

INCREASING WATER RETAINING STRUCTURES LIFE AND SAFETY WITH HYDROGEL TECHNOLOGY

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Abstract

Water retaining concrete structures, specifically reinforced concrete, experience extensive damage due to repeated chemical and physical attack. This attack includes permeation of chlorides and sulfates and stimulates subsequent corrosion of reinforcing steel and soft water attack due to flowing of water and water processing. The recurring cycles of steel corrosion, passivation, and depassivation causes expansion resulting in concrete cracking, delamination, and spalling. The resulting damage leads to shortened concrete life-span and constant demand for repair and replacement of water retaining concrete structures. This research endeavor examined the impact of chloride penetration and depth of water penetration on treated concrete samples. A novel hydrogel technology that has been shown to improve overall concrete durability was compared to a reference mixture to determine the resistance to chemical and physical attack. Hydrogel technologies have been shown to chemically alter the surface and sub-surface of the concrete. This chemical reaction produces more of the backbone of concrete strength, calcium-silicate-hydrate (C-S-H), within the pore structure while reducing or immobilizing the lime, soluble alkalis, and other deleterious materials in the concrete pore solution. Additionally, the rapid formation of the hydrogel physically takes up space within any localized damaged areas inside the concrete to further prevent percolation on the damaged concrete. Ultimately it was shown in laboratory testing that hydrogel technology can be used to increase concrete resiliency to steel corrosion, extend the concrete life of water retaining structures, and reduce the need for premature repair and replacement.

Introduction

Concrete water retaining structures are hydraulic structures designed to obstruct the flow of water and retain water (HydroQuebec, 2021). These structures are highly exposed to harmful permeation of chlorides and subsequent corrosion of reinforcing steel, as well as extreme pressure from surrounding water. These structures are often surface treated by waterproofing with sealers to prevent the passage of water under hydrostatic pressure.

Corrosion of reinforcing bars induced by chloride ion permeation is a major cause of damage in water retaining structures. Chloride attack is responsible for 40% of all concrete deterioration (Mishra, 2021) and is a direct result of the concrete permeability to include pore content, pore size and pore connectivity (Garboczi, 1999). The hardened cement paste of concrete contains voids and capillaries that are created by the excess water in the paste, lack of full hydration, or cracking. These voids contribute to the penetrability of the concrete and allow water and chloride ions to penetrate (Thomas, 2016). Chlorides begin at the surface and slowly penetrate deeper into the subsurface and interfacial zone. The result of chloride attack is corrosion of the reinforced steel within the concrete leading to concrete that fails prematurely.

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In a normal concrete the alkalinity of the concrete protects steel reinforcement from corrosion. High pH value from calcium hydroxide and other deposited alkalis from the cementitious binder facilitate a thin protective layer made of stable ferric-oxides on the surface of the steel which create the passive protection of the reinforcement (Bonic, Curcic, Davidovic, & Savic, 2015) called the passivation layer. This layer is impermeable and stable as long as the pH value of concrete is sufficiently high ($\text{pH} > 11$). However, when the protective layer is disrupted by the amount of chlorides in the pore water around the reinforcement bars, the reinforcement is the passivation layer breaks down and the corrosion process starts again increasing the amount of corroded at the interfacial zone between the reinforcing steel and concrete. (Bonic, Curcic, Davidovic, & Savic, 2015). Steel corrosion causes expansion resulting in cracking, delamination, and spalling. Chloride attack and corrosion is magnified by soft water attack that occurs in many water retaining structures.

Soft water attack occurs in areas where the water, flowing or standing, immediately adjacent to a concrete structure is characterized by a low dissolved ion content. When Portland cement-based concrete is in contact with soft water, the calcium hydroxide (CH) in the hardened cement matrix is leached out as the water tries to establish an ion balance. This leaching of ions from the hydrated matrix of the concrete composite causes a breakdown and softening of the concrete matrix. Many water retaining structures utilize ultraviolet (UV) treatment to disinfect the water. This UV treatment results in low dissolved ion content and the softening of the concrete surface through soft water attack.

The damage due to chlorides and soft water attack is magnified in areas of the structure which experience condensation and wet dry cycles. The soffits of the water retaining structures experience exposure to aerosol particles that are formed from the surrounding water (Anchor, 1981). These particles include organic and inorganic salts. Due to the small particle size and high surface area, these particles cause a drastic effect and are largely responsible for corrosion of reinforced concrete steel through chloride attack. Additionally, in zones of the concrete that experience constant wetting and drying cycles undergo volume change that results in cracked concrete. The cracks increase pore connection and increase the permeability of concrete, ultimately leading to a concrete that is more susceptible to chlorides and corrosion. A waterproofing solution is required to protect the concrete surface from this chemical damage.

Hydrogels have been utilized in the field to effectively manipulate the pore and void structure of deteriorated concrete to reduce the number of pathways that allow migration of deleterious materials (Global, 2020). Hydrogels also absorb the excess water and therefore limit the amount of water that can subsequently migrate through the material. The hydrogels in this research project contain pozzolanic materials that consume calcium hydroxide and other salts to increase the production C-S-H and therefore create a stronger and denser concrete. In addition, the instantaneous creation of the hydrogel physically takes up space within any localized damaged areas inside the concrete. This physical takeover stops percolation and creates a sealing effect so that the concrete is hardened. A denser material reduces the ability for water and harmful chemicals to migrate through the concrete. The objective of this research endeavor was to illustrate the efficacy of a novel hydrogel technology to increase the service life of water retaining structures.

Materials and Methods

An ASTM C 150, Type I/II Portland cement with a Blaine fineness (surface area, m²/g) of 0.345 m²/g was used as the primary cementitious material for experimentation (ASTM International, 2020). The cement composite and concrete samples were made using Portland cement with a chemical composition of: SiO₂, 19.9%; CaO, 63.9%; Al₂O₃, 4.8%; Fe₂O₃, 3.2%; C₃S, 57%; C₂S, 13%; and C₃A, 7%. Two hydrogel technologies by Markham Global, Aquron 2000 and B50 (HYD1 and HYD2), were compared to a reference mixture of standard Portland Cement Concrete. HYD1 was sprayed on top of the concrete samples, over a number of light passes to achieve the coverage rate, listed in Table 1, and satisfy the absorbency of the concrete. HYD2 was mixed into the concrete as a liquid dispersion at the dosage listed in Table 1.

AASHTO T 259 was utilized to determine the resistance of concrete specimens to the penetration of chloride ions. The samples were moist cured for 14-days and then dried until 28-days. HYD 1 hydrogel technology was sprayed onto the concrete surface at 21-days. The samples were then abraded, dams were placed along the edges of the samples, the samples were returned to the drying room, and then ponding of 3% sodium chloride solution was performed at 42-days. The samples were covered in accordance to AASHTO T 259 to prevent evaporation and at 90-days sodium chloride analysis was performed.

BS EN 12390 was utilized to determine the depth of penetration of water under pressure in hardened concrete which has been cured (Institution, 2021). This water pressure is representative of the pressure water retaining structures experience in the field. For the laboratory testing, water is applied under pressure to the surface of hardened concrete. The specimen is then split and the depth of penetration was measured at 90-days after curing.

Table 1 – Concrete Mix Design

Materials / Mix ID	REFERENCE (REF)	HYD 1	HYD 2
Portland Cement (kg/m ³)	307	307	307
Water (kg/m ³)	145	145	145
w/c Ratio	0.47	0.47	0.47
Coarse Aggregate (kg/m ³)	1074	1074	1074
Fine Aggregate (kg/m ³)	820	820	820
Fine / Coarse Aggregate Ratio	0.76	0.76	0.76
High Range Water Reducer (mL/100 kg)	326	326	326
Air Entrainment (mL/100 kg)	42	44	44
HYD 1 (m ² /L)	-	4.5	-
HYD 2 (m ² /L)	-	-	587

Results

The AASTHO T 259 results showed a significant decrease in chloride reduction at both 1.27 centimeters (cm) and 2.54 centimeters when comparing the HYD1 and HYD 2 mixtures to the REF mixture, as shown in Figure 1. The HYD1 reduced chloride penetration by 51% and 76% at 1.27 centimeters and 2.54 centimeters, respectively. The HYD2 reduced chloride penetration by 50% and 71% at 1.27 centimeters and 2.54 centimeters, respectively. This indicates that the both the topical and spray on hydrogel technology densified the concrete to reduce chloride penetration and overall permeability.

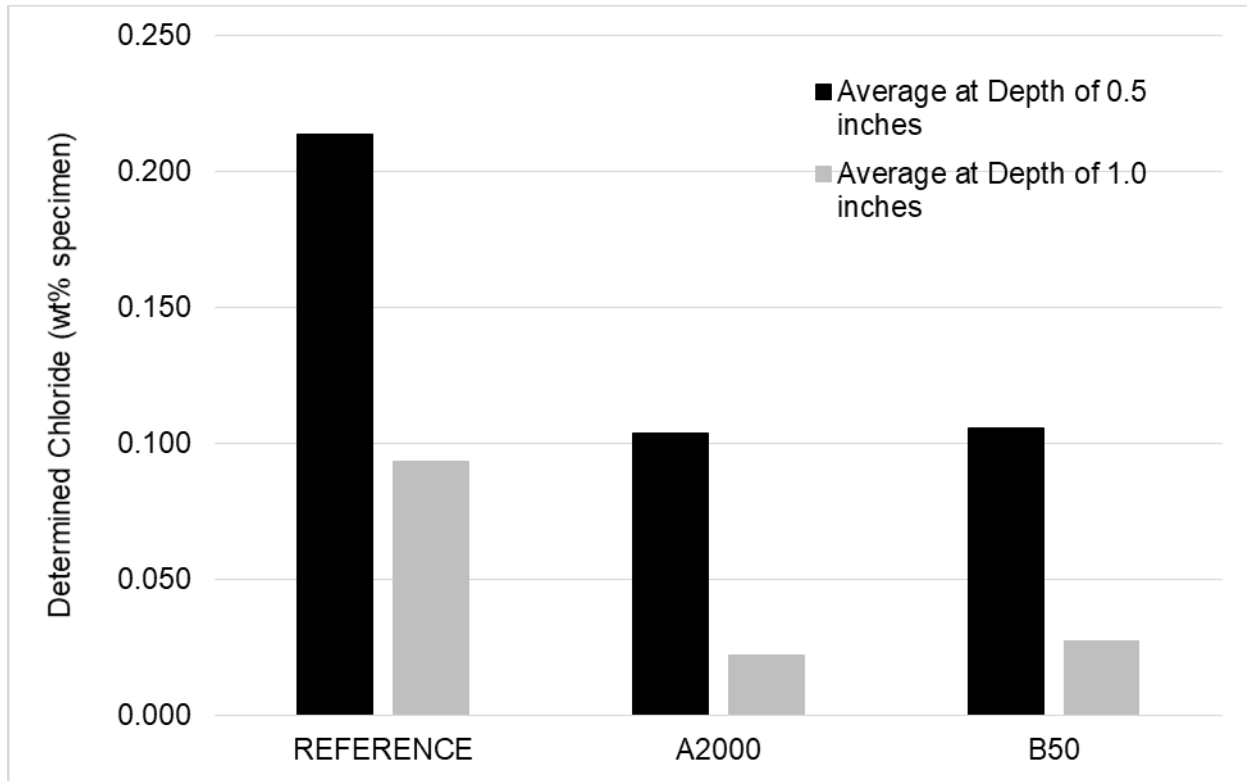


Figure 1 – Chloride Penetration at 1.27 cm and 2.54 cm

The reduction in permeability as demonstrated by chloride penetration results was supported by the BS EN 12390 results for both the HYD1 and HYD2. BS EN 12390 shows the depth of penetration of water under pressure, similar to that experienced in a water retaining structure. The A2000 and B50 showed a 56% and 49% reduction, respectively, when compared to the reference as shown in Table 2. This indicates that the A2000 and B50 are effective at waterproofing the concrete surface to prevent penetration of water.

Table 2 – BS EN 12390 Test Results

Mix ID	Sample	Maximum Depth of Penetration (mm)	Average Depth of Penetration (mm)	Average Change from REF (%)
REF	A	17.25	12.12	-
	B	10.69		
	C	8.41		
HYD1	A	5.92	5.30	57.26
	B	5.88		
	C	4.10		
HYD2	A	5.43	6.33	48.80
	B	7.22		
	C	24.09		

Discussion

Permeation of water and constituents to the concrete pore is a detrimental issue which causes susceptibility to chemical and physical attack, and ultimately premature failure of the concrete surface. Inside the body of hardened concrete, an interconnected system of capillary pores runs from the surface of the concrete throughout the body. Water, salts, and other deleterious materials travel through these channels and can reduce the integrity of concrete. Therefore, measuring the penetration of chlorides through AASHTO T 259 and the depth of penetration of water through BS EN 12390 indicate the concretes susceptibility to chemical attack through these channels.

Water retaining structures experience chloride attack and soft water attack, specifically in areas of condensation and wetting and drying cycles that result in premature failure of the concrete structure. Hydrogel technologies have been shown to chemically alter the surface and sub-surface of the concrete and proven to extend the life of concrete structures (Global, 2020). This chemical reaction produces more of the backbone of concrete strength (C-S-H and other hardened phases) within the pore structure while reducing or immobilizing the lime, soluble alkalis, and other deleterious materials in the concrete pore solution (Global, 2020). The C-S-H is the hardened microstructure of the concrete matrix that develops from the hydration of cementitious of materials and water. C-S-H production within the concrete pore-structure ultimately leads to a denser concrete and a less permeable concrete. The reduction in permeability of the concrete was illustrated by the AASHTO T 259 and BS EN 12390 testing.

Conclusion

This hydrogel technology can be used as waterproofing solution to prevent damage and extend the service-life of concrete in water retaining structures. Hydrogels not only harden the concrete but also prevent damage due to softening from soft water attack in concrete structures. Any surface softening and damage of the concrete increase the rate of water and chloride migration into the concrete, thus accelerating the damage to the concrete body. Application of surface-sprayed and integral hydrogels on concrete works to protect the surface. 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 penetration of chlorides and water. This results in concrete that is less permeable to reduce or nearly eliminate water penetration, thus stopping the migration of damage inducing chemicals and other elements from entering the concrete and damage.

To help prevent the corrosion of reinforced steel due to chloride attack, these hydrogels can be spray applied or mixed into the concrete. The hydrogels create a less porous concrete which slows the deleterious effects that would lead to a deterioration of concrete and steel corrosion. The data presented and evaluated illustrates the impact that hydrogels have on concrete permeability, chloride migration and should be considered as a powerful tool to extend the service life of concrete water retaining structures.

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