Corrosion Resistant Reinforced Concrete for Marine Environments

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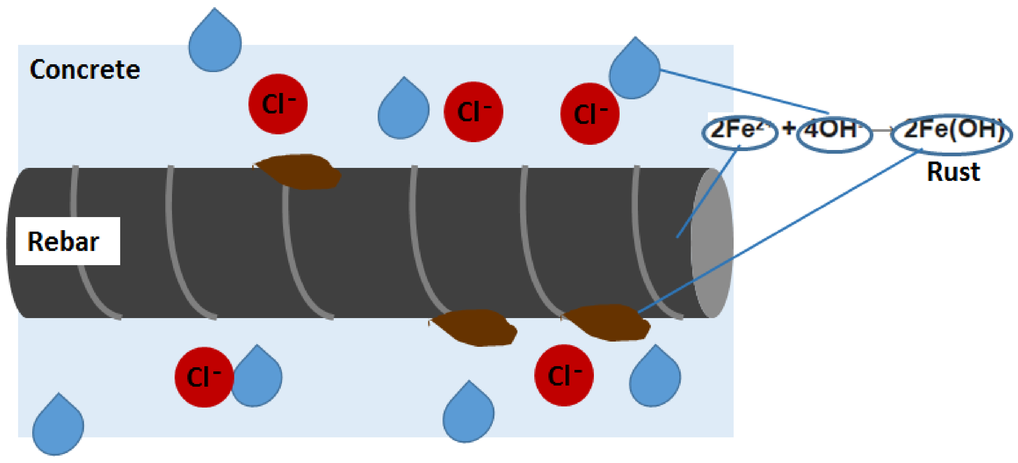
1. Abstract

Corrosion of internal rebar is the leading cause of failure for reinforced concrete in marine environments. The natural permeability of concrete to water and salt ions from the environment leads to chlorine ions diffusing through the concrete and into contact with the underlying steel reinforcement—accelerating oxidation and corrosion of the rebar. The resulting oxidation products exhibit a positive volume change that is constrained by the surrounding concrete, creating internal tensile stresses. Internal stresses facilitate cracking of the overlaying concrete, further accelerating chloride permeability and rebar oxidation that eventually leads to spallation and failure of the concrete. This research explores the efficacy of modifying the concrete composition with additions of: silica fume, Hycrete, and fly ash to resist corrosion and to increase its service life. As chloride permeability is difficult to measure, surface electrical resistivity is leveraged as a proxy measure of chloride permeability, with chloride permeability and electrical resistivity exhibiting a negative correlation. Four select concrete compositions were developed and tested for initial workability; with surface and bulk resistivity, compressive strength, and splitting tensile strength evaluated on cylindrical test specimens at 7 day intervals post-cure, up to 21 days. With considerable effort to consider cost and sustainability, a ranking system was also developed to select the optimal concrete composition to meet the demands of the Navy. This lead to the selection of a concrete composition modified with 10% silica fume in place of Portland cement as the optimal solution, when considering resistivity, workability, and cost.

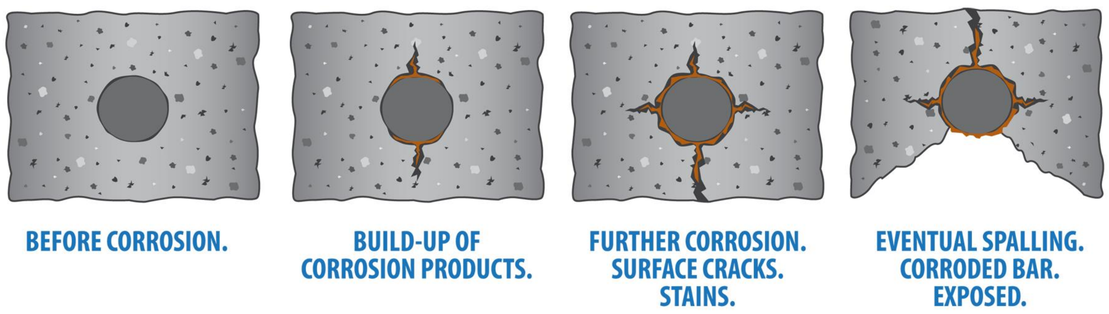
2. Background

Marine environments accelerate the deterioration of reinforced concrete. The high concentration of salt ions, in particular: chloride ions, accelerate corrosion of the internal steel reinforcement as illustrated below.



Corrosion of the steel reinforcement is accelerated with the presence of chloride ions

As the rust begins to form, the volume increase within the concrete causes an internal tensile strain. Concrete is superb in compression strength, but lacks in tensile strength. The internal tensile strain causes cracking and eventually the concrete breaks away from the steel reinforcement as illustrated below[1].



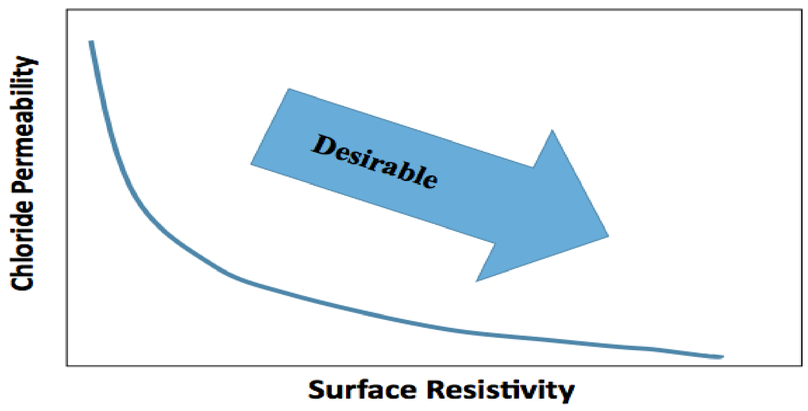
Concrete is composed of fine aggregate (sand), coarse aggregate (gravel or crashed stone), water, and portland cement. Additives can be used to change concrete's characteristics, specifically its permeability.

3. Project Goal

Determine a concrete composition that inhibits the formation of corrosion on the surface of the internal steel reinforcement.

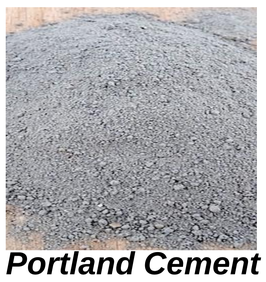
Objective:

1. Increase electrical resistivity to decrease chloride permeability
2. Develop a concrete property ranking system best fitting the Navy's needs.



There is an inverse correlation between chloride permeability and surface resistivity[2]. Testing chloride permeability is rather challenging, so relating it to surface resistivity and simply measuring surface resistivity saves time and resources.

4. Proposed Solutions-Using additives to increase electrical resistivity



Portland Cement
Calcium Silicate Hydraulic Cement
I

Silica Fume
Byproduct of the production of silicon and ferrosilicon in an electric arc furnace
II

Fly Ash
Byproduct of coal combustion
III

Hycrete X1000
Manmade, water based material
IV

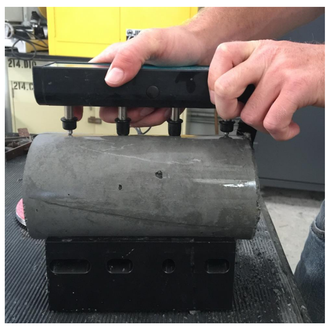
I) Portland Cement - Our standard control mixture, no additives
II) Silica Fume – 10% of the Portland cement in mixture is replaced
III) Fly Ash – 40% of the Portland cement in mixture is replaced
IV) Hycrete X1000 – Per cubic yard, two gallons of water were replaced

5. Testing

I

II

III



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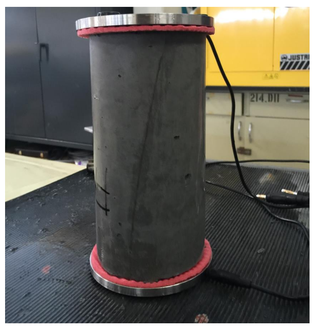

V

I) Splitting Tensile Test
II) Compression Test
III) Slump Test (Workability)
IV) Surface Resistivity
V) Bulk Resistivity

Testing was done on cylinders 8 inches in length and 4 inches in diameter at 7 day intervals, up to 21 days.

6. Results

	Electrical Resistivity	Cost	Workability	Compressive Strength
Portland Cement	standard	standard	standard	standard
Fly Ash	standard	standard	2X standard	1/2 standard
Silica Fume	2X standard	2X standard	1/2 standard	standard
Hycrete	standard	standard	standard	standard

Table 1: A comparison of concrete compositions based off of desired traits with portland cement as the standard.

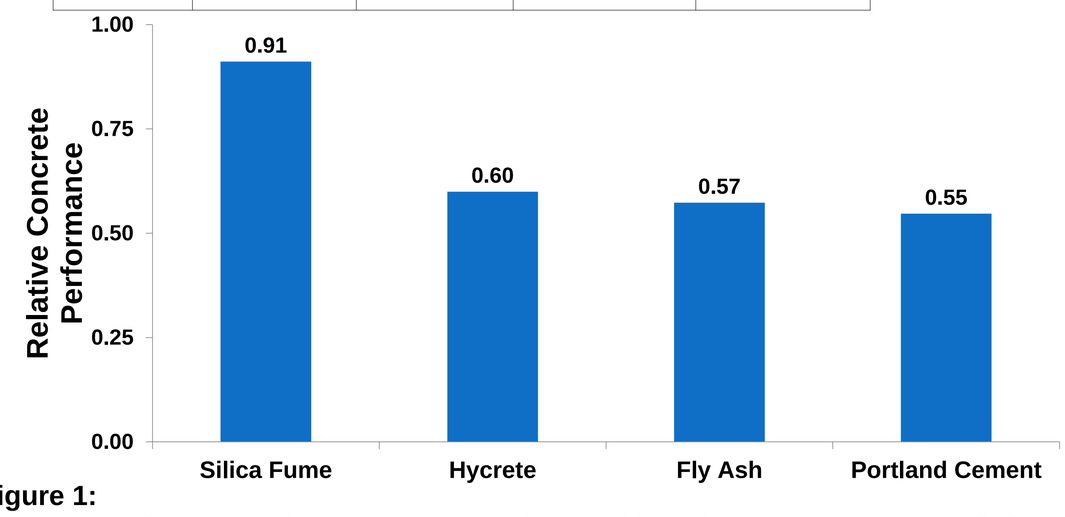

Figure 1:
A relative performance of concrete compositions and how they compare based off of the resistivity, cost, strength, and workability, respectively. 1.00 is the most desired attainable value.

7. Conclusion & Further Work

Conclusion:
Keeping resistivity, cost, strength, and workability in mind, our ranking system shows silica fume as a partial cement replacement to be the best solution between the tested concrete compositions.

Further Work:

1. It should be noted incorrect mixing of silica fume can cause an alkali silica reaction which significantly decrease service life of reinforced concrete. Investigation of techniques to overcome this problem should be investigated.
2. Explore the effectiveness of our modified concrete samples in a marine environment
3. Develop a correlation between electrical resistivity and concrete service life

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References

1. http://thehelpfulengineer.com/index.php/2010/10/carbonation-of-concrete-corrosion/
2. Surface Resistivity Test Evaluation As An Indicator of The Chloride Permeability of Concrete. (n.d.). Retrieved August 08, 2016, from http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/13024/index.cfm