WHITEPAPER

Protecting Precast Sewage Structures with Crystalline Technology

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Premature deterioration of reinforced concrete structures has become a worldwide problem due to its excessive cost effect, environmental impact, and safety issues. Over the last several years many countries and authorities have tried to quantify the impact and cost. The numbers are staggering.

Several studies made between 1998 and 2002 have shown that in the USA alone, corrosion was causing sewer asset losses estimated at around $14 billion per year.[1] In Belgium the figure was estimated to be £4 million per year[2] (5.7 million USD at current rates). Germany estimates the cost of sewer rehabilitation due to corrosion damage at €100 million[3] (109 million USD) and in Sydney, Australia, sewer pipe rehabilitation was estimated at AUS$40 million[4] (28 million USD) with much of the cost due to pipe corrosion.

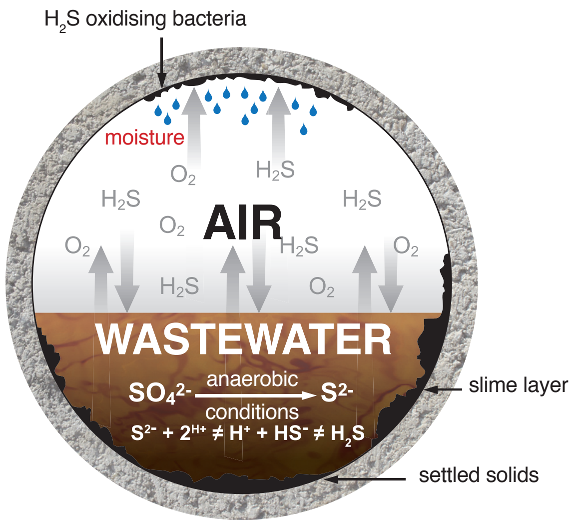
Both physical damage and chemical attack of concrete in sewage and septic systems is possible. However, chemical attack is much more prevalent and has two primary causes: acid attack and sulfate attack. In the wastewater industry, the acid attack mechanism is normally referred to as Microbial Induced Corrosion (MIC) – a process in which sulfides in the waste water stream are transformed by biological reactions into sulfuric acid. The sulfur compounds produced by this reaction penetrate the concrete substrate helping to initiate sulfate attack.

Household sewage and some industrial wastes contain organic matter which will break down and biodegrade in a relatively short time period. This biodegradation is the chemical dissolution of sewage materials by bacteria, fungi, or other biological means. In a sewer or septic environment, the bacteria most responsible for this are sulfate-reducing bacteria (SRB) which reside in a slime layer below the water level.

MIC deterioration at a wastewater treatment plant intake structure with a loss of approximately 2" of concrete.

SRB's, are one of the oldest forms of microorganism with a history that extends back 3.5 billion years. In a sewer system they reduce sulfate in large quantities to obtain energy and in turn produce sulfur compounds as a waste product. These sulfur compounds remain in the water and, when there is not enough turbulence to incorporate sufficient air into the water, the oxygen will be quickly depleted. In the resulting anaerobic (oxygen depleted) condition the bacteria will form hydrogen sulfide (H_2S) as a waste product.

While some of the hydrogen sulfide gas will diffuse out of the water, a certain percentage will remain in solution. If the flow of the sewer water is disturbed, a further significant amount of hydrogen sulfide gas will readily emerge from the solution and accumulate in areas of greater water turbulence such as manholes, lift stations and head work structures of wastewater treatment plants.



MIC corrosion process

Hydrogen sulfide gas is not by itself damaging to concrete. However, it will settle on the surface of the sewage water because it is heavier than air and circulate around a sewer structure's air filled cavity through convective currents. This H_2S, along with the carbon dioxide gas normally found in sewer structures, will dissolve into the moisture on the surface of sewer walls above the flow line and create both a weak sulfuric acid and carbonic acid on the interior surface of the sewer structure. This results in a lowering of the pH level at the surface of the concrete from 12.5 down to a pH of 9.

At higher pH levels the alkaline surface of concrete is not conducive to colonization by bacteria but, over time, the pH of the concrete surface is slowly reduced by both carbonation and the neutralizing effect of hydrogen sulfide in the form of dilute sulfuric acid. Once the pH of the concrete surface drops below 9 and there are sufficient nutrients as well as the presence of moisture and oxygen, the colonization by sulfur bacteria will begin thus initiating the process known as microbial induced corrosion (MIC).

Acidithiobacillus Bacteria Chart

Species Growth Range	Preferred Substrate	Preferred pH
T. Thioparus	H_2S, S^0, $S_2CO_3^{2-}$	5-9
T. Novellus	$S_2CO_3^{2-}$	2.5-8
T. Intermedium	$S_2CO_3^{2-}$	2.5-8
T. Neapolitanus	S^0, $S_2CO_3^{2-}$	3-7
T. Thiooxidans	H_2S, S^0	0.5-3

Typically this starts with T. Thioparus which is the first strain of bacteria to colonize the surface of sanitary and septic sewer structures. As this strain of bacteria continues to consume sulfur compounds it produces waste products with a more concentrated acid further reducing the pH level at the surface of the concrete. As this level drops further it is colonized by another species of bacteria which is able to exist at the lowered pH level while the original bacteria die off due to the reduced pH at the surface of the concrete.

This colonization and die-off of different bacteria continues until the ultimate colonization by T. Thiooxidans which is able to live in an environment where the pH level is as low as 0.5. This is roughly equivalent to a 5% solution of sulfuric acid. Once this point is reached it will cause severe acid attack and as sulfate ions penetrate into the concrete substrate it will also cause an expansive sulfate attack further opening up the concrete to even more and faster destruction.

Microbial Induced Corrosion is site specific and time specific. Therefore, not all of the concrete structures in a sewer collection system are subject to this type of attack. As long as the flow rate in the sewer is either two feet per second or greater, then there is generally not a problem. As a rough estimate, approximately 5% of a sewer system will be susceptible to corrosion. Most municipal authorities are aware of where the problem areas are likely to occur, based on local and historic knowledge or hydrogen sulfide modeling software.

Not all concrete in a sewer environment will be affected to the ultimate degree but once the surface of the concrete has been reduced to a pH 4.5 - 5 range, some initial deterioration in Portland cement structures will occur. The rate of deterioration may be anywhere from 1 mm - 20 mm per year, depending on the volume of hydrogen sulfide gas.

Improving Concrete Durability

There are various ways to increase concrete's the resistance to acids. These include proper mix design to reduce its permeability, enhanced mix design to withstand mild acid attack and finally, in extreme cases, the use of a suitable coating to protect against strong acid and sulfate attack.

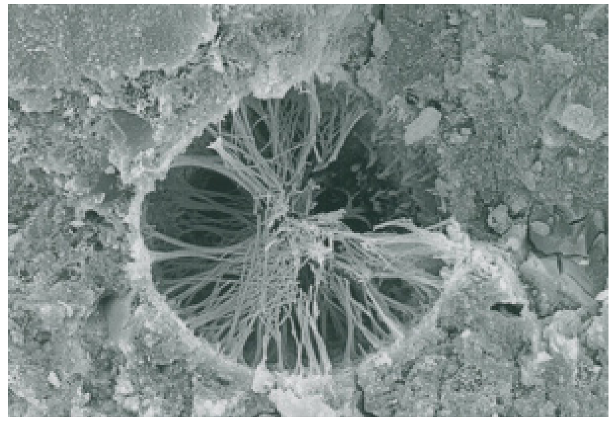
Diffusion or penetration of aggressive substances into concrete through the interconnected pores (e.g. capillary pores) and cracks causes material degradation and deterioration of the structure. Depending on the nature of the diffusive substances, they can attack concrete or the steel reinforcement. By blocking the pores and healing cracks, the mass-transfer rate into the concrete will be decreased thereby enhancing the concrete's durability and the longevity of the structure's service life.

Traditional means for improving the durability of the concrete are through reduction of the water/cement ratio (W/C) and by increasing the moist curing time. More recently, partial replacement of the Portland cement with supplementary cementitious materials (SCMs) such as fly ash and ground granulated blast furnace slag (GGBFS) has become more popular for increasing the durability of concrete exposed to aggressive environments. Nevertheless, it has been observed that these criteria are often not enough by themselves to produce a durable or high performance concrete.

Despite all efforts to increase the durability of concrete exposed to severe sewer environments, the problems still exist. This fact is behind the motivation to produce permeability reducing admixtures that can considerably reduce moisture and chemical transfer into concrete. However, the objective of these admixtures should be to not only reduce the permeability of concrete but to also enhance its resistance to chemical attack.

Crystalline Technology

Xypex crystalline technology is one solution for reducing the permeability of concrete which has also shown a significant improvement in enhancing concrete durability. It is designed to react with the by-products of cement hydration in the capillary tracts and voids of concrete to produce a non-soluble crystalline structure that blocks up the natural porosity of concrete.



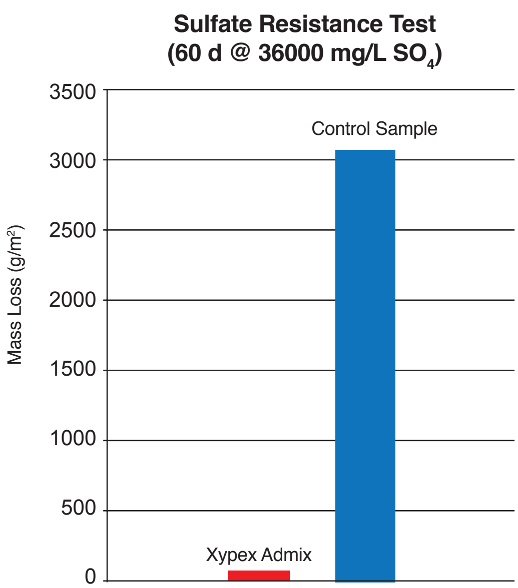
Scanning Electron Microscope image of crystalline formation in a concrete pore.

All causes of deterioration need these paths and passages in order to diffuse into the concrete. By plugging the pores, capillary tracts and micro-cracks with a crystalline formation the diffusion of liquids and gases is significantly reduced thus protecting concrete structures against effects of acid and sulfate attack. In addition to visual evidence of the crystalline formation in the voids of concrete through electron microscope images, independent tests confirm the ability of crystalline technology to significantly extend the service life of concrete structures. The result of this increased durability and longevity is less maintenance and repair work, and dramatically improved sustainability.

Precast concrete manholes manufactured with crystalline technology incorporating red pigment for easier identification.

Crystalline materials are available in powder form that can either be incorporated into a concrete mix for new structures or mixed with water into a slurry consistency for brush or spray application on the surface of existing concrete structures.

Xypex crystalline technology is an effective and inexpensive way to help protect concrete in acidic environments as low as pH 3 while also performing as a 'belt-and-suspenders' secondary line of defense in highly acidic environments. The U.S. Environmental Protection Agency estimates that 95% of manholes have an environment with a pH of 3 or above, making them suitable for a Xypex stand-alone treatment for waterproofing and chemical protection. The remaining 5% of manholes, having an even more aggressive environment, would also benefit from treatment with Xypex Crystalline Technology in conjunction with another complimentary level of protection against such highly aggressive MIC attack.



Accelerated sulfate corrosion test results.

In accelerated sulfate corrosion testing, 150 mm cubes cast with C30/37 classified concrete (4,500 PSI) were exposed to a highly concentrated sulfate solution (36,000 mg/l) for 60 days. Following exposure, all samples were weighed and examined for surface deterioration. The samples formulated with Xypex Admix C-1000 NF had a weight loss of between 38.6 - 90.5 g/m^2 and visual examination showed only minor deterioration at the edges. Control samples had a mass loss between 2,473.0 and 3,693 g/m^2 and visual examination showed significant surface deterioration over the entire surface of the cubes. Based on this testing, there is convincing evidence of Xypex Crystalline Technology's effectiveness in providing a marked increase in resistance when exposed to difficult sulfate conditions.

Terrebonne Parish manholes with crystalline admix show little deterioration after 10 years of service.

Case Study

Xypex Admix C-1000 Red was utilized in the manufacture of approximately 30 precast manholes in 1999 for the Clinton Street Sewer Collection Project in Terrebonne Parish, Louisiana. Xypex Admix was specified for waterproofing and provide chemical protection against degradation of concrete surfaces exposed to acid and sulfate attack. Xypex Admix with a red pigment was used for easy identification and verification of manholes treated with Xypex Admix. The manholes were inspected in August 2010 and found to be in excel- lent condition showing no signs of deterioration whatsoever after more than 10 years of exposure.

Conclusion

Durability of concrete depends on various parameters. In a sewer environment permeability and chemical resistance are especially important. The diffusion rate of aggressive substances is controlled by lowering the permeability of concrete. Lower permeability makes it more difficult for water and corrosive agents to penetrate the concrete. To produce watertight concrete, the influencing factors on permeability such as water/cement ratio, cement content, aggregate proportions and grading, proper vibrating and suitable curing method and duration must be considered. The effect of Xypex Admix on concrete permeability and chemical resistance is well documented. Multiple test results have demonstrated that Xypex Admix significantly enhances the quality and water-tightness of precast concrete products.

References:

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Jim Caruth is a Civil Engineering graduate from the University of Waterloo in Ontario Canada. He is a member of the Association of Professional Engineers of British Columbia and has 25 years of experience in the concrete construction industry. Jim’s background includes experience managing a fly ash importing and distribution company as well as managing the marine transportation division of a large ready mix plant and as the Operations Manager of 500,000 cubic yard per year ready mix operation. Jim also has experience with technical sales for a worldwide manufacturer and leader in the areas of concrete restoration and protection of which he has extensive knowledge.

Jim’s background also includes time on various ACI committees and as a Board Member of the British Columbia Chapter of ACI. He has been a voting member of the CSA A-3000 Cementitious Materials Compendium committee. Jim has also worked on and chaired several committees for the BC Ready Mixed Concrete Association including being awarded a Leadership and Contribution Award in 1998 and the BCRMCA 2003 Award for Outstanding Contribution to the Concrete Industry.

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