) deep shaft that lifts sewage from over 32,000 LF of tunnels in Cobb County, GA. At these extraordinary depths, the design – a wet well within a dry well – required that the permeability of the concrete be extremely low to eliminate all concerns with leaking sewage from the wet well to the dry well (which is used by maintenance personnel). The ground water pressure at 212 ft elevations and the broken and shattered pieces of inconsistent bedrock were major water proofing concerns. PENETRON ADMIX® was specified as the PRAH for this project; over 20,000 cubic yards were treated and successfully water proofed.

Tower Street Reservoir
Located in Harrisonburg, VA, this new 8,000,000 gallon (30.000 m^3) concrete water holding tank replaced a leaking in-ground concrete-lined reservoir. Built by the Crom Corporation, the new tank features the permeability reducing benefits of PENETRON®'s integral crystalline waterproofing technology. Construction of the new tank incorporated a PENETRON ADMIX® Enhanced Shotcrete (PAES) application to protect the reinforcing steel embedded in the concrete shell and to eliminate all leakage from the over 70 ft (21 m) high structure. PENETRON ADMIX®'s ability to reduce concrete permeability under high hydrostatic conditions improved Harrisonburg's water distribution system by eliminating water leakage.

National Road Bikeway Tunnel Rehabilitation

Over 100 years old, the National Road Bikeway tunnel was plagued by groundwater infiltr ation and damage. First built in 1902 in an area of thinly bedded, faintly porous, weak shale with significant groundwater inflows, the main focus of the rehabilitation project was to control water infiltr ation and the subsequent ice build-up and damage. The ability of the PENETRON® technology to reduce the permeability of the new shotcrete liner, even against high hydrostatic head pressure, exceeded the design team's expectation. The ice and water infiltration problem was wholly eliminated.

Singapore Changi Airport /Terminal 3

More than an air transportation hub, the Changi Airport is a symbol of national pride and a benchmark for service excellence. Terminal 3 features innovative passenger facilities and modern architecture. 140,000 m³ of concrete was treated with PENETRON ADMIX®, along with PENETRON® slurry and PENECRETE MORTAR™.

Gardens by the Bay, Marina Bay

The distinctive waterfront gardens are an all-weather 'edutainment' space, an architectural icon, a horticultural attraction, and a showcase of sustainable energy technology – with large cooled conservatories replicating specific climates to house an uncommon range of flowers and plants. The project represented severe waterproofing challenges as it is built entirely on reclaimed land and right next to the ocean. 18,300 m^3 of concrete were cast with PENETRON ADMIX® in the base slab and walls; PENEBAR™ SW 55 was used in the construction joints and PENESEAL PRO® RTU on the mountain walls.

Corredor Duarte

The Corredor Duarte Tunnel, the newest tunnel in the Dominican Republic provides a rapid connection between Santo Domingo and the rest of the country. About 4,000 ft (1,200 m) in length, the tunnel plays a key role in relieving chronic traffic congestion in the capitol. A much thinner shotcrete layer was applied immediately behind the tunnel boring machine, creating a natural load-bearing ring and minimizing deformation of the surrounding layers of rock. PENETRON ADMIX® was used to reduce the permeability of the shotcrete walls. PENEBAR™ SW 55 was used to seal the concrete construction joints. In total, 45 tons of PENETRON ADMIX® and 2,300 m of PENEBAR™ SW-55 were used.

Chennai International Airport

Expanded and modernized to meet higher traffic demands, the Chennai International Airport expanded the international terminal, and added a new domestic passenger terminal, a multi-level car par king facility and a parallel runway to boost capacity to 16 million passengers a year. Located adjacent to the Bay of Bengal, the airport's fluctuating ground water levels (-10 m in summer and -3 m during monsoon) demanded thorough water proofing of all concrete structures and the concrete joints in the basement (10m deep). In total, 125 tons of PENETRON ADMIX® were used in the basement slabs and retaining walls; 15,000 m of PENEBAR™ SW 45 RAPID swellable-type water stops were used to prevent water ingress along the concrete joints.

PENETRON HELLAS
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GR 136 79 ACHARNES
TEL: +30 210 2448250 - FAX: +30 210 2476803
www.penetron.gr - info@penetron.gr

PENETRON ADMIX – THE WORLD'S ONLY THIRD GENERATION, CRYSTALLINE PRAH

A mixture of active ingredients in powder form that is added to the concrete to form an insoluble crystalline structure. The crystals form deep inside the concrete, sealing the pores, capillaries and shrinkage cracks from water penetration.

THE PENETRON® SYSTEM

Uses:

- Drinking water reservoirs
- Sewage and water treatment tanks
- Aquariums
- Tunnels
- Foundations
- Elevator shafts
- Underground vaults
- Industrial installations
- Parking decks
- Traffic-bearing structures
- Base slabs
- Diaphragm walls
- Basements
- Concrete roofs
- Bathrooms
- Any concrete structure requiring protection from water or aggressive chemicals

PENETRON®

Used for waterproofing and chemical protection above and below ground level. Applied in slurry form.

PENECRETE MORTAR®

Used for filling cracks and covers at joints, and to fill form-tie holes, honey-combed areas and routed out cracks in mortar consistency.

PENETRON ADMIX®

An additive mixed into new concrete at the time of batching for complete integral waterproofing.

PENETRON® PLUS

A dry shake, powder formulation used for horizontal surfaces and precast. It is a selected blend designed for ease of trowel-in application.

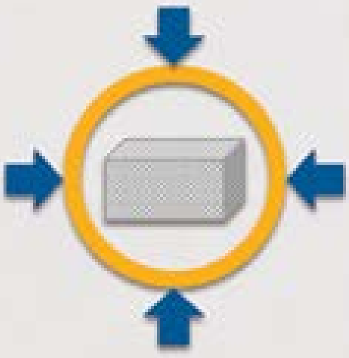
PENEPLUG®

Forms a rapid setting compound capable of stopping severe leaks under pressure.

PENETRON® INJECT

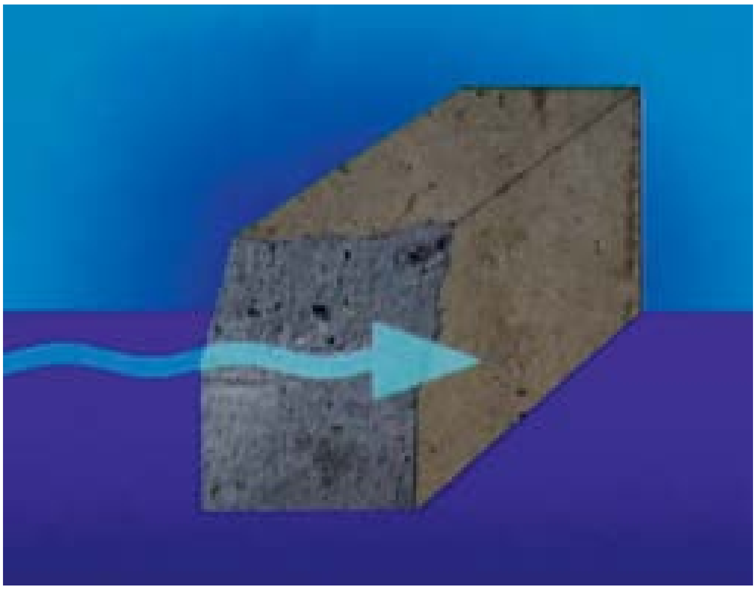
An advanced two component water cut-off injection grout, with integral crystalline waterproofing ability. It waterproofs concrete and rock, by filling and sealing cracks and fissures.

KEY FEATURES

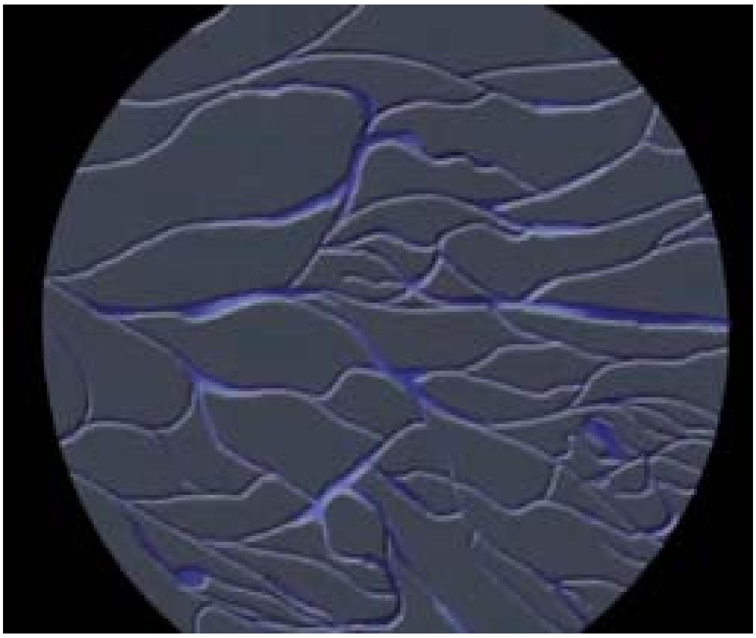


- Permanent dry concrete
- Self-healing throughout the service life
- Versatile, can be applied in different ways
- No known incompatibilities with workability admixtures
- Non-toxic
- Protects against chemical attack (pH 3-11)

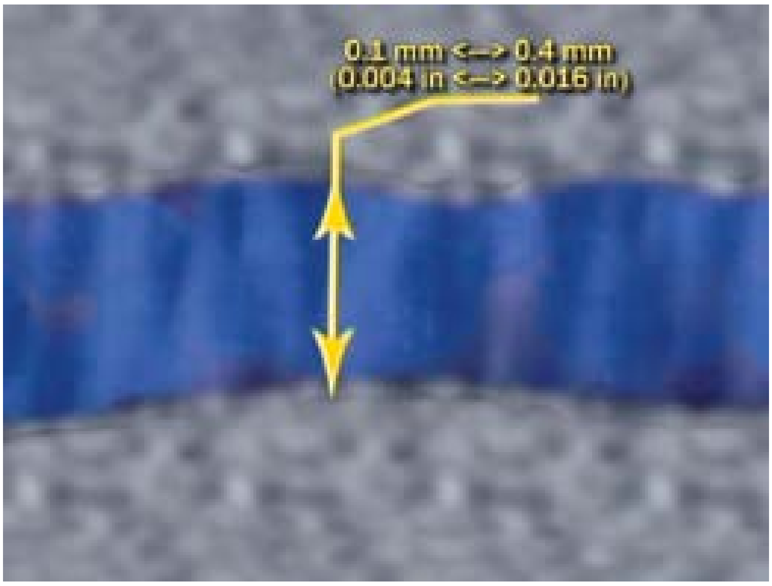
HOW DOES PENETRON ADMIX WORK?



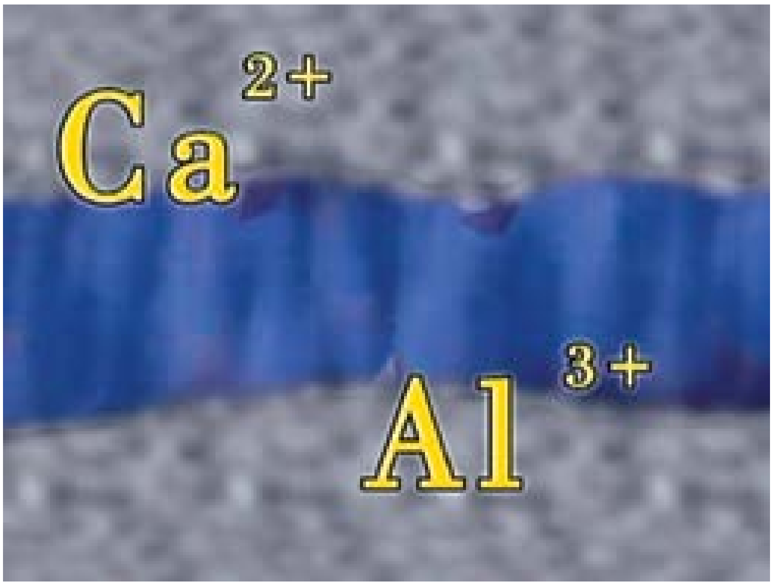
A conventional concrete matrix has a multitude of micro-cracks, pores and capillaries through which water enters the concrete



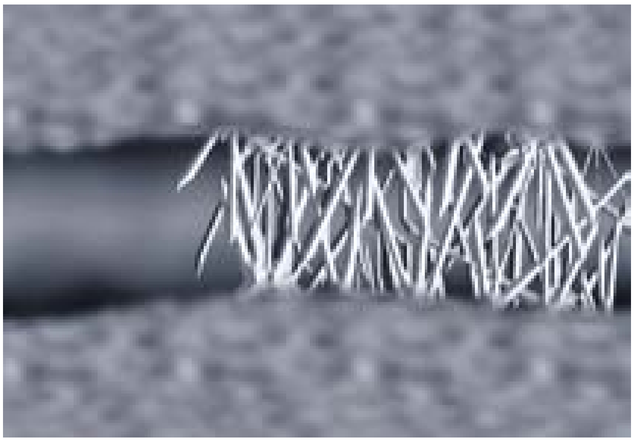
Water passes through the micro-cracks and capillaries in the concrete



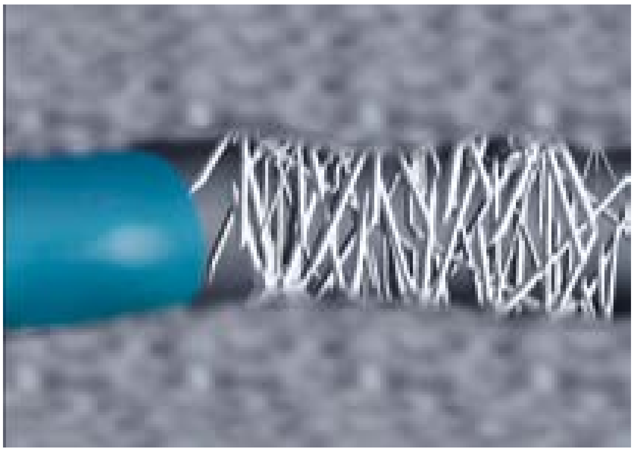
These pores typically have a width of between 0.1 – 0.4 mm



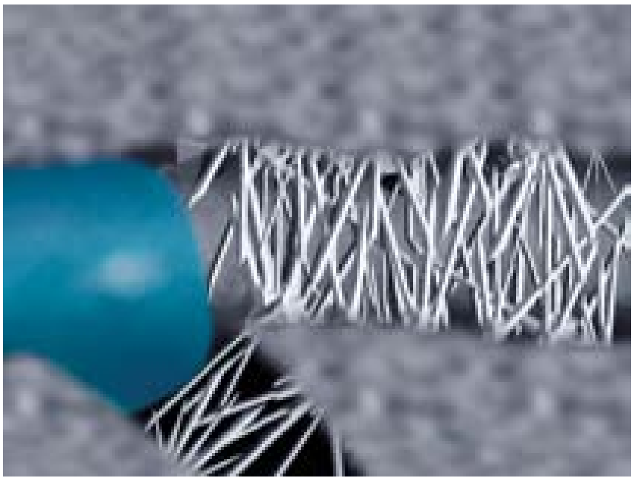
When Penetron Admix is added to the concrete, the crystalline components react with water, calcium hydroxide and aluminum as well as various other metal oxides and salts contained in the concrete



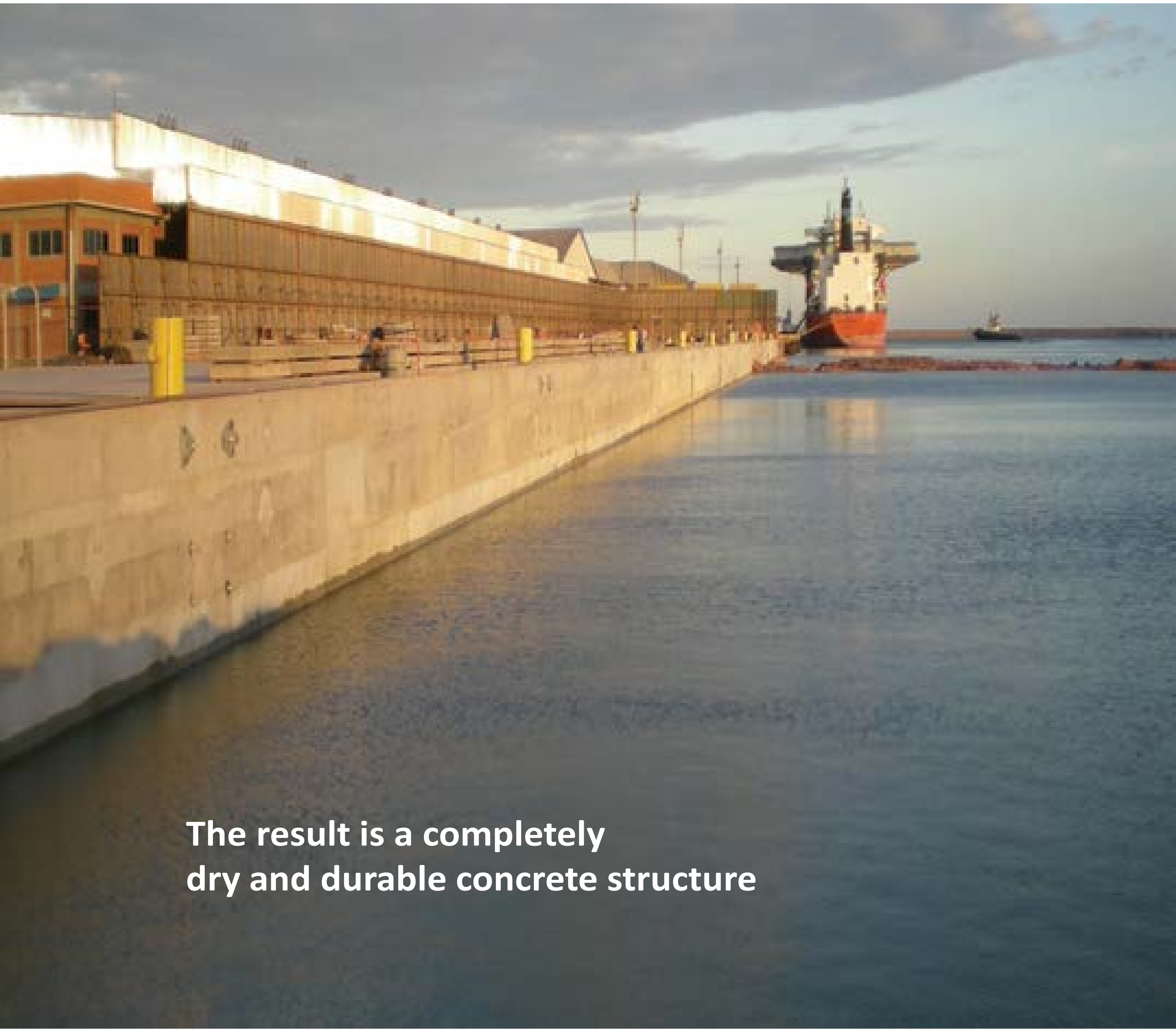
The chemical reaction that follows causes these voids and cracks to be filled with insoluble crystals



Water is unable to pass through these crystal formations, and as a result the concrete becomes impermeable



Should new cracks appear throughout the life of the concrete, crystals will appear in these cracks as well, preventing water from finding new ways to get through



PENETRON®

TOTAL CONCRETE PROTECTION

IPT
Instituto de Pesquisas Tecnológicas

Penetration of water under pressure – NBR 10.787/94 (April 2007)
Concrete: CPII-E 32
at
IPT (Technological Research Institute of São Paulo State), Brazil

Penetration of water under pressure – NBR 10.787/94 (April 2007)
Concrete: CPII-E 32

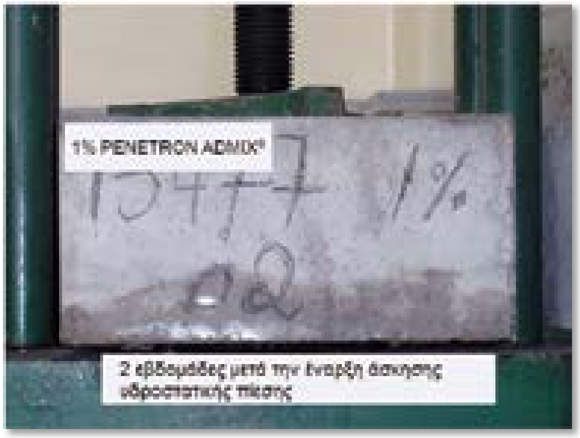
Applied water pressure:

- 1st and 2nd day: 0,1MPa
- 3rd day: 0,3MPa
- 4th to 7th day: 0,7MPa

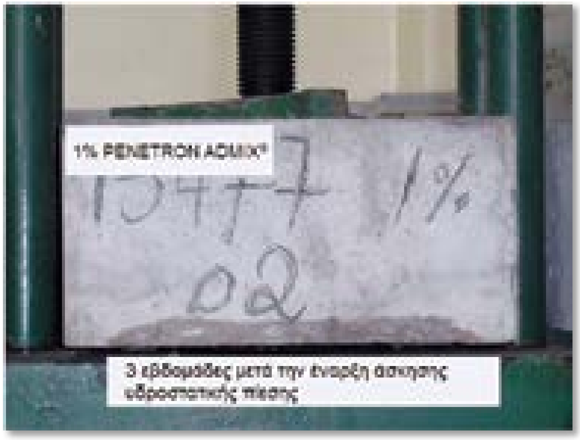
Item	Specification
Cement consumption CPII-E32	350kg/m^3
Compressive strength	20MPa
Fine sand	388kg/m^3
Course aggregate 0	421kg/m^3
Course aggregate 1	632kg/m^3
Water	192kg/m^3
Superplasticizer	0,3% to 0,4%/m^3
Slump test	90±10mm
w/c ratio	0,54
Penetron Admix	1% by weight of cement

Penetration of water under pressure –
NBR 10.787/94 (April 2007)
Concrete: CPII-E 32

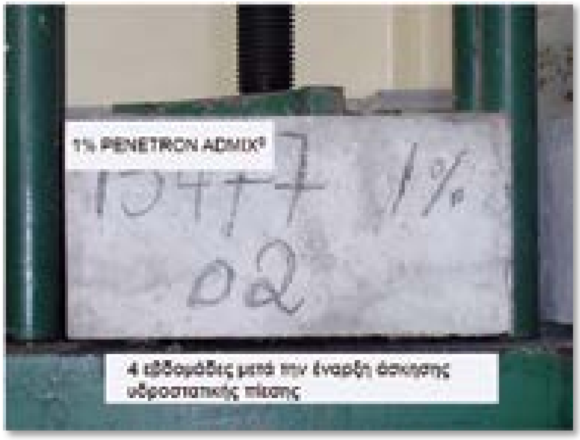
Penetration of water under pressure –
NBR 10.787/94 (April 2007)
Concrete: CPII-E 32



Penetration of water under pressure –
NBR 10.787/94 (April 2007)
Concrete: CPII-E 32



Penetration of water under pressure
– NBR 10.787/94 (April 2007)
Concrete: CPII-E 32



SELECTION OF PRAH

- 3rd generation product that has no negative effect on setting time and strength development of concrete
- Comes in powder form and can be dosed at 0.8-1% by weight of cement in the concrete mix
- No water/cement ratio limitations
- Has the ability to self-heal cracks up to 0.4mm
- Has a longstanding and worldwide track record and been used on major projects

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Long-term durability study on the effect of Penetron Admix on the lifetime of concrete

Compressive strength	Drying shrinkage
Permeability	Self-healing ability
Microscopic examination	Freeze-thaw cycle resistance
Sulfate resistance	Chloride diffusion

Service life estimation

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

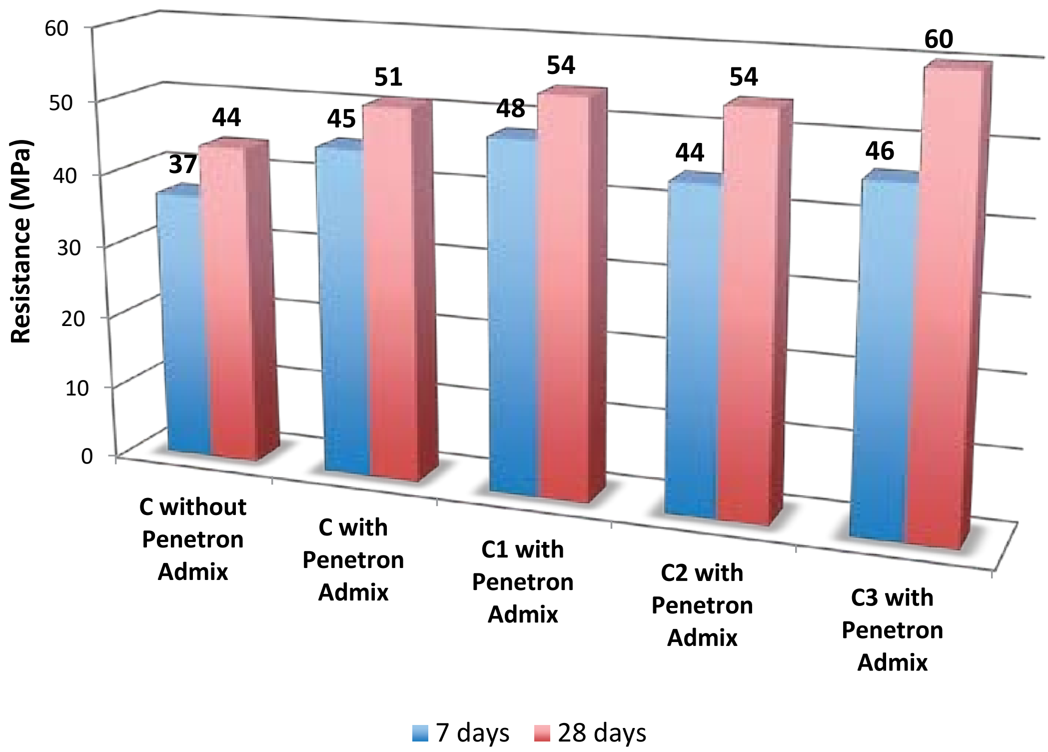
Tests and requirements to obtain high performance durable concrete

TYPE OF TEST	PROPERTY	STANDARD	REQUIREMENT
EXPOSURE TO FREEZE-THAW CYCLES	FREEZE-THAW RESISTANCE	BS 5075-2 or NCh 2185	≤ 0.05% CHANGE IN LENGTH BY EXPANSION.
EXPOSURE TO SULFATE ATTACK	EXPANSION DUE TO SULFATE EXPOSURE	ASTM C1012-13 and ASTM C1157	≤ 0.05% CHANGE IN LENGTH BY EXPANSION AT 6 MONTHS AND <0.10% AT 12 MONTHS
EXPOSURE TO CHLORIDE ATTACK	CHLORIDE DIFFUSION	ASTM C1556-04	YEARS OF SERVICE LIFE OF THE STRUCTURE BEFORE START OF CORROSION OF STEEL REINFORCEMENT.
MECHANICAL RESISTANCE	COMPRESSIVE STRENGTH	NCh 1017 and NCh 1037	> 30 MPa
LENGTH CHANGES DUE TO DRYING	DRYING SHRINKAGE	NCh 2221	< 0,8 mm/m per 1 YEAR.
PERMEABILITY	WATER PENETRATION RESISTANCE	DIN 1048	≤ 20 mm AVERAGE PENETRATION
CAPILLARY ABSORPTION	WATER ABSORPTION	ASTM C 1585, Manual DURAR CYTED.	COATING 3 cm, ≤ 5E-05 $m/s^{1/2}$ (SEVERE ENVIRONMENT)

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

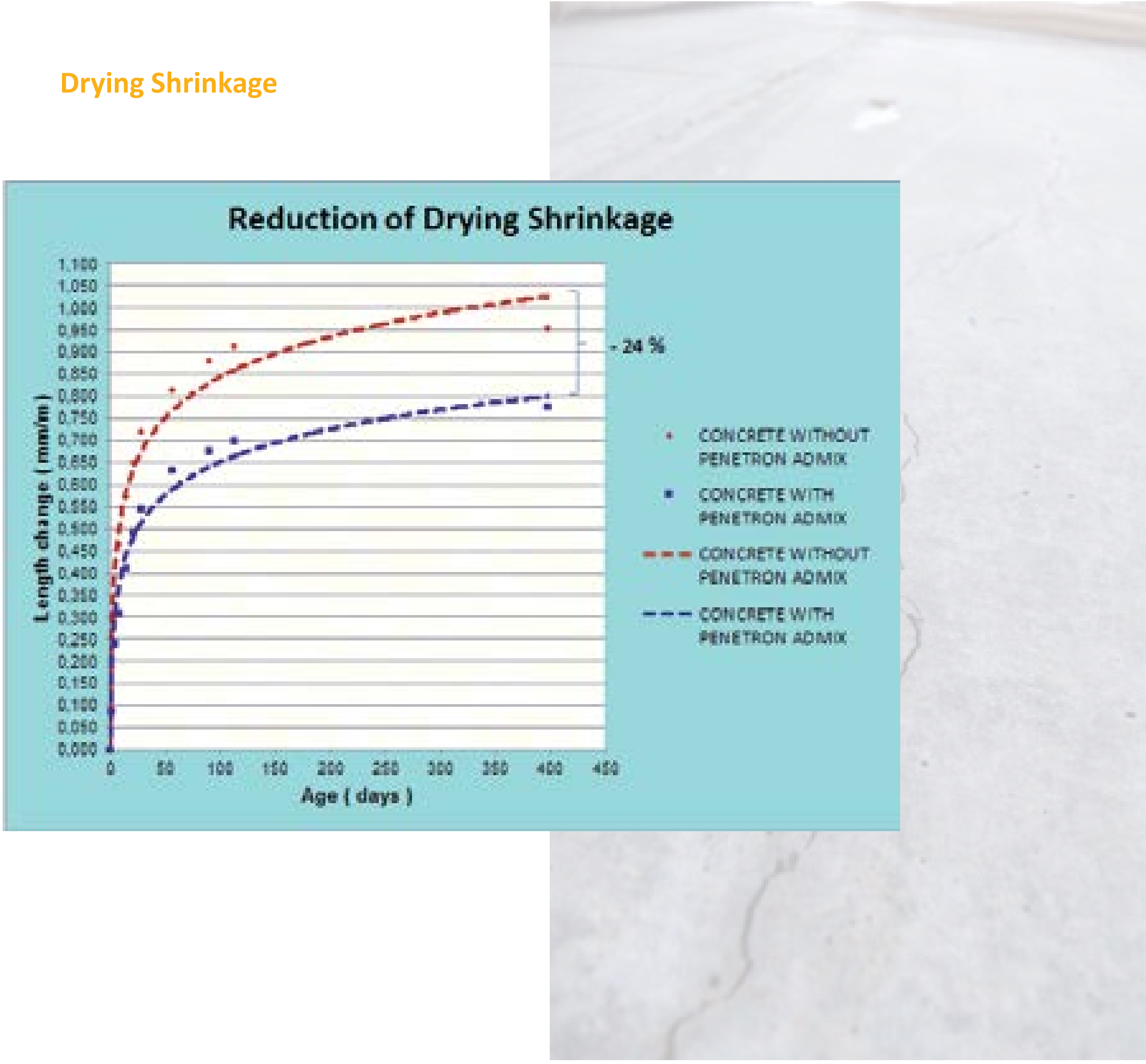
Concrete property testing	
Compressive strength	Drying shrinkage
Permeability	Capillary absorption
Self-healing ability	Microscopic examination

Compressive Strength



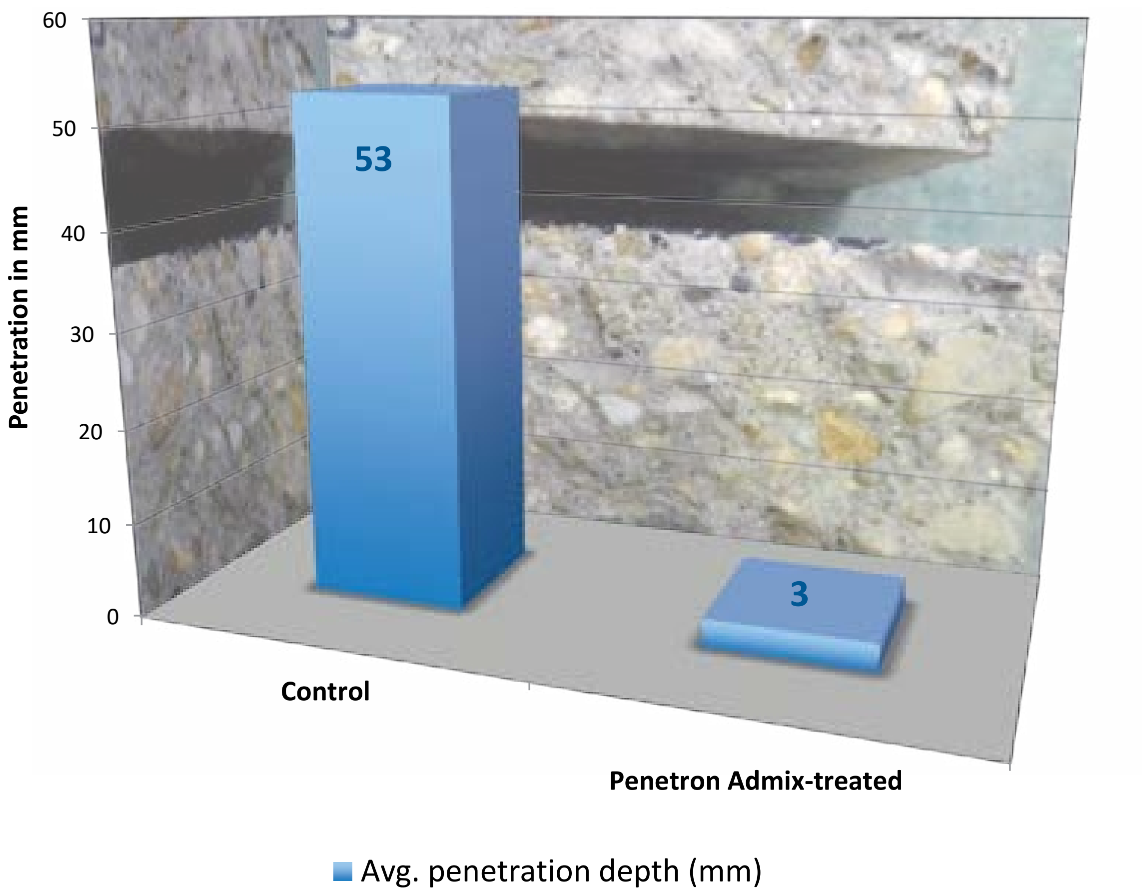
EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Drying Shrinkage



EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

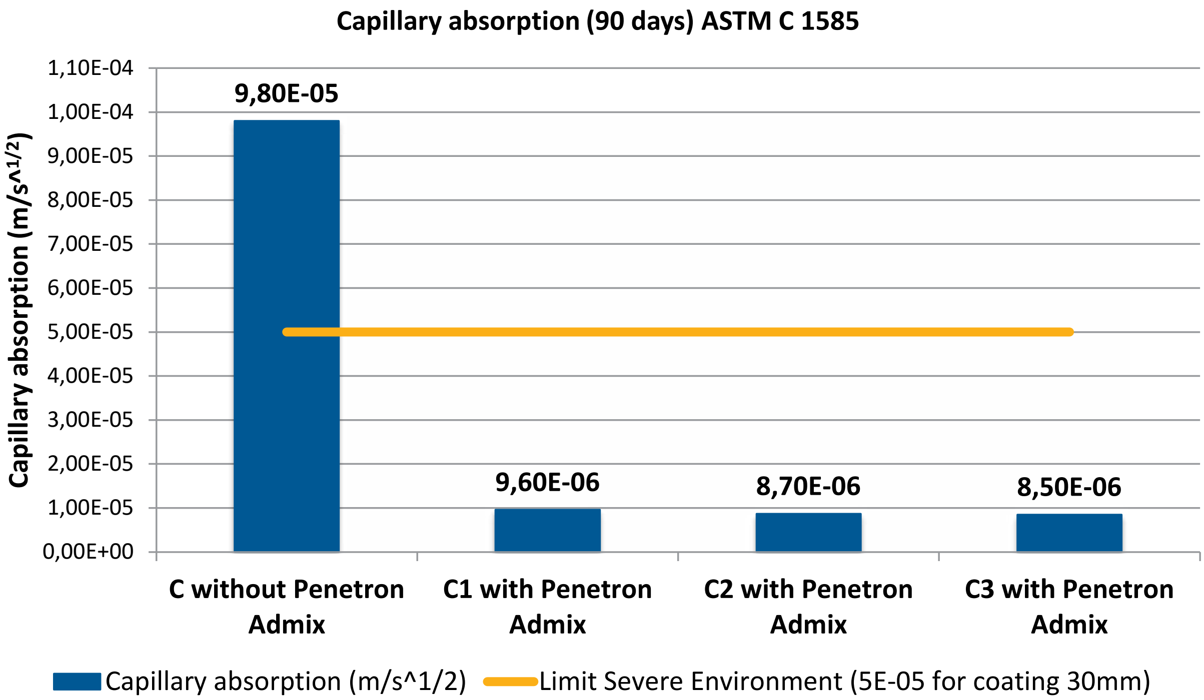
Permeability



DIN 1048 equivalent (MSZ EN 12390-8:2009)

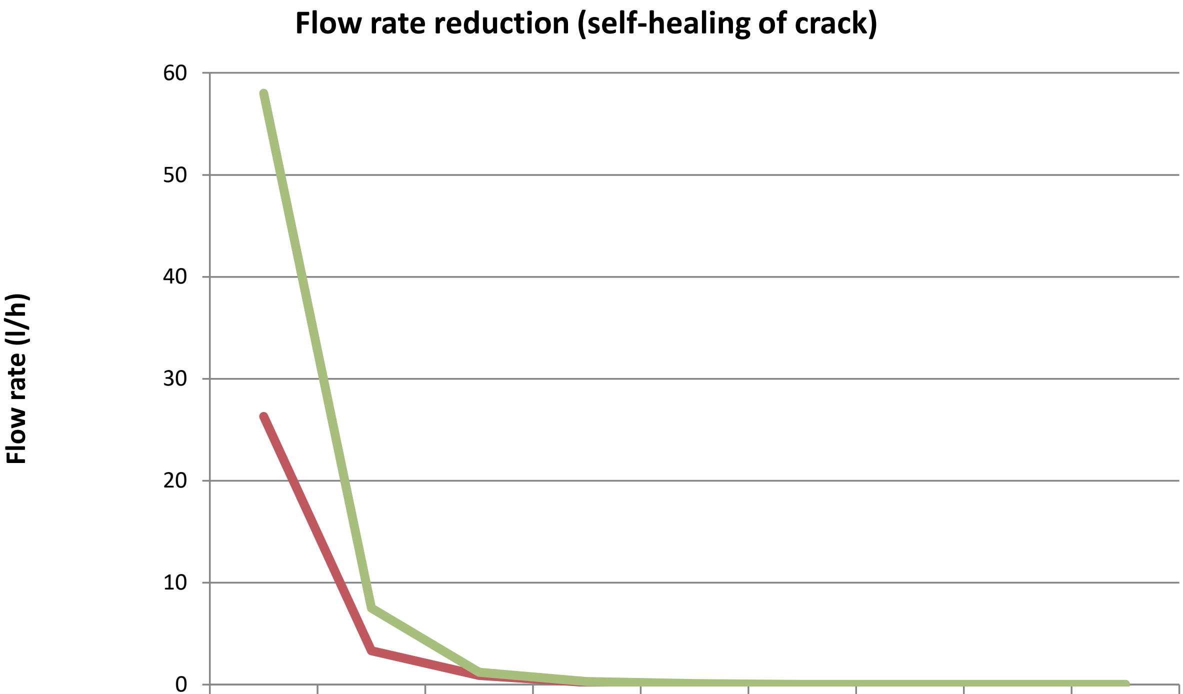
EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Capillary absorption



EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Self-healing abilities



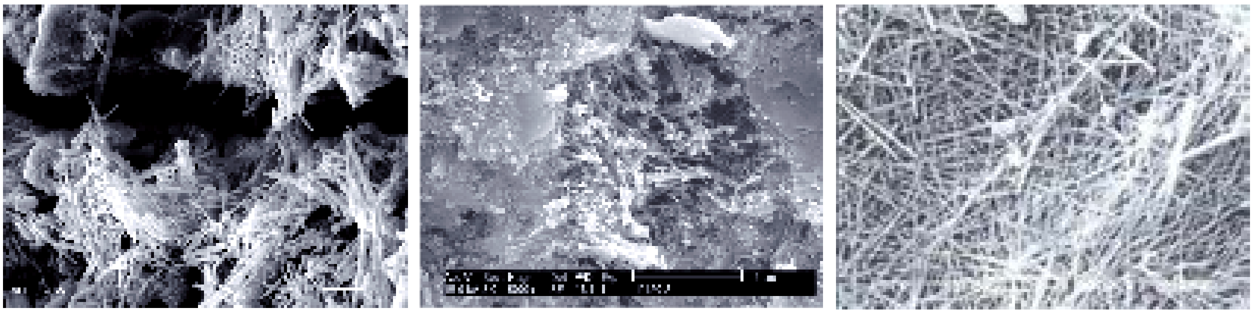
	1	5	8	13	15	21	29	36	39
Crack width 0.4mm	26,3	3,3	0,9	0,2	0	0	0	0	0
Crack width 0.5mm	58	7,5	1,2	0,3	0,1	0	0	0	0

Days

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Microscopic examination

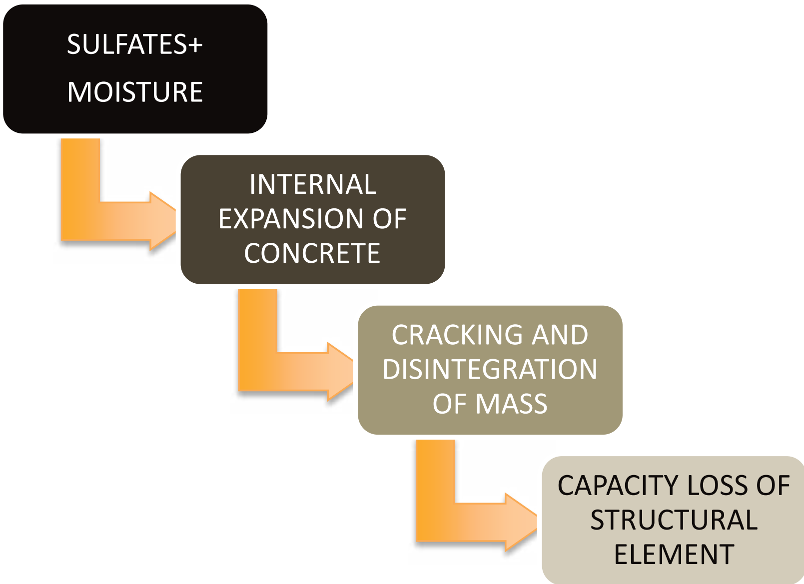
Control sample



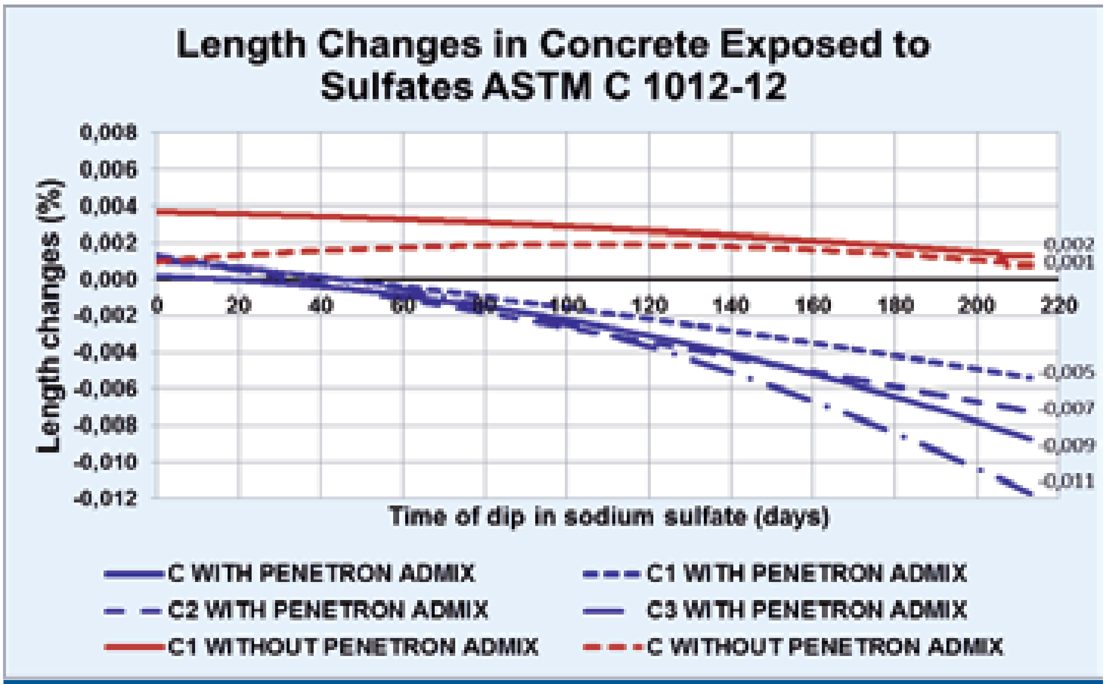
Concrete with Penetron Admix

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Process of deterioration initiated by sulfate attacks



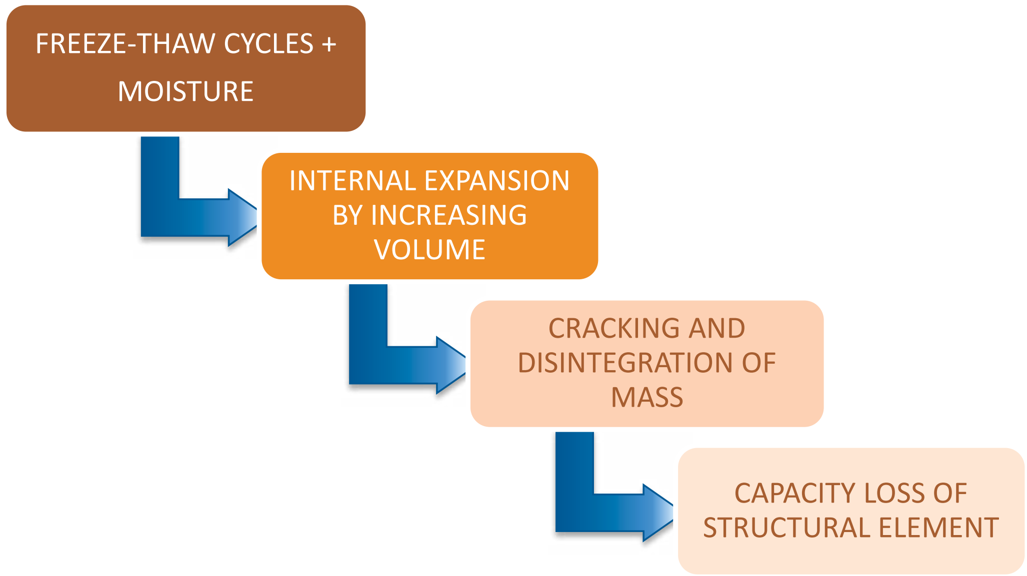
Sulfate Exposure



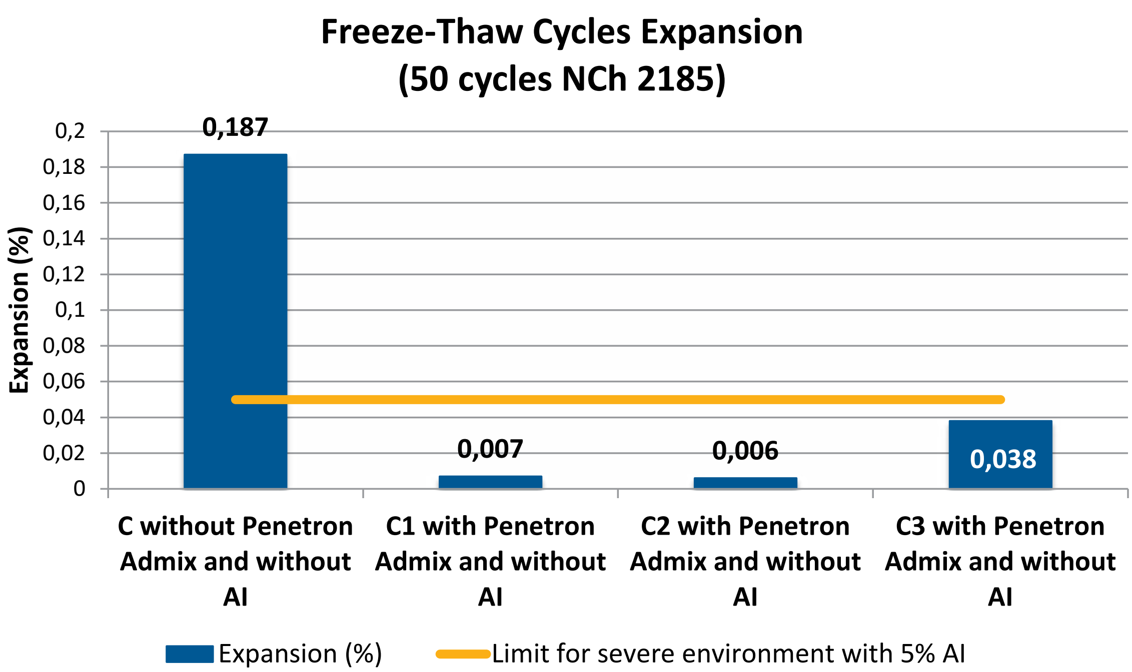
Sulfate exposure leads to cracking (due to expansion) in concrete without Penetron Admix. Treated concrete does not expand/crack and therefore prevents sulfates from entering.

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Process of deterioration initiated by freeze-thaw cycles

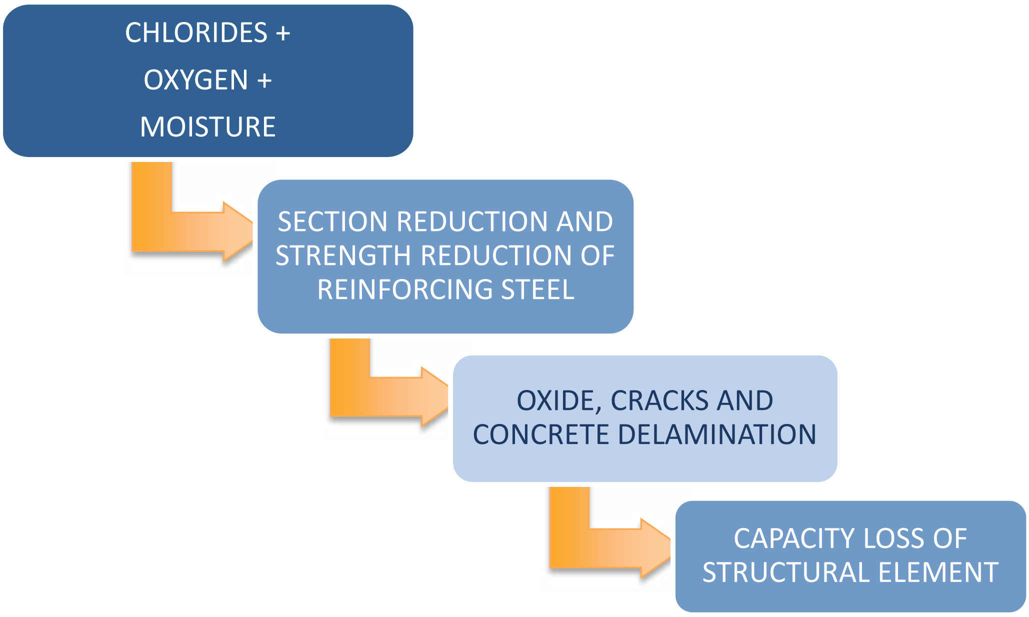


Exposure to Freeze-Thaw-Cycles



EFFECTS OF PENETRON ADMIX
ON THE LIFETIME OF CONCRETE

Process of deterioration initiated by chloride diffusion



Chloride Diffusion

Apparent chloride diffusion coefficient

CONCRETE	Time (days)	Initial Content Cl Cs (%)	Superficial Content Cl Cs (%)	Apparent Diffusion Coefficient Cl (m^2/s)
C without PA	35	0.023	1.084	7.20E-12
C1with PA	35	0.022	1.304	4.90E-12
C2 with PA	35	0.008	1.481	4.66E-12

C and C1: CEM II/B-P
C2: CEM II/B-S
PA: Penetron Admix

ASTM C 1556

EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Determination of concrete service life extension

The 2nd Fick Law of Diffusion

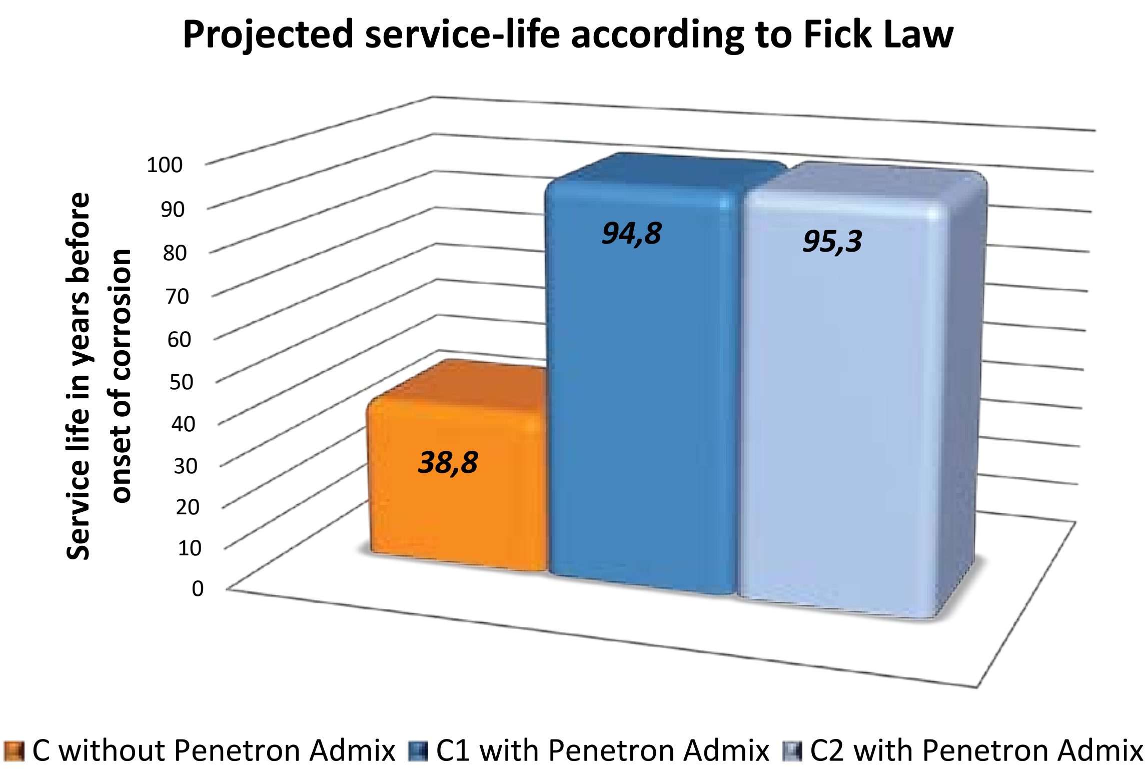
$$C(x,t) = Cs\left[1 - erf\left(\frac{x}{2\sqrt{D_c.t}}\right)\right] \qquad D_c(t) = D_0\left(\frac{t_0}{t}\right)^m$$

$C(x,t)$	Chloride ion concentration at a distance x from the surface of the concrete by an exposure period t (material mass %)
C_s	Chloride ion concentration on the surface of the concrete (material mass %)
x	Coating thickness (m)
t	Exposure time to chloride ion (years)
D_c	Chloride diffusion coefficient (m2 / s)
erf	Error function
$Dc(t)$	Chloride diffusion coefficient at time t (m2 / s)
D_0	Chloride diffusion coefficient at time t_0 (m2 / s)
t_0	Initial chloride diffusion time (years)

Property	C without Penetron Admix	C1 with Penetron Admix	C2 with Penetron Admix
Steel cover (m)	0.06	0.06	0.06
Chloride concentration: Surface, Cs (% mass)	1.53	1.30	1.48
Apparent diffusion coefficient, Da (m^2s)	7.20E-12	4.90E-12	4.66E-12
Diffusion coefficient corrected for age factor, D(t)(m^2/s)	3.22E-13	1.40E-13	1.33E-13
Error function, erf	0.967	0.962	0.966
Chloride concentration limit in concrete, $C_{(x,t)}$ (%)	0.05	0.05	0.05
Chloride concentration limit in concrete, (% rpc)	0.32	0.32	0.32
Service life structure, t (years)	**38.8**	**94.8**	**95.3**

EFFECTS OF PENETRON ADMIX
ON THE LIFETIME OF CONCRETE

Determination of concrete service life extension



EFFECTS OF PENETRON ADMIX ON THE LIFETIME OF CONCRETE

Benefit overview

Property tested	Benefits of concrete with Penetron Admix vs. concrete without PA	Additional benefits
Drying shrinkage (1 year length changes mm/m)	<24%	Less shrinkage cracking
Sulfate resistance changes (ASTM C1012-12)	No internal expansion	No cracking under sulphate attack
Chloride diffusion coefficient (m^2/s) (ASTM C1556-04)	<45%	Low chloride diffusion coefficient prolongs service life of the structure
Freeze-Thaw Cycle length changes (%) (NCh 2185 Of 92)	<10.53% *of control sample*	Eliminates need for air entrainment admixtures
Reduction of permeability (DIN 1048)	>91%	Activation of crystals reduces permeability
Crack width self-healing capacity	≤0.4mm	Self-healing of new cracks
Compressive Strength (Mpa)	>13%	Increases compressive strength
Extension of service-life (in years) (Fick Law)	up to 60 years *(compared to control sample)*	Eliminates need for corrosion inhibitors

PENETRON ADMIX is proven to significantly increase concrete durability/service life and is therefore recommended for **ALL** concrete applications that require an extended life span.

International Projects

Kuningan City, Jakarta, Indonesia

Sportshub, Singapore

Capri Residences, FL, USA

PENETRON

TOTAL CONCRETE PROTECTION

Portocel Aracruz, Brazil

Zipaquira Hospital, Colombia

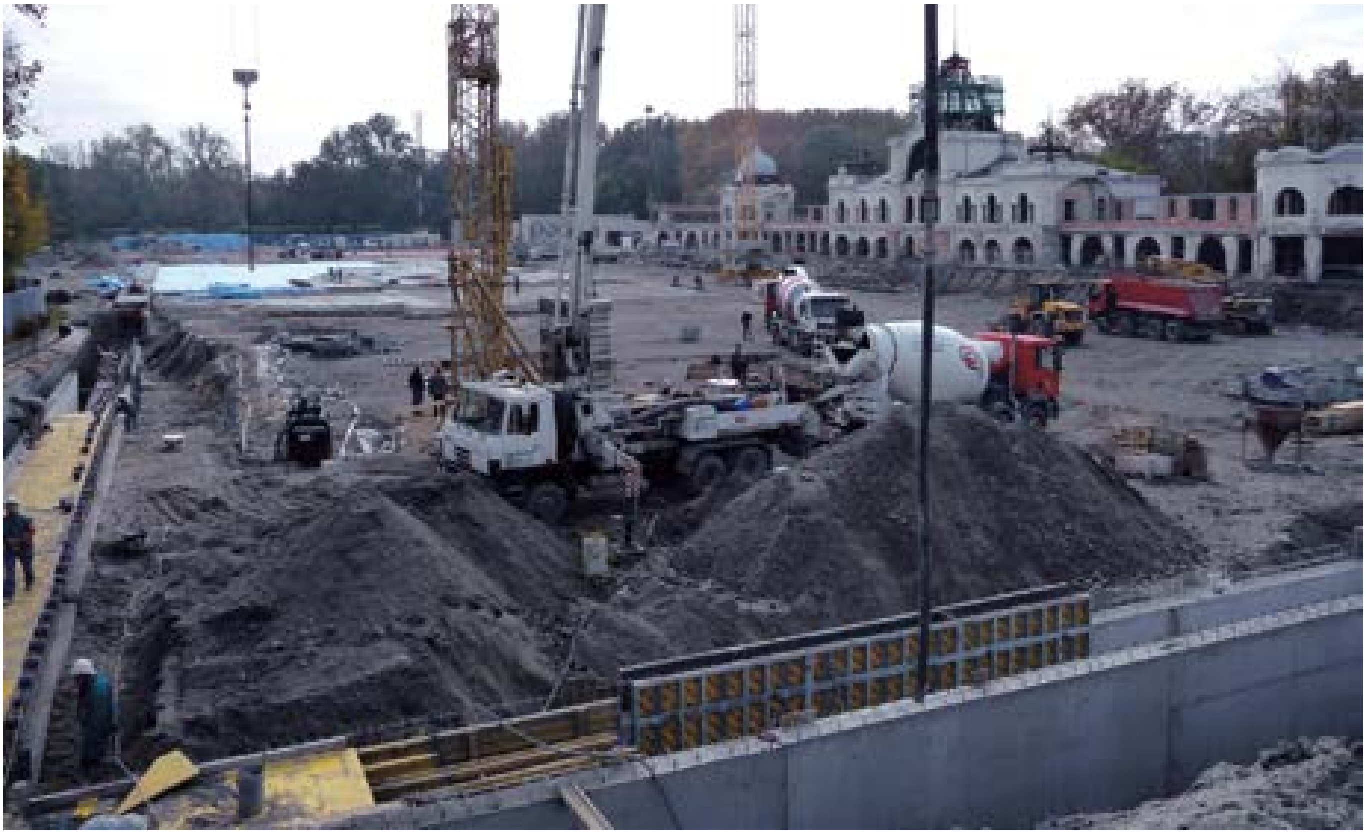
Arahova Conference Center, Greece

Changi Airport Terminal 3, Singapore

Chennai International Airport, India

Mumbai International Airport, India

Guarulhos International Airport, Sao Paulo, Brazil



City Park Budapest, Hungary

Talkatora Stadium, India (2010 Commonwealth Games)

Milan Sud, Sewage Treatment Plant, Italy

Green Point Stadium, Cape Town, South Africa

Gardens by the Bay, Singapore

The Troika, Malaysia

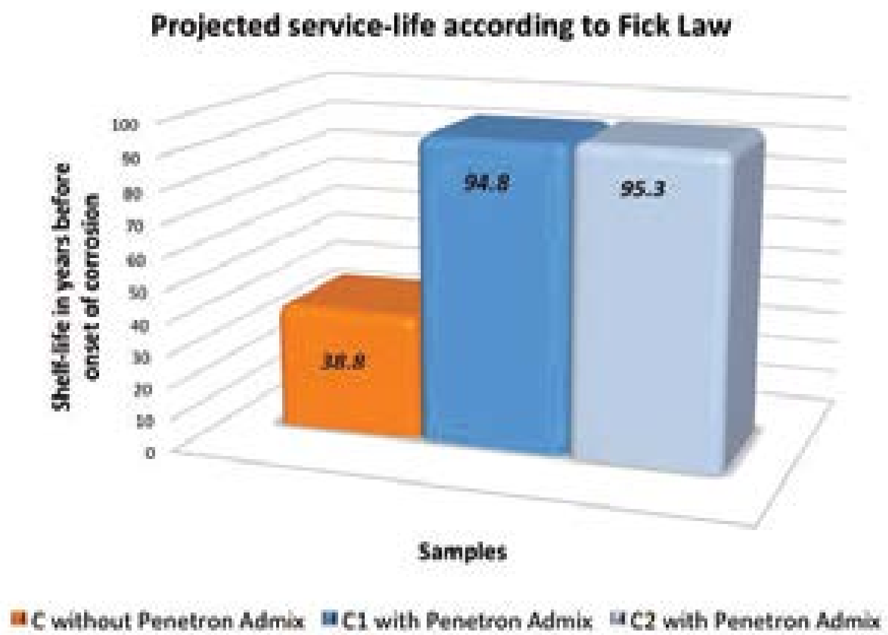
PENETRON INDUSTRY NEWSLETTER October 2014

Add 60 years to service-life of concrete in critical environments

Historically, the prime concern for concrete designers has been its resistance to mechanical stress, i.e. strength. In recent years, durability has emerged as equally important.

However, durability cannot be achieved with reducing the W/C ratio, high compressive strength, more cement, air-entraining admixtures or corrosion inhibitors alone.

To achieve concrete durability in critical environments, properties like low permeability, low shrinkage, self-healing and protection against chemical attack must be realized. **PENETRON ADMIX** incorporates the technology that provides such properties and recent testing has shown it can add up to 60 years or more to a variety of concretes, including CEM II /B-P, CEM II / B–S and CEM III/A, in critical environments before the onset of corrosion.



These results are in line with ACI report 212.R3-10, which concludes that crystalline admixtures are the best PRAH (permeability reducing admixtures for hydrostatic conditions) and increase durability of concrete.

Details of this durability testing are provided below.

Jozef Van Beeck
Director International Sales & Marketing

PENETRON ADMIX DURABILITY RESEARCH RESULTS

In order to establish the effect of **PENETRON ADMIX** on the durability of concrete, a complete research project was executed at leading independent laboratories over a 2-year period. The testing included compressive strength, drying shrinkage, permeability, sulphate resistance, chloride diffusion resistance, freeze-thaw cycle resistance, self-healing ability, microscopic examination of crystalline formation and most importantly – a resulting service-life estimation of concrete treated with PENETRON ADMIX.

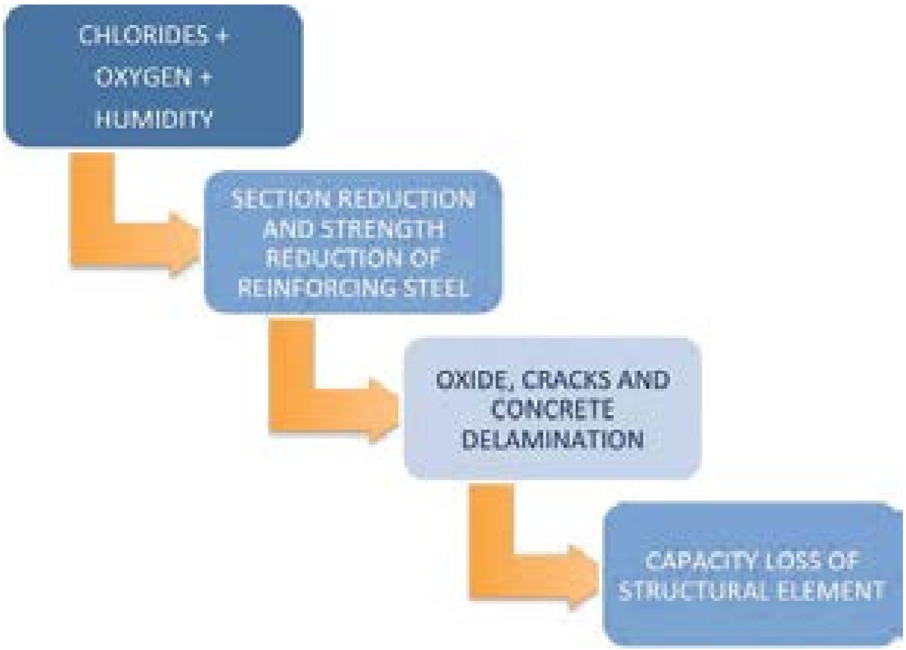
The results of this testing regime are summarized in the following table.

Property tested	Benefits of concrete with Penetron Admix vs. concrete without PA	Additional benefits
Drying shrinkage (1 year length changes mm/m)	<24%	Less shrinkage cracking
Sulphate resistance changes (ASTM C1012-12)	No internal expansion	No cracking under sulphate attack
Chloride diffusion coefficient (m^2/s) (ASTM C1556-04)	<45%	Low chloride diffusion coefficient prolongs service life of the structure
Freeze-Thaw Cycle length changes (%) (NCh 2185 Of 92)	<10.53% *of control sample*	Eliminates need for air entrainment admixtures
Reduction of permeability (DIN 1048)	>91%	Activation of crystals reduces permeability
Crack width self-healing capacity	≤0.4mm	Self-healing of new cracks
Compressive Strength (Mpa)	>13%	Increases compressive strength
Extension of service-life (in years) (Fick Law)	up to 60 years *(compared to control sample)*	Eliminates need for corrosion inhibitors

Each test result will be expanded upon in detail in these durability updates going forward – in this issue we will focus on the service-life estimation based on Chloride diffusion only.

SERVICE-LIFE ESTIMATION OF CONCRETE IN CRITICAL ENVIRONMENTS

The mechanism of concrete deterioration by chloride diffusion looks as follows.



Chloride diffusion testing performed according to ASTM C1556 yielded the following results, with and without PENETRON ADMIX.

Table 2. Apparent chloride diffusion coefficient

CONCRETE	Time (Days)	Initial Content Cl Ci (%)	Superficial Content Cl Cs(%)	Apparent Diffusion Coefficient Cl(m^2/s)
C WITHOUT PA	35	0,023	1,084	7,20E-12
C1 WITH PA	35	0,022	1,304	4,90E-12
C2 WITH PA	35	0,008	1,481	4,66E-12

C and C1: CEM II/B-P
C 2: CEM II / B-S
PA : PENETRON ADMIX

Using the **2nd Fick law of diffusion**, we can then estimate the service-life of concrete based on the chloride diffusion coefficient and the cover of steel, obtaining the following results.

$$C(x,t) = C_S\left[1 - erf\left(\frac{x}{2\sqrt{D_C \cdot t}}\right)\right] \qquad D_C(t) = D_0\left(\frac{t_0}{t}\right)^m$$

Property	C without Penetron Admix	C1 with Penetron Admix	C2 with Penetron Admix
Steel cover (m)	0.06	0.06	0.06
Chloride concentration: Surface, Cs (% mass)	1.53	1.30	1.48
Apparent diffusion coefficient, Da (m^2s)	7.20E-12	4.90E-12	4.66E-12
Diffusion coefficient corrected for age factor, D(t)(m^2/s)	3.22E-13	1.40E-13	1.33E-13
Error function, erf	0.967	0.962	0.966
Chloride concentration limit in concrete, $C_{(x,t)}$ (%)	0.05	0.05	0.05
Chloride concentration limit in concrete, (% rpc)	0.32	0.32	0.32
Service life structure, t (years)	38.8	94.8	95.3

Note: testing was done under exposure conditions conforming to ASTM C1556

This testing shows that, in an environment with chloride concentrations 4.7 times higher than true marine environments, PENETRON ADMIX treated concrete can add up to 60 years and more to the service-life of a conventional concrete, before the onset of corrosion.

A second chloride migration test in accordance with Nordtest, done on an extremely durable concrete mix design CEM III/A, still yielded another 40 years of service-life extension with PENETRON ADMIX.

CASE STUDY : SINGAPORE SPORTS HUB / NEW SINGAPORE NATIONAL STADIUM

Location: Kallang, Singapore
Date: 2014
Architect: AECOM / Arup Sport / DP Architects
Contractor: Dragages Singapore Pte. Ltd.

Singapore is now home to the world's largest dome structure

The Singapore Sports Hub, built on the original site of the National Stadium, has opened its doors on June 30, 2014 and is the country's new central sports destination.

Works on the site began in September 2010 after the demolition of the former Singapore National Stadium. The new facility includes a new 55'000 capacity National Stadium, a 3'000 capacity indoor Aquatic Centre with leisure facilities, a 3'000-capacity multi-purpose Indoor Arena, 41'000 square meters of commercial space and a Water Sports Centre on the shores of the Kallang Basin. This includes a Sports Promenade, the Singapore Sports Museum, the Sports Hub Library as well as the Kallang Wave Shopping Mall.

The Sports Hub's centerpiece is the new Singapore National Stadium. This landmark structure is currently the world's only multi-purpose arena with mechanized and automated retractable seating configurations on its lower tier. Within 48 hours the stadium can be reconfigured to host different events such as concerts, football and rugby matches, cricket and athletic events. The dome structure features a retractable roof, making the National Stadium an all-weather event facility.

Approved by the Singapore Environmental Council (SEC) with the Singapore Green Label, the PENETRON System was chosen to ensure the concrete durability on this iconic, green building development. PENETRON ADMIX was used on approximately 55'000 cubic meters of base slab and retaining walls. Penebar SW 55 waterstops were installed in over 18'500 meters of construction joints. In addition, 16'000 square meters of internal wet areas and exposed concrete including the RC roof were treated with Peneseal Pro.

The project is yet another milestone in PENETRON's long-standing track record of protecting Singapore's infrastructure.

PENETRON INDUSTRY NEWSLETTER

April 2015

Welcome to the 30th edition of the PENETRON Industry Newsletter.

In our previous concrete durability update, we highlighted how PENETRON ADMIX increases the service life of concrete structures in critical environments by 60 years and more. This life-extension capacity was established by means of the treated concrete's chloride diffusion coefficient and the 2nd Fick law. (read here)

In this issue, we will expand on another aspect of concrete durability -- its ability to resist sulfate attack. Extensive testing has shown that concrete treated with PENETRON ADMIX is virtually resistant to sulfate attack.

Further, we discuss how concrete durability should be tested. Too often, traditional testing methods (such as surface water absorption testing) are being used to test advanced hydrophilic protection systems, which leads to the wrong conclusions. Permeability testing is the only way to verify a true PRAH's (Permeabiity Reducing Admixture for Hydrostatic conditions) performance.

Last but not least, we invite you to have a look at some recent PENETRON projects in Norway, USA, Saudi Arabia and the UAE.

Jozef Van Beeck
Director International Sales & Marketing

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sulfate attack

PRAN vs PRAH / absorption versus permeability

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Kempinski Hotel Jeddah, Saudi Arabia

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PENETRON ADMIX durability research: Resistance to sulfate attack

Sulfate attack typically occurs where water containing dissolved sulfate penetrates the concrete. The ensuing reaction causes the composition and microstructure of the concrete to change. These changes include extensive cracking and loss of bond between the cement paste and aggregate, which in turn cause an internal expansive force.

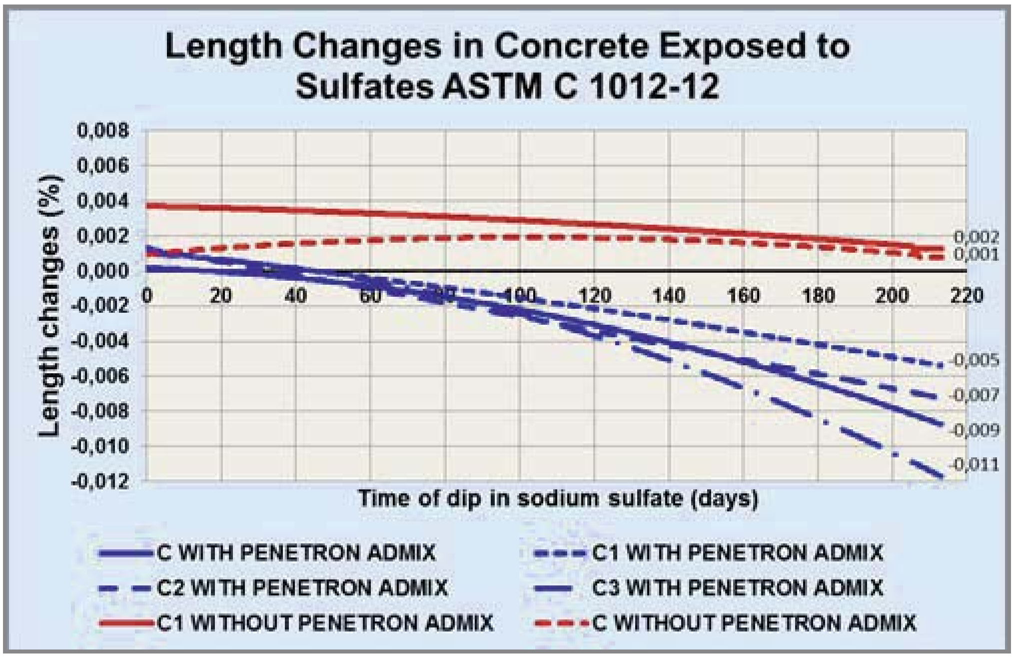


Figure 14. Changes in length of concrete exposed to sulfate, according to ASTM C1012.

Extensive testing has shown that concrete treated with PENETRON ADMIX, subjected to a solution of sodium sulfate, does not show any change in length by such expansion. Untreated concrete samples subjected to the same sodium sulfate solution showed significant change in length as well as disintegration of mass.

PRAN vs PRAH / absorption versus permeability

PRAN vs PRAH / absorption versus permeability

It is a common and risky misconception in many construction markets today, that capillary absorption tests are suitable to demonstrate the performance of permeability-reducing admixtures for hydrostatic pressure (PRAH).

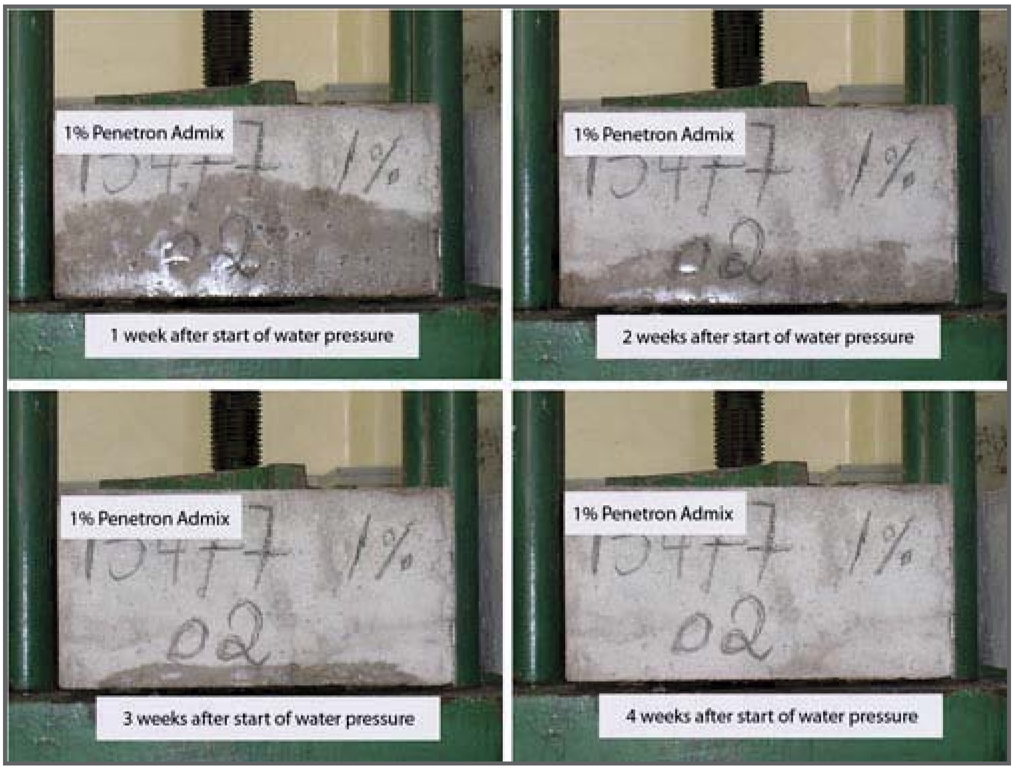
Integral waterproofing admixtures are designed to reduce water ingress into concrete by reducing the permeability of concrete. Hence, the American concrete Institute (ACI) has classified a new category of concrete admixtures called “Permeability-Reducing Admixtures” (PRA), subdivided into “permeability-reducing admixtures for non-hydrostatic conditions” (PRAN) and “permeability-reducing admixtures for hydrostatic conditions” (PRAH).

The ACI 212-3R-10-N report suggests that only crystalline admixtures, like **PENETRON ADMIX**, qualify as true PRAH. Crystalline admixtures are hydrophilic materials that form insoluble crystalline structures, which seal pores, microcracks and capillaries, reducing concrete permeability even under high hydrostatic pressure.

Hydrophobic or water repellant chemicals such as pore blockers, fall under the category of PRAN. These materials are designed to repel water by blocking pores and capillaries with a water repellant substance. To demonstrate the water-repellent function, manufacturers of hydrophobic admixtures employ capillary absorption tests, such as ASTM C1585 and BS EN 1881-122. These tests measure water absorption after immersion of the sample in water. No pressure is applied, which is why no indication of the level of protection of hydrophobic admixtures exposed to hydrostatic conditions can be established. Due to the uneven coating of the hydrophobic lining and open capillary system, the protection against water under pressure is extremely limited (usually a few centimeters of water head). This limits their use to protection against rain or minimizing dampness.

Crystalline admixtures withstand high, hydrostatic pressure. To determine their performance, only permeability tests such as DIN 1048 pt. 5, BS EN 12390-8 or ASTM D5084 should be used. These tests apply water under pressure and, contrary to absorption tests, are able to give an indication of the performance under hydrostatic conditions. **Since a lot of the water applied during this test is taken up by the crystalline reaction to form crystals, a true performance indication can be achieved by repeating the test cycle over several weeks (see 4 week test images below).**

To read more on this subject, click here.



Aker Solutions, Stavanger, Norway

Aker Solutions, a global Norwegian company that provides oilfield products and services, recently inaugurated a new office facility in Stavanger. This new building is the global headquarters for the Operations division and home to 2,600 employees. PENETRON ADMIX was used for the extensive below-ground structures for protection from groundwater and seawater at the construction site.

Located adjacent to the North Sea, the Stavanger headquarters features eight above-ground office floors (43,000 m^2 / 484,400 square feet) and two below-ground floors for a basement with bicycle parking for 1,000 bicycles and a parking garage (65,000 m^2 / 700,000 square feet) with space for 500 cars.

The site was reclaimed ocean frontage directly on the coastline, exposing the site to the water table and chloride penetration from the seawater. About 11,000m^3 of concrete were treated with PENETRON ADMIX, including the building's foundation and basement structures. PENETRON ADMIX was chosen to ensure comprehensive waterproofing and to reduce permeability for chloride ions in the concrete and optimize durability.

PENETRON ADMIX performed flawlessly and allowed construction to proceed without any delays, delivering to the client a completely protected and durable concrete foundation.

Kempinski Hotel Jeddah, Saudi Arabia

The Kempinski Hotel Jeddah is located on Jeddah Corniche providing magnificent views of the Red Sea. Designed to be the first green intelligent hotel in the Kingdom of Saudi Arabia, the 260-meter high tower will boast 321 units: 250 luxury guest rooms and suites, with the rest as serviced apartments spread over 70 floors.

The Kempinski Hotel Jeddah will be the finest address for leisure travelers in Jeddah. The hotel will include a full array of first class facilities including luxurious leisure suites, two restaurants offering a range of international cuisines, a 1000 sqm ballroom, a wellness center and spa, and swimming pool. Corporate guests can take advantage of corporate and meetings facilities, including fully equipped modern meeting rooms, VIP rooms and business suites.

Due to its close proximity to the Red Sea it was imperative to provide a 100% solution when it came to the protection and waterproofing of the raft foundation, retaining walls, and other water-retaining structures such as the water tanks and swimming pools. In order to ensure total concrete protection on this prestigious project. PENETRON ADMIX was added to approximately 30,000m^3 of concrete supplied by Saudi Readymix.

Abu Dhabi National Paper Mill (Expansion), Mussafah, UAE

Abu Dhabi National Paper Mill (ADNPM) is one of the largest and most technically advanced producers of jumbo tissue paper rolls in the Middle East. ADNPM follows the highest quality, environmental and health & safety standards including ISO 9001, 14001 and OHSAS 18001. The facility includes manufacturing and storage areas, an effluent treatment plant as well as administration offices and parking. It has a total area of 60,000 square meters and produces over 65,000 tons of tissue paper per year. The paper, produced from the highest-grade virgin pulp, is used to make table napkins, kitchen and hand towels, and facial and toilet tissues.

In 2014 the expansion of the facility saw a new production line (PM3) added to ADNPM.

The building features a 6m deep basement, which is located one meter below the sea water level.

PENETRON ADMIX was tested and chosen as the preferred concrete protection solution and added to the concrete mix of the slab and retaining walls of the new production line facility. All construction joints were sealed using PENEBAR SW 45 waterstop.

PENETRON, PENECRETE MORTAR AND PENEPLUG were employed to treat leaks in the piles.

Manhattan District Garage 1/2/5, New York, USA

Previously located at Pier 52 on the Hudson River, the garage facility was moved to the corner of Spring & West Streets to make waterfront land available for the recently established Hudson River Park. The new Manhattan District 1/2/5 Garage serves the Department of Sanitation New York (DSNY) as a base of operations for three separate District Garages, as well as the UPS Staging Lot operations for Lower Manhattan.

The Manhattan District 1/2/5 Garage accommodates over 150 sanitation vehicles, a separate vehicle wash, personnel facilities for each district, and centralized fueling and repair facilities. A benchmark project for NYC's Active Design program, the garage features a green roof to protect the building and enhance storm water retention and thermal performance. Designed by Dattner Architects in association with WXY Architecture + Urban Design, the project is set to achieve a LEED Gold certification.

The garage is a five-level structure with a total floor area of about 427,250 square feet (39,700m^2). The parking levels, with approximately 266 parking spaces, accommodate vehicle parking and storage, offices, and locker facilities. The building was constructed on a concrete slab with pilings (no cellar) using PENETRON ADMIX SB. In addition, there are two 15,000 L (4,000 gallon) underground tanks, also treated with PENETRON ADMIX, for storage of liquid calcium chloride, which is applied with rock salt to melt snow and ice. Overall, about 12,230m^3 (16,000 cubic yards) of concrete were treated with PENETRON ADMIX for all concrete structures.

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CHEMICAL ADMIXTURES FOR CONCRETE

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This document discusses commonly used chemical admixtures for concrete and describes the basic use of these admixtures. It is targeted at those in the concrete industry not involved in determining the specific mixture proportions of concrete or in measuring the properties of the concrete. Students, craftsmen, inspectors, and contractors may find this a valuable introduction to a complex topic. The document is not intended to be a state-of-the-art report, user's guide, or a technical discussion of past and present research findings. More detailed information is available in ACI Committee Report 212.3R, "Chemical Admixtures for Concrete" and 212.4R, "Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete."

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CHAPTER 1—INTRODUCTION

1.1—History

Admixtures have long been recognized as important components of concrete used to improve its performance. The original use of admixtures in cementitious mixtures is not well documented. It is believed that the introduction of some of these materials may have been part of rituals or other ceremonies. It is known that cement mixed with organic matter was applied as a surface coat for water resistance or tinting purposes. Materials used in early concrete and masonry included milk and lard by the Romans; eggs during the middle ages in Europe; polished glutinous rice paste, lacquer, tung oil, blackstrap molasses, and extracts from elm soaked in water and boiled bananas by the Chinese; and in Mesoamerica and Peru, cactus juice and latex from rubber plants. The purpose of these materials is widely unknown. It is known that the Mayans used bark extracts and other substances as set retarders to keep stucco workable for a long period of time. More recently chemical admixtures have been used to help concrete producers meet sustainability requirements that are necessary for modern construction. For concrete these requirements can be related to extended life cycles, use of recycled materials, stormwater management, and reduced energy usage. Chemical admixtures are used to facilitate the increased use of supplementary cementitious materials, lower permeability, and improve the long term durability of concrete.

1.2—Definitions & Glossary

Concrete is composed principally of aggregates, hydraulic cement, and water, and may contain supplementary cementitious materials (SCM) and chemical admixtures. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of a chemical admixture or air-entraining cement. Chemical admixtures are usually added to concrete as a specified volume in relation to the mass of portland cement or total cementitious material.

Admixtures interact with the hydrating cementitious system by physical and chemical actions, modifying one or more of the properties of concrete in the fresh or hardened states. According to ACI 212.3R-10, “Report on Chemical Admixtures for Concrete,” an admixture or combination of admixtures may be the only feasible way to achieve the desired performance from a concrete mixture in some cases. There are many kinds of chemical admixtures that can function in a variety of ways to modify the chemical and physical properties of concrete. This bulletin provides information on the types of chemical admixtures and how they affect the properties of concrete, mortar, and grout. Definitions of certain types of admixtures and other selected terms can be found below and are taken from ACI Concrete Terminology.[1]

Admixture—A material other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing. (The admixtures referred to in this definition are also known as Chemical Admixtures.)

Admixture, accelerating—An admixture that causes an increase in the rate of hydration of the hydraulic cement, and thus, shortens the time of setting, increases the rate of strength development, or both.

Admixture, air-entraining—An admixture that causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing.

Admixture, permeability-reducing – An admixture used to reduce the ingress of water and water borne chemicals into concrete. Admixtures may be further sub-divided into permeability-reducing admixtures for non-hydrostatic conditions (PRAN) or hydrostatic conditions (PRAH).

Admixture, retarding—An admixture that causes a decrease in the rate of hydration of the hydraulic cement and lengthens the time of setting.

Admixture, water-reducing—An admixture that either increases slump of a fresh cementitious mixture without increasing water content or maintains slump with a reduced amount of water, the effect being due to factors other than air entrainment.

Admixture, water-reducing high-range—A water-reducing admixture capable of producing great water reduction, great flowability, or both, without causing undue set retardation or air entrainment in cementitious paste.

Aggregate, reactive—Aggregate containing substances capable of reacting chemically with the products of solution or hydration of the portland cement in concrete or mortar under ordinary conditions of exposure, resulting in some cases in harmful expansion, cracking, or staining.

Air, entrained—Microscopic air bubbles intentionally incorporated in a cementitious paste during mixing, usually by use of a surface-active agent; typically between 0.0004 and 0.04 in. (10 and 1000 μm) in diameter and spherical or nearly so.

Air, entrapped—Air voids in concrete that are not purposely entrained and that are larger, mainly irregular in shape, and less useful than those of entrained air; and 1 mm or larger in size.

Air content—The volume of air voids in cement paste, mortar, or concrete, exclusive of pore space in aggregate particles, usually expressed as a percentage of total volume of the paste, mortar, or concrete.

Alkali—Salts of alkali metals, principally sodium and potassium; specifically sodium and potassium occurring in constituents of concrete and mortar, usually expressed in chemical analysis as the oxides Na_2O and K_2O.

Alkali-aggregate reaction—Chemical reaction in either mortar or concrete between alkalies (sodium and potassium) from portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of concrete or mortar may result.

Alkali-carbonate reaction—The reaction between the alkalies (sodium and potassium) in portland cement and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

Alkali-silica reaction—A generally deleterious dissolution and swelling of siliceous aggregates in the presence of pore solutions comprised of alkali hydroxides; the reaction products may cause abnormal expansion and cracking of concrete.

Calcium chloride—A crystalline solid, $CaCl_2$; in various technical grades, used as a drying agent, as an accelerator for fresh concrete, a deicing chemical, and for other purposes.

Cement, portland—A hydraulic cement produced by pulverizing clinker formed by heating a mixture, usually of limestone and clay, to 1400 to 1600°C (2550 to 2900°F). Calcium sulfate is usually ground with the clinker to control set.

Cementitious—Having cementing properties.

Sulfate attack—Either a chemical or physical reaction or both between sulfates usually in soil or groundwater and concrete or mortar; the chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix, often causing deterioration.

Sulfate resistance—Ability of concrete or mortar to withstand sulfate attack.

CHAPTER 2—OVERVIEW

2.1—Function

Chemical admixtures discussed in this document are available in liquid and powder form. Liquid admixtures are dispensed through mechanical dispensers as the concrete is batched, but can be introduced to the concrete by other means, such as hand dosing or truck mounted dispensers. Powders are usually introduced in pre-packaged units that contain a prescribed amount. Most times the units consist of bags that can be opened and the contents added while mixing, or bags that are made to disintegrate and disperse their contents while mixing. Generally, admixtures in powdered form are introduced to the concrete after batching. A discussion of dispensing equipment for liquid admixtures is given in Chapter 6. The dosages used vary widely depending on several factors including, type of admixture, performance desired, environmental conditions, and many others. The uses of admixtures are outlined by the following functions that they perform:

- Increase workability without increasing water content or decrease the water content at the same workability;
- Retard or accelerate initial time of setting;
- Reduce or prevent shrinkage or create slight expansion;
- Modify the rate or capacity for bleeding;
- Reduce segregation;
- Improve pumpability;
- Reduce rate of slump loss;
- Retard or reduce heat evolution during early hardening;
- Accelerate the rate of strength development at early ages;
- Increase strength (compressive, tensile, or flexural);
- Increase durability or resistance to severe conditions of exposure, including application of deicing salts and other chemicals;
- Decrease permeability of concrete;
- Control expansion caused by the reaction of alkalis with reactive aggregate constituents;
- Increase bond of concrete to steel reinforcement;
- Increase bond between existing and new concrete;
- Improve impact and abrasion resistance;
- Inhibit corrosion of embedded metal;
- Produce colored concrete or mortar; and
- Aid in achieving sustainability requirements.

2.2—Effectiveness and Compatibility

The effectiveness of any admixture will vary depending on its concentration in the concrete and the effect of the various other constituents of the concrete mixture. Each class of admixture is defined by its primary function. It may have one or more secondary functions, however, and its use may affect, positively or negatively, concrete properties other than those desired. Therefore, adequate testing should be performed to determine the effects of an admixture on the plastic properties of concrete such as slump, rate of slump loss (that is the relationship between slump and time), air content, and setting time. In addition, testing should be performed to determine the effect of the admixture on the hardened properties of concrete that may be of interest, for example, strength development, drying shrinkage, modulus of elasticity, or permeability. The final decision as to the use of any admixture and the brand, class, or type, depends on its ability to meet or enhance specific concrete performance needs.

Many improvements can be achieved by proper selection and application of specific admixtures. The selection process should focus on the functional qualities required by structural demands, architectural requirements, and contractor needs.

Whatever the approach, be it a single water-reducing admixture or a combination approach, the use of admixtures can be beneficial. Admixtures provide additional means of controlling the quality of concrete by modifying some of its properties, however, they cannot correct for poor-quality materials, improper proportioning of the concrete, and inappropriate placement procedures.

It is quite common for a concrete mixture to contain more than one admixture. In the simplest cases, such as paving or residential applications, a concrete mixture may be dosed with only a water-reducing admixture and an air-entraining admixture. High-performance concrete mixtures may be dosed with as many as five admixtures, depending on the specific application. Therefore, it is imperative that the admixtures that are used in a given concrete mixture are compatible to prevent undesired effects such as rapid slump loss, air-entrainment difficulties, severe set retardation, or improper strength development.

A typical rule of thumb is for all admixtures to be added separately to a concrete mixture and not pre-blended before introduction into the mixture. In addition, admixture manufacturers typically provide information on potential incompatibility with other admixture chemistries on product data sheets. However, it should be noted that incompatibility issues in concrete mixtures are typically due to undesired chemical interactions, physical interactions, or both between chemical admixtures and other mixture ingredients, in particular, the cementitious materials system. Sulfate imbalance in the system is typically a contributing factor in such cases. In addition, certain types of clay that may be present on aggregate surfaces can also result in incompatibility issues. Therefore, pre-project testing should be performed using materials proposed for use on a project to identify potential incompatibility issues prior to the start of a project. This testing requires knowledge of the rate of slump loss and the setting time under relatively hot and cold conditions (in addition to laboratory conditions). Concrete producers have used a number of means to determine the potential for incompatibility including calorimetry, other types of thermal measurements, laboratory concrete trials, and concrete plant trials. Test placements on-site are recommended to verify proper workability, finishability, and setting time of the proposed mixture.

2.3—References and Standards

Guide to Durable Concrete ACI 201.2R
Chemical Admixtures for Concrete ACI 212.3R
Buiding Code Requirements for
Structural Concrete ACI 318/318M
Superplasticizers in Ready Mixed Concrete NRMCA No. 158
Air-Entraining Admixtures ASTM C260
Standard Specification for Air-Entraining
Admixtures for Concrete AASHTO M 154
Standard Specification for Air-Entraining
Admixtures for Concrete CRD-C 13
Chemical Admixtures ASTM C494/C494M
Standard Specification for Chemical
Admixtures for Concrete AASHTO M 194
Standard Specification for Water
Permeability of Concrete CRD-C 48
Standard Specification for Chemical
Admixtures for Concrete CRD-C 87
Calcium Chloride ASTM D98
Standard Specification for Calcium Chloride AASHTO M 144
Foaming Agents ASTM C869/C869M
Admixtures for Shotcrete ASTM C1141/C1141M
Admixtures for Use in Producing
Flowing Concrete ASTM C1017/C1017M
Grout Fluidifier For Preplaced Aggregate
Concrete ASTM C937
Pigments for Integrally Colored Concrete ASTM C979/C979M
Testing Hardened Concrete – Depth of Penetration of Water Under Pressure BS EN 12390-8
Testing Concrete – Method for Determination of Water Absorption BS EN 1881 – Part 122
Testing Hardened Concrete DIN 1048

*ASTM ASTM International
AASHTO American Association of State Highway and Transportation Officials
CRD Army Corps of Engineers, Chief of Research and Development
BS EN – European Standards
DIN – German Standards

CHAPTER 3—AIR-ENTRAINING ADMIXTURES

3.1—History

One of the most significant innovations in concrete technology was made during the 1930s. It was noted that certain concrete pavements were more able to withstand the detrimental effects of freezing and thawing cycles than others. These cycles, and the damage caused, were a major inhibitor to durability of concrete pavements and other exterior applications. Investigation showed that the more durable pavements were slightly less dense, and that the cement used had been obtained from mills using beef tallow as a grinding aid in the manufacturing of cement. The beef tallow acted as an air-entraining agent, which improved the durability of the pavements. Later, after rigorous investigation, air-entrained concrete was specified in climates where freezing-and-thawing resistance was needed.

Air-entraining admixtures (AEA) are primarily used to stabilize tiny air bubbles in concrete that protect against damage from repeated freezing-and-thawing cycles. Until the mid-1990s, the most commonly used air-entraining admixture for concrete was a neutralized wood resin. Newer formulations may instead be formulated from synthetic detergents such as the salts of organic acids and sulfonated hydrocarbons. These modern formulations offer enhanced performance such as improved stability compared to early formulations. Today, most State Department of Transportation (DOT) specifications have limits that require the use of an air-entraining admixture in pavements.

3.2—Mechanism

The space occupied by the mixing water in fresh concrete rarely becomes completely filled with cementitious hydration products after the concrete has hardened. The remaining spaces are capillary pores. Under saturated conditions, these cavities are filled with water. If this water freezes, the resulting expansion of water to ice (approximately 9%) creates internal pressure in a confined space. This stress exceeds the tensile strength of concrete. The result in non air-entrained concrete is cracking, scaling, and spalling.

Entrained air voids make the capillaries discontinuous. As a result of the mixing action, air-entraining admixtures stabilize air bubbles in the cement paste that become a component of the hardened concrete. The resultant air-void system consists of uniformly dispersed spherical voids, usually between 10 and 1000 μm (0.4 to 40 mil) in diameter. Because the air voids are generally larger than the capillaries, they form tiny reservoirs that act as safety valves during ice expansion, accommodating the increased volume and preventing the build-up of internal pressure. Air entrainment in concrete is expressed as a percent of the overall concrete volume.

Entrained air should not be confused with entrapped air. Entrapped air is due to normal mixing and results in large, non-uniform air bubbles that do not have the correct size and spacing required to prevent damage in concrete caused by freezing water. Proper air entrainment, or air void structures require the use of an admixture, either added to the plastic concrete or blended with the cement during manufacturing.

3.3—Use of air-entraining admixtures

Air-entraining admixtures should be required to conform to ASTM C260, "Standard Specification for Air-Entraining Admixtures for Concrete." Dosage rates of air-entraining admixtures generally range from 15 to 130 mL per 100 kg (1/4 to 2 fl oz per 100 lb) of cementitious material. Higher dosages are sometimes required depending on the materials and mixture proportions. For example, concrete containing fly ash or other pozzolans often requires higher doses of air-entraining admixture to achieve the same air content compared to a similar concrete using only portland cement. Trial mixtures should be performed to ensure compatibility between air-entraining admixtures and other concrete components, including other chemical admixtures. Table 1 summarizes some of the factors that influence the entrained air content of fresh concrete.

3.4—Properties of Entrained Air

Entrained air must be present in the proper amount, and have the proper size and spacing factor to provide protection from freezing and thawing. The term "spacing factor" represents the maximum distance that water would have to move before reaching an air void reservoir. For adequate protection in a water saturated freezing and thawing environment, the spacing factor should not be greater than 0.2 mm (0.008 in.).

Another factor that must be considered is the size of the air voids. For a given air content, the air voids cannot be too large if the proper spacing factor is to be achieved without using an unacceptable amount of air. The term "specific surface" is used to indicate the average size of the air voids. It represents the surface area of the air voids in concrete per unit volume of air. For adequate resistance to repeated freezing and thawing in a water-saturated environment, the specific surface should be greater than 24 mm^2/mm^3 (600 $in.^2/in.^3$).

The total volume of entrained air recommended by ACI Committee 201 for normal-strength concrete based on exposure conditions and aggregate size is listed in Table 2. Specified air contents, such as those listed in Table 2, are required to meet the spacing factor and specific surface requirements described above. Methods to analyze the air void system in hardened concrete are described in ASTM C457, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete."

Table 1 Factors affecting the air content of concrete at a given dosage of admixture*

Factor	Effect on air content
Cement	An increase in the fineness of cement will decrease the air content. As the alkali content of the cement increases, the air content may increase. An increase in the amount of cementitious materials can decrease the air content.
Fine aggregate	An increase in the fine fraction passing the 150 µm (No. 100) sieve will decrease the amount of entrained air. An increase in the middle fractions passing the 1.18 mm (No. 16) sieve, but retained on the 600 µm (No. 30) sieve and 300 µm (No. 50) sieve, will increase the air content. Certain clays may make entraining air difficult.
Coarse aggregate	Dust on the coarse aggregate will decrease the air content. Crushed stone concrete may result in lower air than a gravel concrete.
Water	Small quantities of household or industrial detergents contaminating the water may affect the amount of entrained air. If hard water is used for batching, the air content may be reduced.
Pozzolans and slag cement	Fly ash, silica fume, natural pozzolans, and slag cement can affect the dosage rate of air-entraining admixtures.
Admixtures	Chemical admixtures generally affect the dosage rate of air-entraining admixtures.
Slump	For less than a 75 mm (3 in.) slump, additional admixture may be needed. Increase in slump to about 150 mm (6 in.) will increase the air content. At slumps above 150 mm (6 in.), air may become less stable and the air content may decrease.
Temperature	An increase in concrete temperature will decrease the air content. Increase in temperature from 21 to 38 °C (70 to 100 °F) may reduce air contents by 25%. Reductions from 21 to 4 °C (70 to 40 °F) may increase air contents by as much as 40%. Dosages of air-entraining admixtures must be adjusted when changes in concrete temperatures take place.
Concrete mixer	The amount of air entrained by any given mixer (stationary, paving, or transit) will decrease as the blades become worn or become coated with hardened concrete buildup. Air contents often increase during the first 70 revolutions of mixing then will hold for a short duration before decreasing. Air content will increase if the mixer is loaded to less than capacity and will decrease if the mixer is overloaded. In very small loads in a drum mixer, however, air becomes more difficult to entrain.

* Information from Portland Cement Association document Manual on Control of Air Content in Concrete by Whiting and Nagi.

Table 2—Total Air Content for Concrete Exposed to Cycles of Freezing and Thawing*

Nominal maximum aggregate size, in.†	Air content, % Exposure Class F1	Air content, % Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2‡	4	5
3‡	3.5	4.5

* Information from Table 4.4.1 of ACI 318-11, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary."

† See ASTM C33 for tolerance on oversize for various nominal maximum size designations.

‡ Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.

In addition to resistance to freezing and thawing, air entrainment can have other effects on concrete, some positive and some negative. Air entrainment can increase workability and improvement pumpability, especially for mixtures with low or moderate cementitious contents. Air-entrained concrete will also show reduced bleeding and segregation, however the reduced bleeding rate could lead to surface crusting and plastic cracking for flatwork placed in warm, windy conditions with low humidity. The compressive strength will be significantly affected by the air content, and typically an increase of 1% in air content will decrease compressive strength by about 5% for concrete mixtures with a compressive strength in the range of 2l to 35 MPa (3000 to 5000 psi). Adding air entrainment can also improve the finish of the surface of slabs and reduce the occurrence of voids and sand streaking on wall surfaces. Air entrainment, however, is *not* recommended for interior steel troweled floors, where air contents in excess of 3% can lead to premature finishing that in turn causes blistering and delamination. Air entrainment will not affect the setting time of the concrete.

3.5—Handling and Testing of Air-Entrained Concrete

The air content of fresh concrete should be closely monitored. The measurement of entrained air content should be performed immediately before discharging the concrete into the forms. Samples for acceptance testing, however, should be taken from the middle of the batch in accordance with ASTM C172, "Standard Practice for Sampling Freshly Mixed Concrete." Density (unit weight) must also be measured.

The methods and materials for performing air-content tests on concrete are described in ASTM C231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," and ASTM C173, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method." The gravimetric method (ASTM C138, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete,") is not generally used in the field because it requires knowledge of the theoretical unit weight of the concrete on an air-free basis. Density should also be monitored in the field to verify uniformity between batch mixture proportions and air contents. Hardened cylinder weight should be recorded on concrete test reports adjacent to compressive strength. Cylinders should be weighed immediately after demolding. Air content should be measured each time concrete is sampled, and air meters should be calibrated regularly.

Many factors are involved in the delivery and placement of properly air-entrained concrete. Poor concrete placement, consolidation, and finishing techniques may decrease the air content. After adding an air-entraining admixture, the air content will increase to a maximum value, and then slowly decrease with continued mixing. Pumping and placement operations can reduce the air content, particularly for shotcrete, and in some cases it may be required to test the air content at the point of final discharge in addition to compliance testing at the mixing truck. Even the configuration of the boom on a pump may affect the air content, and tests have shown that there is more air loss when the boom is in a vertical position as opposed to a more horizontal position. Even for concrete with suitable air entrainment, proper placement, consolidation, and curing are critical to producing concrete with adequate durability to cycles of freezing and thawing. Concrete must still be properly proportioned using sound aggregates and must also be protected from freezing until the concrete reaches a strength of about 28 MPa (4000 psi).

CHAPTER 4—WATER-REDUCING AND SET-CONTROLLING ADMIXTURES

4.1—Types and composition

In general, these chemicals act as dispersants for portland cement particles. By separating and spreading out the cement particles, internal friction is reduced, and slump and workability of the concrete is increased. Alternatively, the same workability can be achieved using less water, which lowers the water–cementitious material ratio (*w*/*cm*) for a given cement content.

Lowering *w/cm* is a key method for improving durability. These admixtures also provide the ability to control the time of setting to meet changing jobsite and climatic conditions.

The strength improvement resulting from water-reducing admixtures is primarily a result of reducing the *w/cm* and increasing cement efficiency. For a given air content, concrete strength is inversely proportional to the *w/cm* and, therefore, the reduction in water needed to achieve the desired slump and workability when a water-reducing agent is used will result in an increase in strength. The increase in strength using a water-reducing admixture often exceeds the strength from simply reducing the water content. This is due to the admixture's dispersing effect on cement that results in increased hydration efficiency.

Water-reducing admixtures are based on a variety of materials; the most common of which are:

- Lignosulfonic acids and their salts;
- Hydroxylated polymers;
- Hydroxylated carboxylic acids and their salts;
- Sulfonated melamine or naphthalene formaldehyde condensates; and
- Polyether-polycarboxylates.

Each material can have different properties when used as an admixture. In particular, the amount of water reduction and the degree of set retardation can vary considerably. Some materials will entrain air, and other may affect bleeding and finishing properties. A commercial formulation may include accelerating agents or defoamers to counteract these side effects. As a result, it can be difficult to predict an admixture's performance based on its primary ingredient, even if this information is made available. ASTM C494 "Standard Specification for Chemical Admixtures for Concrete," classifies admixtures into categories based on performance:

- Type A Water-reducing admixtures;
- Type B Retarding admixtures;
- Type C Accelerating admixtures;
- Type D Water-reducing and retarding admixture;
- Type E Water-reducing and accelerating admixtures;
- Type F Water-reducing, high-range, admixtures;
- Type G Water-reducing, high-range, and retarding admixtures; and
- Type S Specific performance admixtures.

Admixtures types A through F covered by ASTM C494 are designed to serve a specific purpose. ASTM C494 outlines the performance requirements for an admixture to qualify for each category. Depending on the category, required properties may include the degree of water reduction, minimum or maximum variations in setting time, compressive strength, and the length change of hardened specimens. Some admixtures will meet the requirements of several categories, such as Type A and Type D. In such cases, the admixture will meet Type A requirements at low doses, and will meet Type D requirements at higher doses due to additional set retardation caused by higher dosages of those particular admixtures.

The Type S category can apply to any specialty admixture that does not fit into the other more common categories. The Type S category does not attempt to address the primary purpose of specialty admixtures, but instead provides guidelines for their effects on properties such as setting time and compressive strength to help users avoid unexpected variations in performance. Upon request, a manufacturer is required to provide data to substantiate the specific benefits of the Type S admixture.

ASTM C494 does not cover all possible concrete requirements, and additional properties will need to be tested depending on the application. Proper use of admixtures should begin by gathering available information and comparing the different types and brands that are available. Consideration must be given to information such as uniformity, dispensing, long-term performance, and available service. These are points that cannot be assessed by concrete tests but could determine successful admixture use.

The admixture manufacturer should be able to provide information covering typical dosage rates, times of setting, and strength gain for local materials and conditions. The evaluation of admixtures should be made with specific job materials (including other chemical admixtures under consideration) under anticipated ambient conditions. Laboratory tests conducted on concrete with water-reducing admixtures should indicate the effect on pertinent properties for the construction project, including: water requirement, air content, slump, rate of slump loss, bleeding, time of setting, compressive strength, flexural strength, and resistance to cycles of freezing and thawing. Following the laboratory tests, field test should be conducted to determine how the admixtures will perform in actual field conditions, considering all relevant factors such as placement equipment, weather and delivery distances.

4.2—Type A, water-reducing admixtures

Type A water-reducing admixtures will decrease mixing water content by 5 to 12%, depending on the admixture, dosage, and other materials and proportions. Type A water-reducing admixtures are useful when placing concrete by means of a pump or tremie, and can assist with applications where placing concrete would otherwise be difficult. They also may improve the properties of concrete containing aggregates that are harsh, poorly graded, or both.

Dosage rates of water-reducing admixtures depend on the type and amount of active ingredients in the admixture. The dosage is based on the cementitious materials content of the concrete mixture and is expressed as milliliters per hundred kilograms (fluid ounces per hundred pounds) of cementitious materials. Typically, the dosage rates of Type A water-reducing admixtures range from 130 to 390 mL per 100 kg (2 to 6 fl oz per 100 lb) of cementitious materials. Higher dosages may result in excessive retardation of the concrete setting time. Manufacturers recommended dosage rates should be followed and trial batches with local materials should be performed to determine the dosage rate for a given concrete mixture. In some occasions, dosages higher or lower than the manufacturer's recommendations may be used, but testing is necessary to ensure the resulting concrete meets the requirements of the project.

The primary ingredients of water-reducing admixtures are organic, which tend to retard the time of setting of the concrete. This retardation may be offset by small additions of chloride or nonchloride accelerating admixtures at the batch plant. Typically, Type A admixtures already contain some accelerating admixtures that offset this natural retardation. Care should be taken to ensure that addition of chloride does not exceed the ACI 318 limits for maximum chloride-ion content in reinforced or prestressed concrete.

4.3—Type B, retarding, and Type D, water-reducing and retarding admixtures

4.3.1 *Conventional retarding admixtures*—Two types of admixtures are used for the same basic purpose: to offset unwanted effects of high temperature, such as acceleration of set and reduction of 28-day compressive strength, and to keep concrete workable during the entire placing and consolidation period. Figure 1 indicates the relationship between temperature and setting time of concrete and specifically indicates why retarding admixture formulations are needed in warmer weather.

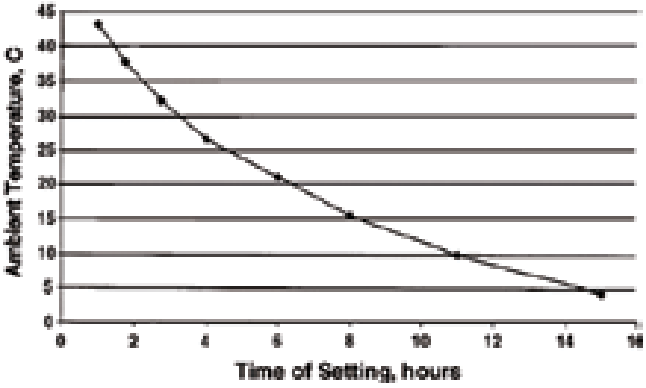

Fig. 1 Relationship between temperature and setting time of concrete. (°F = °C×9/5 + 32)

The benefits derived from retarding formulations include the following:

- Permits greater flexibility in extending the time of set and the prevention of cold joints;
- Facilitates finishing in hot weather; and
- Permits full form deflection before initial set of concrete.

As with Type A admixtures, their dosage rates are based on the amount of cementitious materials in the concrete mixture. While both Type B and Type D may provide some water-reduction, Type D is more effective in achieving this goal. The amount of retardation depends upon many factors including: admixture concentration, dosage rate, concrete proportions, and ambient and concrete temperatures.

Different sources and types of cement or different lots of cements from the same source may require different amounts of the admixture to obtain the desired results because of variations in chemical composition, fineness, or both. The time at which the retarding admixture is introduced into the concrete may affect the results. Allowing the cement to become totally wet and delaying admixture addition until all other materials are batched and mixed may result in increased retardation and greater slump increase.

Increased retardation may also be obtained with a higher dosage of the retarding admixture. When high dosages of retarding admixture are used, however, rapid stiffening can occur with some sources of cement, resulting in severe slump loss and difficulties in concrete placement, consolidation, and finishing.

4.3.2 *Extended-set admixtures* - Advances in admixture technology have resulted in the development of highly potent retarding admixtures called extended-set admixtures or hydration-controlling admixtures. These admixtures are capable of stopping the hydration of cementitious systems, thereby providing a means to control the hydration and setting characteristics of concrete.

Extended-set admixtures are used in three primary applications: stabilization of concrete wash water, stabilization of returned plastic concrete, and stabilization of freshly batched concrete for long hauls. The use of extended-set admixtures in stabilization of concrete wash water eliminates the dumping of water that is used to wash out a ready-mixed concrete truck drum while keeping the fins and inner drum clean. The process is relatively simple and involves the addition of low dosages of the extended-set admixture to the wash water to control the hydration of concrete stuck to the fins and inside the drum. The stabilized wash water may be included in the mixing water for fresh concrete that is batched the next day or after a weekend. The setting and strength development characteristics of concrete are not adversely affected by the use of stabilized wash water.

The use of extended-set admixtures to stabilize returned unhardened concrete has made it possible to reuse such concrete during the same production day or the next day in lieu of disposal. The dosage of extended-set admixture required depends on several factors that include the ambient and concrete temperatures, the ingredients used in the manufacture of the concrete, and the age of the concrete. Stabilized concrete is reused by batching fresh concrete on top of the stabilized concrete. In overnight applications, an accelerating admixture may be used to reinitiate the hydration process before adding fresh concrete. Increasingly, extended-set admixtures are being used for long hauls and to maintain slump and concrete temperature during transit, especially in warm weather. For this application, the extended-set admixture is added during or immediately after batching, and the required dosage is established based on the amount of retardation desired.

4.4—Type C, accelerating, and Type E, water-reducing and accelerating admixtures

Accelerating admixtures are added to concrete to decrease both the initial and final time of set and accelerate the early strength development. Figure 1, which shows the relationship between temperature and setting time of concrete, specifically indicates why accelerating admixture formulations are needed.

The earlier setting time and increased early strength gain of concrete brought about by an accelerating admixture will result in a number of benefits, including reduced bleeding, earlier finishing, improved protection against early exposure to freezing and thawing, earlier use of structure, and reduction of protection time to achieve a given quality. Accelerating admixtures do not normally act as anti-freeze agents; therefore, protection of the concrete at early ages is required when freezing temperatures are expected.

Although calcium chloride is the most effective and economical accelerator for concrete, its potential to cause corrosion of reinforcing steel limits its use. ACI Committee 318 limits the water-soluble chloride-ion content based on the intended use of the concrete and many government agencies prohibit its use.

The following guidelines should be considered before using calcium chloride or chloride-bearing admixture:

- It should not be used in prestressed concrete because of its potential for causing corrosion;
- The presence of chloride ion has been associated with corrosion of galvanized steel such as when this material is used as permanent forms for roof decks;
- Where sulfate-resisting concrete is required, calcium chloride should not be used;
- Calcium chloride should be avoided in reinforced concrete in a moist condition. In non-reinforced concrete, the level of calcium chloride used should not exceed 2% by weight of cementitious material;
- Calcium chloride should be dissolved in a portion of mixing water before batching because undissolved lumps may later disfigure concrete surfaces;
- Calcium chloride precipitates most air-entraining agents so it must be dispensed separately into the mixture; and
- Field experience and laboratory tests have demonstrated that the use of uncoated aluminum conduit in reinforced concrete containing 1% or more of calcium chloride may lead to sufficient corrosion of the aluminum to collapse the conduit or crack the concrete.

Non-chloride accelerating admixtures are available that provide the benefits of an accelerating admixture without the increased risk of corrosion from chloride. Formulations based on salts of formates, nitrates, nitrites, and thiocyanates are available from admixture manufacturers. These nonchloride accelerators are effective for set acceleration and strength development: however, the degree of effectiveness of some of these admixtures is dependent on the ambient temperature and concrete temperature at the time of placement.

Some formulations will give protection against freezing to concrete placed in sub-freezing ambient temperatures, and form the basis of cold weather admixture systems (Section 5.5). These nonchloride accelerating admixtures offer year-round versatility because they are available to be used for acceleration purposes in cool weather and for sub-freezing protection.

4.5—High-range, water-reducing admixtures

High-range, water-reducing admixtures (HRWR), often called superplasticizers, serve a similar function to conventional water-reducing admixtures, but are much more efficient and can allow for reduced water contents of 30% or more without the side effect of excessive set retardation. By varying the dosage rate and the amount of mixing water, an HRWR admixture can be used to produce:

- Concrete of normal workability at a lower *w/cm*;
- Highly flowable, nearly self-leveling concrete at the same or lower *w/cm* as concrete of normal workability; and
- A combination of the two; that is, concrete of moderately increased workability with a reduction in the *w/cm*.

When used for the purpose of producing flowing concrete, HRWR admixtures facilitate both concrete placement and consolidation.

HRWR admixtures should meet the requirements of ASTM C494 for classification as Type F, high-range, water-reducing, or Type G, high-range water-reducing and retarding admixtures. When used to produce flowing concrete, they should also meet the requirements of ASTM C1017, "Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete," Type 1, plasticizing, or Type 2, plasticizing and retarding admixtures. HRWR admixtures are organic products that typically fall into three families based on ingredients:

- Sulfonated melamine-formaldehyde condensate;
- Sulfonated naphthalene-formaldehyde condensate; and
- Polyether-polycarboxylates.

HRWR admixtures act in a manner similar to conventional water-reducing admixtures, except they are more efficient at dispersing fine-grained materials such as cement, fly ash, slag cement, natural pozzolans, and silica fume. The most widely used HRWR admixtures do not entrain air but may alter the air-void system. Concrete containing HRWR admixtures, however, may have adequate resistance to freezing and thawing even though the spacing factors may be greater than 0.2 mm (0.008 in.).[2]

A characteristic of some older HRWR admixtures is that their slump-increasing effect is retained in concrete for 30 to 60 min. The amount of time that the concrete retains the increased slump is dependent upon the type and quantity of cement, the temperature of the concrete, the type of HRWR admixture, the dosage rate used, the initial slump of the concrete, the mixing time, and the thoroughness of mixing. Modern HRWR admixtures based on polyether-polycarboxylate technology are different chemically and more effective than older HRWR admixtures. Polyether-polycarboxylate HRWR admixtures also retard less and develop strength faster compared to the other HRWR admixture formulations. Because of their increased efficiency, polyether-polycarboxylate HRWRs have gained widespread acceptance, particularly in precast concrete applications and in making self-consolidating concrete, a high-performance concrete with high flowability that requires minimal or no vibration for consolidation. With some HRWR admixtures, it is possible to redose the concrete to regain the increased workability. HRWR admixtures that offer extended slump life are also commercially available.

HRWR admixtures can be used with conventional water-reducing admixtures or retarding admixtures to reduce slump loss and stickiness, especially in silica-fume concrete mixtures. These combinations of admixtures may also cause unanticipated or excessive set retardation, so trial batches should be performed.

The strength of hardened concrete containing HRWR admixtures is normally higher than that predicted by the lower *w/cm* alone. As with conventional admixtures, this is believed to be due to the dispersing effect of HRWR admixtures on the cement and other cementitious or pozzolanic materials. Because the *w/cm* of mixtures containing HRWR admixtures is typically low, shrinkage and permeability may also be reduced and the overall durability of the concrete may be increased.

A good summary of benefits and limitations for this class of admixtures can be found in National Ready Mixed Concrete Association (NRMCA) Publication No. 158, "Superplasticizers in Ready Mixed Concrete."

4.6—Mid-range, water-reducing admixtures

Water-reducing admixtures that provide moderate water reduction without significantly delaying the setting characteristics of concrete are also available. These admixtures provide more water reduction than most conventional (Type A) water-reducing admixtures but not enough to be classified as high-range, water-reducing admixtures (Type F). As a result, they are often referred to as mid-range, water-reducing admixtures. These admixtures can help reduce stickiness and improve finishability and pumpability of concrete including concrete containing silica fume, or concrete made with manufactured or harsh sand. Mid-range, water-reducing admixtures are typically used in a slump range of 125 to 200 mm (5 to 8 in.) and may entrain additional air. Therefore, evaluations should be performed to establish air-entraining admixture dosage for a desired air content.

4.7—Admixtures for self-consolidating concrete

Self-consolidating concrete (SCC) describes a specialized, high-slump concrete mixture able to flow and consolidate under its own weight with little or no vibration and without segregation or excessive bleeding. SCC is useful for placing concrete through heavily congested reinforcement and for building structures that require very smooth formed surfaces. The properties of SCC are made possible through a combination of admixture selection and an increase in the fines content compared to normal slump concrete. SCC mixtures usually contain a polyether-polycarboxylate HRWR admixture (Section 4.5) to provide the required slump and flow. Higher levels of fines are used to increase cohesiveness and prevent segregation and bleeding in the highly plasticized concrete, although alternatively a viscosity modifying admixture (VMA) can be used to increase stability (see Section 5.4). SCC may contain other categories of admixtures, depending on the application.

4.8—Admixtures for slump and workability retention

Admixtures that provide slump and workability retention without affecting the initial time of set of concrete or early-age strength development, as is the case with retarding admixtures, are available in the industry. On their own, these workability-retaining admixtures have minimal effect on water reduction and can be used in combination with normal, mid-range, or high-range, water-reducing admixtures to provide desired levels of workability retention in concrete mixtures, in particular, high-slump concretes or SCC mixtures. Workability-retaining admixtures should meet the Type S requirements in ASTM C 494.

CHAPTER 5—SPECIALTY ADMIXTURES

5.1—Corrosion-inhibiting admixtures

Reinforcing steel corrosion is a major concern with regard to the durability of reinforced concrete structures. Each year, numerous bridges, parking garages, and other concrete structures undergo extensive repair and rehabilitation to restore their structural integrity as a result of corrosion damage.

The high alkalinity of new concrete protects reinforcement from corrosion due to the formation of a corrosion resistant passive layer at the surface of the steel. However, this passive layer can be destabilized in concrete contaminated by chlorides, which allows corrosion to begin if there is sufficient moisture and oxygen present at the surface of the steel. Chlorides can be introduced into concrete from deicing salts that are used in winter months to melt snow or ice, from seawater, or from the concrete mixture ingredients.

There are several ways of combating chloride-induced corrosion, one of which is the use of corrosion-inhibiting admixtures. These admixtures are added to concrete during batching and they protect embedded reinforcement by delaying the onset of corrosion and also by reducing the rate of corrosion after initiation. There are several commercially available inhibitors on the market. Active ingredients include inorganic materials such as calcium nitrite, and organic materials such as amines and esters. Calcium nitrite resists corrosion by stabilizing the passive layer in the presence of chloride ions. However, the dose of calcium nitrite must be sufficient for the level of chloride contamination. Organic inhibitors function by forming a protective film at the surface of the steel to help resist moisture and chemical attack. As with all admixtures, the manufacturer's recommendations should be followed with regard to dosage.

Although corrosion inhibiting admixtures can help resist corrosion, these admixtures are intended to compliment, rather than replace, proper mixture proportioning and good concrete practices. For example, corrosion resistance can also be increased by reducing the permeability of the concrete through the use of low *w/cm* (possibly with the aid of a HRWR admixture, Section 4.5) or with a permeability reducing admixture (Section 5.6). Some available corrosion inhibitors will accelerate the time of set in concrete and therefore retarding admixtures may be necessary to improve working time. Adjustments to batch water are usually necessary, depending on the dosage, to ensure that maximum water content for the mixture is not exceeded.

5.2—Shrinkage-reducing admixtures

The loss of moisture from concrete as it dries results in a volume contraction called drying shrinkage. Drying shrinkage tends to be undesirable when it leads to cracking due to either internal or external restraint, curling of floor slabs, and excessive loss of prestress in prestressed concrete applications. The magnitude of drying shrinkage can be reduced by minimizing the unit water content of a concrete mixture, using good-quality aggregates, and using the largest coarse aggregate size and content consistent with the particular application. In addition, admixtures have been introduced to help further reduce drying shrinkage. These are based on organic materials such as propylene glycol or related compounds that reduce the surface tension of water in the capillary pores of concrete, thereby reducing the tension forces within the concrete matrix that lead to drying shrinkage. This mode of action should not be confused with shrinkage-compensating materials such as expansive, or Type K, cements. Manufacturer's recommendations should be followed with regard to dosage and suitability of shrinkage-reducing admixtures for use in freezing-and-thawing environments.

5.3—Admixtures for controlling alkali-silica reactivity

Alkali-silica reactivity (ASR) is a destructive reaction between soluble alkalis in concrete and reactive silica in certain types of aggregate. Reactive forms of silica will dissolve in the highly alkaline pore solution, and then react with sodium or potassium ions to produce a water-absorptive gel that expands and fractures the concrete. The reaction is typically slow and is dependent on the total amount of alkali present in the concrete, the reactivity of the aggregates, and the availability of moisture. ASR can be mitigated by using low-alkali cement, sufficient amounts of pozzolans or slag cement, and if economically feasible, non-reactive aggregates. Alternatively, ASR can be mitigated by using lithium-based chemical admixtures. Lithium compounds are effective at reducing ASR because if lithium ions are present in a sufficient ratio to sodium and potassium, they will preferentially react with silica to form non-absorptive lithium silicates. The required dose of lithium admixture is calculated based on the alkali content of the concrete to supply the correct ratio of lithium to other alkalis. Lithium admixtures can accelerate the time of set in concrete. Commercially available retarding admixtures are used when increased working time is needed.

5.4—Admixtures for underwater concrete

Placing concrete underwater can be particularly challenging because of the potential for washout of the cement and fines from the mixture, which can reduce the strength and integrity of the in-place concrete. Although placement techniques, such as tremies, have been used successfully to place concrete underwater, there are situations where enhanced cohesiveness of the concrete mixture is required, necessitating the use of an antiwashout or viscosity-modifying admixture (VMA). Some of these admixtures are formulated from either cellulose ether or whelan gum, and they work simply by binding excess water in the concrete mixture, thereby increasing the cohesiveness and viscosity of the concrete. The overall benefit is a reduction in washout of cement and fines, resistance to dilution with water as the mixture is placed, and preservation of the integrity of the in-place concrete. Another use of VMAs is to prevent segregation in high-slump concrete, SCC, or mixtures deficient in fines. Proper placement techniques should be followed even with concrete treated with a VMA or antiwashout admixture.

5.5—Admixture for cold weather

As described in ACI 212.3R-10, cold-weather admixtures systems have been developed that allow concrete to be placed and cured in subfreezing temperatures. The requirements for these systems are described in ASTM C1622, "Standard Specification for Cold-Weather Admixture Systems." Freeze-resistant admixtures suppress the freezing point of concrete and permit placement and curing of the concrete below the freezing point of water. These admixtures will usually contain a non-chloride accelerating admixture (Type C), but will use a much higher dose than what would be used for concrete placed at temperatures above freezing. Other components may include water-reducing admixtures (Types A, E, or F), and other materials found to depress the freezing point of water, including corrosion-inhibiting admixtures (Section 5.1) or shrinkage-reducing admixtures (Section 5.2). Despite the cold weather, some systems will use a set-retarding admixture (Type B or D) to avoid early stiffening of the concrete due to the high level of accelerating admixture. Due to the variability in systems available, each system should be evaluated for properties important to construction, such as slump, working time, stability of entrained air, finishing properties, setting time and strength gain.

5.6—Permeability-reducing admixtures

The penetration of water and water-borne chemicals is the root cause of most of the destructive mechanisms that damage concrete. Additionally, the penetration of water through concrete can compromise interior living spaces, contaminate potable water reservoirs, or allow contaminated water to escape into the environment. Water can enter concrete though the network of pores and capillaries that forms during cement hydration, or through cracks and other voids in the concrete. Therefore, almost all concrete structures require protection from water. Common methods of protection include the application of surface applied sealers and membranes that act as a physical barrier between the concrete and the source of water. Increasingly, concrete structures are being designed with permeability-reducing admixtures (PRAs) to resist water penetration, in which the protection becomes an integral part of the concrete itself rather than just a surface barrier.

There is a wide variety of PRAs available, and it is important to match the properties of an admixture to the actual service conditions. For this reason, ACI 212 divides PRAs into two categories: permeability-reducing admixture for hydrostatic conditions (PRAH), and permeability-reducing admixture for non-hydrostatic conditions (PRAN).

PRAHs are primarily intended for use in concrete that is exposed to water under pressure and are sometimes called waterproofing admixtures. They provide the highest level of water resistance and are suitable for permanently damp or submerged environments. Typical applications include concrete installed underground, pools, tunnels, and water reservoirs. To resist water under pressure, PRAHs use a pore blocking mechanism that is stable even under high hydrostatic pressure. Materials include hydrophilic crystalline chemicals that react with cement and water to grow pore blocking deposits or polymer globules that pack into pores under pressure. In the case of crystalline admixtures, the admixture can reactivate in the presence of incoming water (such as though a crack) and generate new deposits that increase the self-sealing capacity of cracked, leaking concrete. It is important to test PRAHs using methods that apply direct water pressure to the concrete. Suitable methods include the US Army Corps of Engineers CRD-C48, "Standard Test Method for Water Permeability of Concrete," or the European test methods BS EN 12390-8, "Testing Hardened Concrete. Depth of Penetration of Water Under Pressure," and DIN 1048-2, "Testing Concrete: Testing of Hardened Concrete Components."

PRANs are intended for applications that are not subject to hydrostatic pressure, and are sometimes called dampproofing admixtures. Most PRANs contain water repellent chemicals that shed water and reduce water absorption into the concrete. Water repellent ingredients can include various soaps, oils, and long chain fatty acid derivatives. Other PRANs are based on finely divided solids such as talc, bentonite, colloidal silica, and silicates. These fillers reduce water migration through pores, although not to the same degree as a PRAH, and are sometimes called densifiers. PRANs can be tested using non-hydrostatic absorption test methods such as ASTM C1585, "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes," and BS EN 1881-122, "Testing Concrete Part 122: Method for Determination of Water Absorption." Note that these absorption tests are not reliable for evaluating PRAHs because they do not apply water under pressure.

The use of a PRA will not compensate for poor concrete practices. The concrete must be fully consolidated and properly cured. The PRA manufacturer should be consulted regarding proper selection and use.

CHAPTER 6—ADMIXTURE DISPENSERS

6.1—Industry requirements and dispensing methods

The subject of liquid admixture dispensers covers the entire process from storage at the producer's plant to introduction into the concrete batch before discharge. Their operation may be separated into four functions:

1. The dispenser transports the admixture from storage to the batch;
2. The dispenser measures the quantity of admixture required;
3. The dispenser provides verification of the volume dispensed; and
4. The dispenser injects the admixture into or onto the batch.

These are the basic functions. In practice, some of the functions may be combined, for example, measurement and verification. For reliability, the functions may be interlocked to prevent false or inaccurate batching of the admixture and to dispense the admixture in the optimal sequence in the concrete production process.

6.2—Accuracy requirements

Standards of operation for admixture dispensers are specified by scientific groups, concrete producers' trade organizations, and government agencies with authority over concrete production contracts.

The NRMCA and ASTM C94, "Standard Specification for Ready-Mixed Concrete," specify a batching tolerance of 3% of the required volume or the minimum recommended dosage rate per unit of cement, whichever is greater.

6.3—Application considerations and compatibility

Admixture dispensing systems are complex, using parts made of different materials. Therefore, the admixture dispensed through this system should be chemically and operationally compatible with these materials.

The basic rules of application and injection are that the admixtures should not be mixed together. Table 3 contains some suggested practices for admixture sequencing. Other sequencing practices may be used if test data supports the practice.

Table 3—Suggested Admixture Sequencing Practices

ADMIXTURES	INJECTION SEQUENCE
Air-entraining admixture	With early water or on sand
Water-reducing admixtures	Follow air-entraining solution
Accelerating admixtures	With water, do not mix with air-entraining admixture
High-range, water-reducing admixtures	With the last portion of the water at the batch plant
Polycarboxylate high-range, water-reducing admixtures	With early water or with the last portion of the water at the batch plant
Other admixtures types	Consult manufacturer

6.4—Field and truck mounted dispensers

For a number of reasons, some admixtures are dosed at the jobsite. This could be because the mixture contains a high dosage of accelerator or the placing contractor has an admixture not supplied by the concrete producer. In these cases, the use of a truck-mounted dispenser in the form of a calibrated storage tank can be used. The tank is usually charged with the admixture at the same time the concrete is loaded. The contractor can request an increase in slump by injection of a HRWR admixture, and the driver will dispense the required amount into the turning drum. The volume dispensed will be recorded on the delivery ticket. The injection should be performed under pressure through a spray nozzle to thoroughly disperse the admixture into the drum. Field dispensers, consisting of a measuring unit, pump, and dosing wand can also be used at the job site.

6.5—Dispenser maintenance

It is incumbent on the concrete producer to take as great an interest in the admixture dispensing equipment as in the rest of the batch plant. Operating personnel should be trained in the proper operation, winterization, maintenance, and calibration of admixture dispensers. Spare parts should be retained as needed for immediate repairs. Regular cleaning and calibration of the systems should be performed by qualified internal personnel or by the admixture supplier's service representative. Admixtures have too powerful an influence on the quality of the concrete produced for their dispensing to be given cursory attention.

CHAPTER 7—CONCLUSION

Chemical admixtures have become a very useful and integral component of modern concrete practices. Admixtures are not a panacea for every ill the concrete producer, architect, engineer, owner, or contractor faces when dealing with the many variables of concrete, but they do offer significant improvements in both the plastic and hardened state to all concrete. Continued research and development will provide additional reliability, economy, and performance for creating sustainable concrete.

CHAPTER 8— REFERENCES

8.1—Cited references

1. ACI, "ACI Concrete Terminology," American Concrete Institute, Farmington Hills, MI, http://terminology.concrete.org.

2. Ramachandran, V. S., "Concrete Admixtures Handbook: Properties, Science, and Technology," 2nd Edition, 1995, pp. 472-474. [AU1:]

8.2—List of relevant ASTM standards

C94 Standard Specification for Ready-Mixed Concrete

C138 Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C143 Standard Test Method for Slump of Hydraulic-Cement Concrete

C150 Standard Specification for Portland Cement

C173 Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C260 Standard Specification for Air-Entraining Admixtures for Concrete

C494 Standard Specification for Chemical Admixtures for Concrete

C869 Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete

C937 Standard Specification for Grout Fluidifier for Preplaced-Aggregate Concrete

C979 Standard Specification for Pigments for Integrally Colored Concrete

C1012 Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

C1017 Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

C1141 Standard Specification for Admixtures for Shotcrete

C1157 Standard Performance Specification for Hydraulic Cement

D98 Standard Specification for Calcium Chloride

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Theodor Mentzikofakis
General Director/Managing Partner
PENETRON HELLAS

The main goal of our company, during these past 10 years, remains the exact same! Following the bright worldwide course of **PENETRON INTERNATIONAL**, we desire **PENETRON HELLAS** to play, in the wider area of South East Europe, an important role in the field of construction chemicals' technologies, such as with the 3rd generation crystal growth concrete products. Our goal today, is the further strengthening of the existing distribution and technical support network, in South East Europe, with the parallel development of our products' range, for a better coverage of the applications and the market's demands.

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Personally, I am proud of this past decade's outcomes, as well as of the fact, that, despite of the adverse economic conditions and the ongoing crisis, our company continues, in a creative and rising manner, its work and achievements!

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10 YEARS

Thank you!

Course

Since the meeting of CEO and president of **PENETRON INTERNATIONAL**, Mr. Robert Revera, with Mr. Theodor Mentzikofakis (experienced member in the field of Construction Chemicals at the time), in the International Structuring Expo, SAIE 2006, in Italy (view the 1st picture above), where they agreed the establishment of **PENETRON HELLAS**, since this year, to the celebration for the 10 years anniversary of **PENETRON HELLAS** (view the 2nd picture above), many goals have been achieved and they prepare us for even higher achievements, as the company's president declared.

Mr. Jozef Van Beeck, Director of International Sales & Marketing and member of the **PENETRON INTERNATIONAL** management team (view the 3rd picture above), declared as well, that the achievements of **PENETRON HELLAS**, at such a difficult, both global and local, business environment, highlight the effectiveness of the Greek team, and the dynamics, which the company develops internationally during the past years. Company's growth, with the establishment of collaborators, besides the expanded Greek network, to Cyprus and to all the Balcans, integrates the distribution network and the technical support to the wider area.

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