Increasing Coastal Concrete-Life with Hydrogel Technology

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Summary
Coastal concrete is an integral portion of global infrastructure, which has connected civilizations throughout time. Despite the long-term use, there are a plethora of issues resulting from the physical and chemical attack on concrete at the ports and coastal regions. The aggressive coastal environment causes premature concrete deterioration like cracking and carbonation. The ensuing permeability increase opens a direct path to the reinforcing steel thereby allowing chloride and sulphate attack. The long-term impact of this concrete deterioration on Government and Private entities is an endless strain on asset maintenance, repair budgets, insurance claims and litigation. Two methods were used to elucidate the impact of the hydrogel technology on concrete: BS EN 12930-8, Depth of Penetration Under Water Pressure and AASHTO T259, Test for Resistance of Concrete to Chloride Ion Penetration. The values reported from both methods confirmed that the hydrogel technology reduced water and chloride migration. The purpose of this paper was to showcase the novel use of hydrogel technology to increase the service life of concrete structures in ports and coastal regions among others

Keywords: Maritime, Hydrogels, Concrete, Service-Life, Maintenance

Introduction

Coastal concrete is an integral portion of global infrastructure, which has connected civilizations throughout time. Despite this long-term use, maintenance efforts have fallen behind as numerous issues associated with the physical and chemical attack of concrete along the coast persist. This chemical and physical attack is due to the aggressive marine environment at these coastal locations and ports. The concrete substrate acts as a hardened sponge with interconnecting pores from the surface of the concrete into the body. Harmful salt and deleterious materials from the marine environment penetrate the surface and migrate throughout the concrete body. These deleterious materials include chlorides and sulfates present in the surrounding seawater, as well as the coastal rock and sand. These salts can lead to Calcium Oxychloride (Ca-OXY) formation, which causes durability issues due to the expansive nature of Ca-OXY. Ca-OXY formation occurs due to the reaction of calcium hydroxide (CH) with calcium chloride ($CaCl_2$) or magnesium chloride (MgCl2) from salt (Suranenia, 2016). Ca-OXY is an expansive salt which causes premature concrete joint failure and furthers corrosive reactions within the hydrated cement matrix of the rest of the concrete structure (Suraneni, 2017). Concrete structures in marine environments experience reinforcing steel corrosion from chloride attack. Chlorides begin at the surface and slowly penetrate deeper into the subsurface, and in some cases the body of the concrete, weakening the interfacial zone between the aggregate, reinforcing steel and the hydrated cementitious matrix. Regardless of the origin and path, the result of chloride attack is corrosion of the reinforced steel within the concrete, leading to concrete that fails prematurely. The Portland Cement Association found that the leading cause of concrete deterioration is corrosion of reinforcing steel and other embedded metals (PCA, 2002). Steel corrosion causes expansion resulting in cracking, delamination, and spalling shown in **Figure 1**. The result of this deterioration is an endless strain on concrete maintenance and repair budgets.

Figure 1 - Damage of concrete surface due to chloride and sulphate attack (Belkowitz J. , 2015).

A hydrogel is recognized as a three-dimensional (3D) network of crosslinked, hydrophilic polymer chains. Hydrogels are an innovative means to effectively manipulate the pore and void structure of concrete (Krafcik M. B., 2018). Hydrogels have been used in concrete as a means to reduce the number of pathways that allow migration of deleterious materials (Krafcik M. M., 2017). In the case of the hydrogel technology, the silica-based hydrogel can absorb cementitious pore water, maintain the hydrogel 3D integrity, and (if the composition and environment of the hydrogel permits) develop into more of the backbone of concrete strength, calcium-silicate-hydrate (C-S-H) (Hu, 2019).

Data

<u>AASHTO T 259</u>

At both depths the HYD reduced the chloride concentration by more than 50% compared to the REF. The chlorides measured at both-depths (12.5- and 25.0-mm) is illustrated in bar chart form in **Figure 2** and shows the positive impact that the hydrogel technology has on reducing the amount of sodium chloride concentration. The T 259 test is designed to identify the impact that a concrete admixture or additive has on salt migration. Whether by mechanical or chemical action, the rate by which chlorides enter concrete is faster with chloride-based solutions when compared to solutions without chlorides (Honga, 2000). This chloride migration is made possible through the concrete pore network connectivity. (Winslow, 1994). The hydrated cementitious matrix of the concrete composite and the hydrogel caused a reduction in pores (and voids) and connection between pores in order to create the environment for a reduction in the permeability and the depth of chloride penetration.

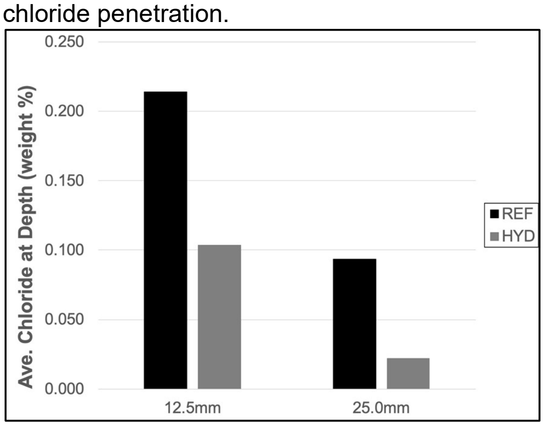

Figure 2 - Averaged T 259 data set from REF and HYD Samples

<u>BS 12930-8</u>

The depth of water penetration is illustrated in bar chart form in **Figure 3** and like the chloride penetration data, shows the positive influence that the hydrogel technology has on reducing water penetration under pressure. The application of the hydrogel technology (HYD) resulted in an average water depth reduction of over 50% when compared to the REF. Like the T 259, the water migration of the 12930-8 is related to the pores and pore connectivity within the hydrated cementitious matrix of the concrete composite. To reduce the depth of water penetration, the pathways or percolation must first be reduced. Furthermore, the material within these pathways must be robust enough, to withstand the pressured water penetration over time.

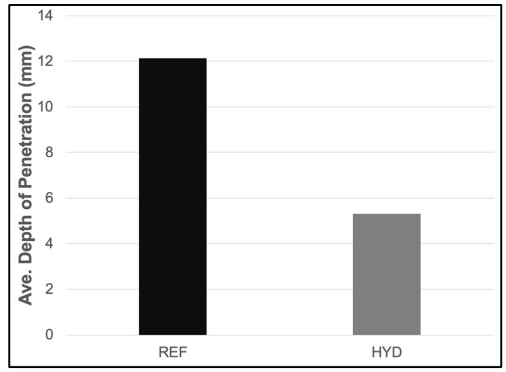

Figure 3 - Averaged 12930-8 data set from REF and HYD Samples

Conclusion

This paper introduced the reader to the susceptibility of concrete to the physical and chemical attack from contaminants like sodium chloride that are introduced and transmitted through the saltwater and surrounding rock and sand. Concrete's susceptibility to this water and chloride ingress leads to corrosion of the concrete and reinforcing steel, which is the number one cause for premature concrete failure. Based on the data and detail presented, the hydrogel technology can be used to prevent damage caused by migrating water and salts and extend the service-life of concrete in maritime environments. Application of surface-sprayed hydrogels protects the concrete surface, sub-surface, and in some cases, the concrete body. As mentioned, the hydrogel reacts with the cementitious compounds and by-products from cementitious hydration to form an improved surface which is harder and less permeable. The hydrogel penetrates hardened concrete and forms a gel within the pores of the concrete to reduce or eliminate the penetration of liquids. The positive impact of the hydrogel technology and the application resulted in concrete that was less permeable, with a greater resiliency to chloride penetration. Ultimately this research establishes the efficacy of the hydrogel technology to reduce water penetration, thus impeding the damage inducing chemicals and other elements from entering the concrete and reaching the steel reinforcement. The hardened, less permeable concrete that results from the application of these hydrogels protects the marine structure from further physical and chemical attack. If utilized proactively, these hydrogels can extend the service life of marine structures.