White Paper

# Sustainability of Concrete Structures with Crystalline Technology

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# Sustainability of Concrete Structures with Crystalline Technology

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Engineers, architects and contractors understand that in discussing sustainability in construction we are talking about employing an array of "best practices" in design, material selection and processes to reduce the impact on the environment, protect human health and not compromise the fundamental needs of future generations.

One aspect of these "best practices" is the extensive use of concrete. In today's world, this would seem to be counter intuitive given that everybody points to the amount of carbon dioxide released during the production of Portland cement which is approximately 8% of the worldwide total of $CO_2$ emissions. The reality is, concrete is a great building material and certainly the most widely used so it is no wonder that vast amounts of cement need to be produced to satisfy the demand and in turn this drives up the carbon dioxide emissions. It is a victim of its own success.

In response, the construction industry has modified concrete mix designs to include supplementary cementing materials such as fly ash and slag to help reduce the consumption of Portland cement while at the same time helping to recycle these other materials. The utilization of a number of different admixtures helps in this process with the intent being to produce a "greener" more durable and sustainable building product.

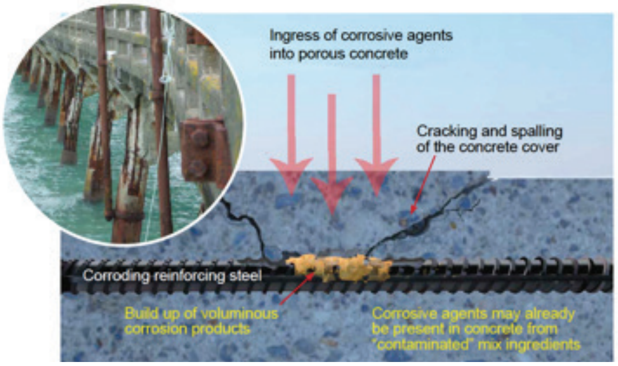
The sustainability of a concrete structure is inextricably tied to both its strength and durability and can be defined as environmental impact over lifetime performance. By increasing the performance of concrete and its service life and decreasing its environmental impact the sustainability of a concrete structure will be increased.

If concrete is designed to have enhanced durability not only will it have a longer life span but the maintenance and repair work required over its life cycle can be significantly reduced thus further improving the structure's sustainability. As an example, if a normal concrete structure in a marine environment need to be repaired after ten to fifteen years due to different forms of deterioration, the repair materials, cement, water, aggregate, etc. are all environmental resources that add to the environmental impact.

The production of these materials requires energy which in turn generates carbon dioxide emissions. Transportation to the site, labor and other inputs result in added $CO_2$ emissions all of which add to the impact on the environment. By doubling the structures life or maintenance cycle there is a significant beneficial impact on its sustainability.

One of the most effective means of improving durability and extending the service life of concrete is to prevent the intrusion of deleterious substances into the substrate. This can be achieved by producing a less permeable concrete and involves the use of both water reducing admixtures to lower the water cement ratio as well as permeability reducing admixtures (PRAs) to lower capillary porosity. The less permeable the concrete the more sustainable it becomes. Aggressive substances that cause deterioration, such as chloride ions, carbon dioxide in the air or various other chemicals found in the soil such as sulfates, can diffuse into concrete via interconnected pores (capillary tracts), as well as surface cracks and micro cracks in the substrate. In addition, because cement is a chemical compound, there are various by-products of cement hydration inside the concrete that will react with these intruding liquids and gases. The resulting interactions can accelerate the deterioration of the concrete structure.

These chemical reactions that occur within concrete structures can have a devastating impact on resilience and strength. For example, carbon dioxide can reduce the pH of the concrete to 9 - 9.5 making it easier to initiate corrosion of the steel reinforcement. Using the inherent porosity of concrete, chloride ions can penetrate the surface of the steel reinforcement via the interconnected pores and cracks and when the concentration of chloride ions reaches a critical level it initiates the corrosion of the steel reinforcement.



The precondition for these chemical reactions to take place is their intrusion, via cracks or pores, into the concrete substrate. If we can block or reduce the porosity and heal the cracks in concrete then we can create an integral barrier which significantly reduces the rate of diffusion of liquids and gases.

A highly effective means of producing such a barrier in the concrete substrate is through the use of a reactive crystalline technology which generates a non-soluble crystalline structure inside the pores and cracks thus reducing the permeability of the treated concrete. It can be incorporated into a structure as it is being constructed or later on in the life cycle as a maintenance material that will further enhance durability.

Integral crystalline technology is manufactured in the form of a dry powder compound consisting of Portland cement, very fine treated silica sand, and proprietary chemicals. The proprietary chemicals are reactive with the by-products of cement hydration and combine within the concrete matrix to produce a non-soluble crystalline formation that blocks up the capillary tracts and fine shrinkage cracks in the concrete. Specific formulations are produced for application either as a coating material, concrete admixture or dry shake product.

When a cement particle hydrates, the reaction between water and the cement causes it to become a hard, solid, rocklike mass. The reaction also generates chemical by-products that lie dormant in the concrete. Crystalline technology adds another set of chemicals to the mixture. When these two groups, the by-products of cement hydration and the crystalline chemicals, are brought together in the presence of moisture, a chemical reaction occurs which produces a new non-soluble structure in the capillaries, micro cracks and macro cracks that are found in the concrete substrate. By means of the crystalline reaction the porosity of the concrete is greatly reduced and the ability of water or water borne chemicals to penetrate the substrate is greatly diminished.

Scanning electron microscope images show the newly-formed crystalline structures bridging and healing the capillary tracts and cracks in the concrete which reduces the diffusion of aggressive substances into the concrete and significantly extends the life of the structure.

In addition to visual evidence of the effect of the crystals in the form of electron microscope images both independent permeability and chemical resistance studies attest to the ability of crystalline technology to extend concrete structure service life by as much as a century.

## Chloride Attack

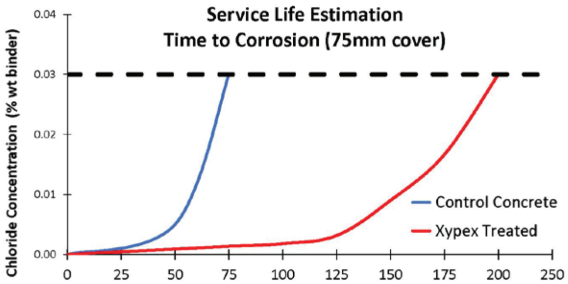
A common problem for marine structures, bridges and concrete structures along roadways in cold climates is chloride attack which occurs when chloride ions reach the steel reinforcement via interconnected pores and cracks in the concrete. Once the chloride ions have reached a critical concentration level they are able to break down the naturally passivating alkaline film surrounding the steel and form an electrochemical corrosion cell which results in the breakdown of the steel and the formation of rust which occupies a larger volume than the original steel.

| | Maximum Water-soluble Chloride Ion ($Cl^-$) in concrete (% by Weight of Cement) |
|---|---|
| Prestressed concrete | 0.06 |
| Reinforced concrete exposed to chloride in service | 0.25 |
| Reinforced concrete that will be dry or protected from moisture in service | 1.00 |
| Other reinforced concrete construction | 0.30 |

*Taken from Table 4.4.1 in ACI 318/318R*

When this occurs, expansion of the steel inside the concrete results in cracking and spalling eventually leading to reduction in the strength of the concrete structures.

Testing carried out at the University of New South Wales, (Australia) by the Australian Centre of Construction Innovation demonstrated that concrete integrally treated with Xypex Admix crystalline technology reduced the diffusion of chloride ions such that calculations based on estimated service life showed a doubling of the expected time to corrosion when compared to an untreated control mix. The chloride diffusion coefficient, derived from the Testing carried out at the University of New South Wales, (Australia) by the Australian Centre of Construction Innovation demonstrated that concrete integrally treated with Xypex Admix crystalline technology reduced the diffusion of chloride ions such that calculations based on estimated service life showed a doubling of the expected time to corrosion when compared to an untreated control mix. The chloride diffusion coefficient, derived from the chloride profile after long-term exposure, is considered one of the best indicators of chloride resistance.



## Field Testing Results – Chlorides

In addition to laboratory testing, several field investigations also show the effectiveness of crystalline waterproofing technology in reducing chloride attack.

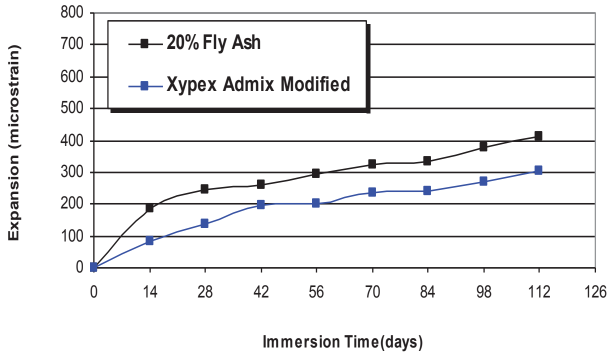
The University of Wisconsin-Milwaukee conducted field testing on nine bridges that had been treated with various corrosion mitigation strategies including surface sealers and three different admixtures. The Xypex crystalline treated bridge was constructed in 1995 leaving some areas of the bridge deck as control sections. The bridge was cored in 2000 and chloride concentrations taken at several depths including that of the reinforcing steel. The study found that the Xypex Crystalline admixture was the only one to significantly reduce chloride ingress. At a 2" (50 mm) depth, the Xypex treated bridge section showed an average 55% reduction in chloride content as compared with the control section.

## Sulfate Attack

Sulfate attack is a water borne mechanism whereby sulphate ions react with compounds in the cement matrix and produce an expansive reaction that disrupts the concrete and breaks it down. By waterproofing the concrete and decreasing the permeability of the substrate you greatly diminish the amount of sulphate ion that can diffuse into the pores of the concrete. If you can prevent the sulphates from entering the concrete then you can reduce sulphate attack and increase the resistance and durability of the concrete.

The reactive chemicals in Xypex's crystalline technology combine with various calcium compounds in the concrete. These calcium compounds are given off as by-products of cement hydration and are one building block for sulphate attack. By reacting with calcium hydroxide and turning it into anon-soluble complex the crystalline technology limits the amount of free CH available for the initial sulphate reaction. This has a direct effect on the rest of the sulphate corrosion process.

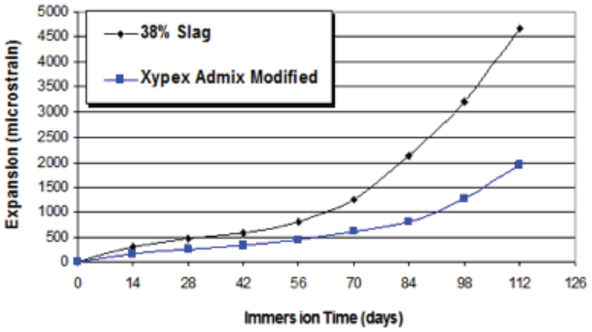
Testing for sulphate resistance per AS2350-14 showed the beneficial effect of crystalline technology on both fly ash and slag cement concretes with reductions in sulphate expansion ranging from 27% - 58%.



## Chemical Attack

Concrete can be attacked by acidic or caustic materials but the more prevalent form of attack is from acids. These acids can be manmade (think of battery acid) or naturally occurring (microbial induced corrosion in sanitary sewer structures, acetic and lactic acids in agriculture, acid mine waste) and can be classified as either weak or strong depending on how aggressive they are to Portland cement substrates. Caustic chemicals that may harm concrete are manmade such as sodium hydroxide (caustic soda) and are few in number.

One thing that all chemicals have in common is that they need to be in liquid form to attack the concrete. Chemicals in solid form can be stored on concrete surfaces without worry but once they are in liquid form they will have a measured pH level and will be able to penetrate the concrete through its inherent capillary porosity as well as micro and macro cracks.



Once inside concrete the acid reacts with calcium hydroxide to form a calcium salt which, depending on the acid, will be either very soluble or slightly soluble. As an example, acids such as hydrochloric, nitric, and sulfuric acids which are known to be aggressive produce calcium salts that are highly soluble whereas phosphoric or humic acids produce calcium salts that are not readily soluble.

The basic sulfuric acid reaction can be described as shown below:

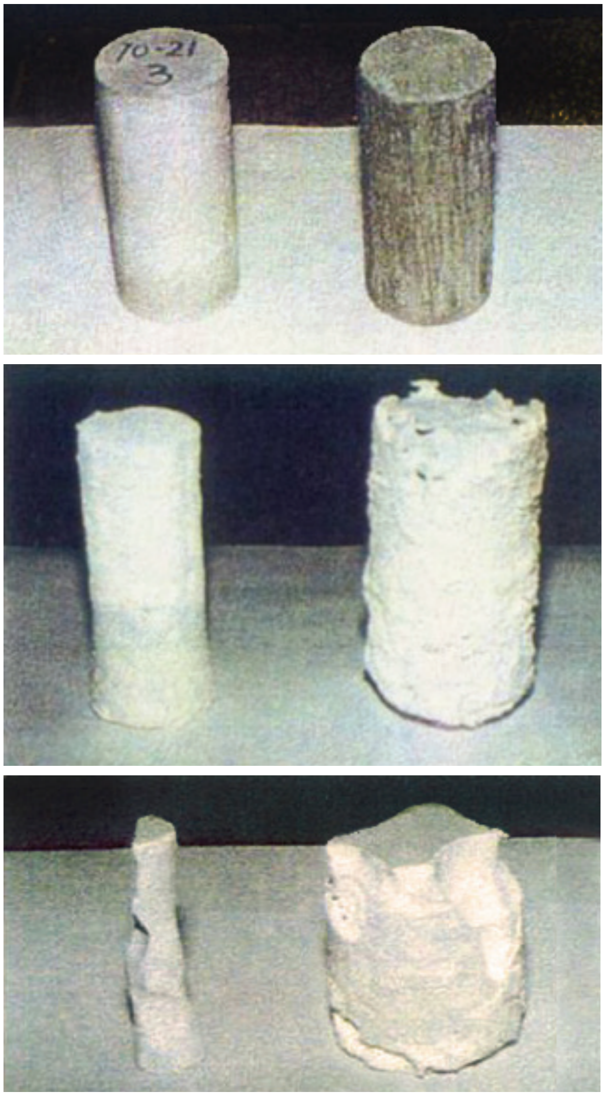
**Acid + Calcium Hydroxide = Calcium Salt + Water**

$$H_2SO_4 + Ca(OH)_2 = Ca(SO)_4 = 2H_2O$$

Once all of the calcium hydroxide is consumed the acid will then attack the calcium silicate hydrate which is the true cementing holding all of the aggregates together and this can cause substantial structural damage to concrete.

Chemical attack in any form results in deterioration of the concrete structure which affects not only its durability but also reduces the life of structure. Fortunately, the use of crystalline technology is one way to help mitigate this and increase both the durability and the service life of concrete structures by reducing permeability and protecting of the concrete over a wide pH range.

Testing has shown that concrete which has been treated with this technology has an enhanced resistance to chemicals where the pH range is from 3.0 - 11.0 in constant contact and 2.0 - 12.0 in periodic contact. Accelerated testing using the crystalline technology coating system in a 5% solution of sulfuric acid for 100 days displayed a. Both sets were subjected to a solution of 5% $H_2SO_4$ (pH 0.7) for 100 days. The Xypex treatment suppressed the erosion of the concrete mortar to 1/8 that of the untreated specimens.



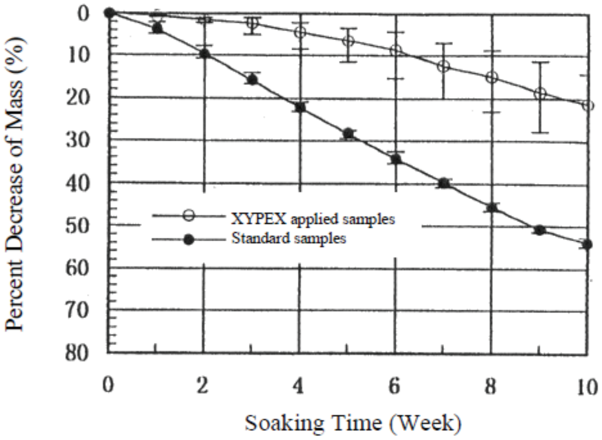
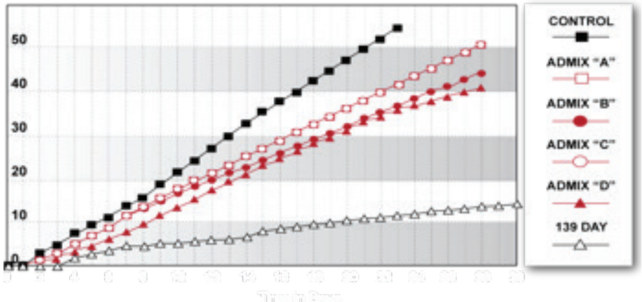


Figure-1 Change in mass of the samples in a 5% sulfuric acid solution environment.

Concrete samples containing the crystalline technology admixture were dosed at various rates (3, 5 & 7%) and evaluated against untreated concrete samples. All specimens were immersed in a 7% solution of sulfuric acid. Each day they were removed briefly from this solution and weighed to determine mass loss. This continued until each sample had lost 50% of its mass. The crystalline technology treated samples exhibited significantly lower mass loss than the control samples.



There are two aspects to the sustainability of concrete structures, The first is lifetime performance in terms of an extended service life and reduced maintenance to help minimize the impact that the structure has on the environment over the course of its life cycle. The second aspect that also needs to be considered is the impact that the selected materials or methods used have on the environment both now and in the future.

Crystalline waterproofing technology can be used as a concrete admixture or a coating system to eliminate the need for petroleum based membranes or coatings. The technology contains no VOCs which compares favorably with fluid applied membranes which may contain significant amounts of VOCs.

Unlike membranes and other surface coatings, crystalline waterproofing technology becomes an integral part of the concrete and cannot be punctured or damaged during backfilling and does not deteriorate over time thus reducing the possibility of ongoing maintenance needs. At the end of a structures life, concrete waterproofed with crystalline technology products (coatings, dry shake or admixture) is fully recyclable whereas concrete which has an adhered membrane cannot be recycled.

Because cement production is a substantial contributor of atmospheric $CO_2$, finding ways of fully extending service life leads to a reduction of cement consumption. Crystalline technology is fully compatible with fly ash and slag replacement in the concrete allowing the use of high replacement mix designs while still maintaining the same level of impermeability and performance.