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The Corrosion Behavior of AISI 304L Stainless Steel in Simulated Concrete Pore Solution. And A New Marketing Plan for Stainless Steel Rebars.

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Abstract

The purpose of this project is to study the corrosion behavior of AISI 304L stainless steel, and to present the results for a new marketing strategy for a steel rebar manufacturer. This experiment involved the usage of cyclic potentiodynamic polarization tests to investigate the effect of chlorides on the pitting corrosion behavior of AISI 304L stainless steel in a simulated concrete pore solution with 3.5 wt.% chlorides. The results of this experiment showed that the chlorides caused a large increase in the corrosion current density of AISI 304L stainless steel indicating increased susceptibility to general corrosion and pitting corrosion. The corrosion marketing project resulted in a ready-to-go marketing plan for a rebar manufacturer including a direct mail sales letter, a campaign chart, and instructions for how to test and improve the marketing campaign.

Executive Summary

The purpose of this project has two parts. The first is to study the corrosion behavior of AISI 304L stainless steel in a simulated concrete pore solution. It's well known that chlorides are the cause of corrosion-related failures for reinforced concrete structures. This project studies the effect of those chlorides on localized pitting corrosion. The second purpose for this project is to create a new marketing strategy for selling greater amounts of stainless steel rebars to concrete contractors. This part of the project is important because it gives new companies, researchers, and entrepreneurs a better way to push their products into the market. It also helps to ensure concrete contractors are using long lasting corrosion resistant materials to build structures- which saves money on costly repairs as well as lives lost due to corrosion-related disasters.

To study the corrosion of AISI 304L stainless steel in the presence of chlorides, cyclic potentiodynamic polarization tests were used. The experimental limitations for this project include a lack of visual testing for the steel- however, these problems can easily be solved in the future by conducting different electrochemical tests, a weight loss experiment, and a salt-fog test using different types of steel.

The results for this experiment show that chlorides cause a large increase in the corrosion current density of AISI 304L stainless steel meaning the corrosion rate is much higher. The tests also showed increased susceptibility to pitting because of the large hysteresis between the forward and reverse reactions during the cyclic potentiodynamic polarization experiment, as well as the decrease in corrosion potential which indicates the breakdown of the protective passive layer. The results for the Corrosion Marketing Project included a ready-to-go marketing plan for a Steel Rebar Company that includes a strategic diagram and a sales letter.

The experimental recommendations for this project include future tests to build on the results for this experiment. These tests would include multiple CPP tests at different chloride concentrations and a salt fog chamber test AISI 304L, AISI 316, and carbon steel to visually compare the damages and further validate the results of this project.

The marketing recommendations for this project can be used by a Rebar Company. The first step is to use the sales letter shown later in this report by sending it through direct mail in plain white envelopes and first class postage to different concrete contractors. These letters will move decision makers to call a salesperson at the facility creating inbound sales leads instead of outbound leads. Then track the results to calculate the return on investment using the lifetime value of a customer. If the return on investment is positive- then scale the marketing campaign. If the return on investment is not high enough, then adjust the mailing list or the sales letter until the results are scalable.

Introduction

This report features Kenny Aronson's Honor's Project completed in 2020. There are two parts of this project. The first part studies the corrosion behavior of AISI 304L stainless steel in a simulated concrete pore solution. The second part is a Corrosion Marketing Project where the goal is to create a new marketing plan for a Steel Rebar Manufacturer.

Corrosion is an expensive problem for any structure made with reinforced steel concrete. A recent NACE study estimated the yearly cost for bridge repair due to corrosion activity as $13.6 billion per year. The rest of this report will go deeper into the corrosion behavior behind those costs, strategies to reduce those costs, and how to get more companies in the United States to reduce their corrosion risk in concrete structures (NACE International. Highways and Bridges).

This project the corrosion behavior of AISI 304L stainless steel in a simulated concrete pore solution. This report will examine the tendency for AISI 304L to suffer from pitting corrosion in two scenarios. One is a test in a concrete pore solution with no chlorides. The other test happens concrete pore solution with 3.5% NaCl. These two tests are used because the most common cause of corrosion failure for reinforcing rebars is chloride ingress. And these two tests will help to show how those chlorides affect the corrosion rate and electrochemical parameters of AISI 304L Stainless steel. This phenomenon will be discussed more in the background section.

This part of the project started with planning the experiments. A project proposal was created and sent off to the Honor's College detailing what experiments were to be conducted, what materials, and a timeline for completion. This is where the team determined that AISI 304L stainless steel was to be studied, along with cyclic potentiodynamic polarization (CPP) tests because they're great for studying the localized corrosion behavior of metals.

After the plan was ready, the experiments were completed with the help of graduate student Ulises Martin Diaz. These experiments resulted in a set of CPP plots, a table of electrochemical parameters for the different tests, and a discussion around those results.

After the tests for AISI 304L stainless steel were finished, the data was analyzed and reported. This analysis includes an interpretation of what the CPP plots mean for the corrosion behavior of AISI 304L stainless steel- and they can be found in the Results and Conclusions section. After this, the corrosion marketing project began. The purpose of this portion of this part of the project was to gain experience in how to turn a theoretical idea or new technology into a real world business. This project also shows how an existing company can push more of their products into the market- and how rebar manufacturers can push safer reinforcing materials into the Concrete Industry. The corrosion marketing project involved the creation of a marketing plan for how to sell more stainless steel to concrete contractors.

The scope of the Corrosion Marketing Project involves research, strategy, planning, and writing for a sales letter for a Stainless Steel Rebar Manufacturer. This material, as well as an execution plan for how to use this marketing material, are also found in the "Marketing Process and Results" section.

This project is important for many reasons. As stated earlier, NACE estimated the yearly bridge repair cost due to corrosion as $13.6 billion. Not only that, concrete-related disasters are responsible for lost lives all over the world every year. And this great expense in money and lives can be reduced by building concrete structures with safer materials. This investigation should shows concrete contractors, governments, and construction companies can use better materials so they can cut down on their yearly repairs.

Where things get tricky is how these corrosion disasters can be hard to detect. Many concrete-related disasters are due to the formation of small pits and cracks which lead to sudden failure by stress corrosion cracking. This report studies how these small pits and cracks form, how big of a problem they are for AISI 304L stainless steel- and how chlorides play a role in the localized corrosion of AISI 304L steel.

The Corrosion Marketing Project is also important, because research, innovation, and brainstorming new technologies is only half of the battle. The other half is figuring out a way to push these new inventions or ideas into existing businesses- or how to turn them into a new business. Efficiently taking great ideas out into the real world is a tough and expensive problem for many entrepreneurs, academics, and companies. This part of the project will investigate a stronger way to sell more stainless steel rebars for a real manufacturer- and it can also be used by other researchers, inventors, and academic entrepreneurs who want to bring their ideas to market.

The rest of this report is laid out in a logical order. The next section is the Background- where much of the existing research on AISI 304L stainless steel, corrosion in concrete pores, and pitting is found. The background section also includes predictions for what was expected to happen during the tests. The next section is the Experimental Methods section- which includes a discussion of what experiments were selected, as well as reference materials for how to reproduce these tests.

The next section of this report is our data and analysis section where the charts and data are presented. Then the discussion and conclusions section contains a discussion around the data, what it means, and how it can be applied to the real world. Finally, there's the Marketing Process and Results section which has an overview for the strategy, research, and materials created during the Corrosion Marketing Project.

Background

Concrete is the most common construction material used for load bearing elements. That concrete is typically reinforced with either carbon steel, AISI 316 Stainless steel, or AISI 304L stainless steel. Reinforced concrete is the main building material for thousands of buildings, bridges, and structures all over the United States. AISI 304L stainless steel is a great choice for rebars due to its great corrosion resistance, good mechanical properties, formability, and its chromia passive layer which protects the metal against corrosion. (Lekatou A. 2013, S. Tsouli. 2018)

Reinforced concrete can last for hundreds of years. But the biggest threat to any structure made of concrete is rapid deterioration of safety and service life due to rebar corrosion. (Liu Jin 2020) This corrosion is normally due to either concrete carbonation or through chloride ingress into the pore structure which causes a decrease in the pH of the local solution- resulting in accelerated corrosion in the local environment (I.G. Ogunsanya 2019, Sang Ah Lee 2020). This usually happens when concrete is subjected to an aggressive marine environment such as a bridge or a pier. (A. Baustista 2015, S Ahmad 2003, M. Moreno 2004) However, stainless-steels have been the go-to material choice for aggressive environments for creating concrete structures which last longer (M. Serdar 2013, H. Luo 2015, A. Fattah 2016). However even stainless steels are susceptible to pitting corrosion if the protective film is damaged or in the presence of chloride ions. This report focuses on the effects of chloride ingress for AISI 304L stainless steel reinforced concrete.

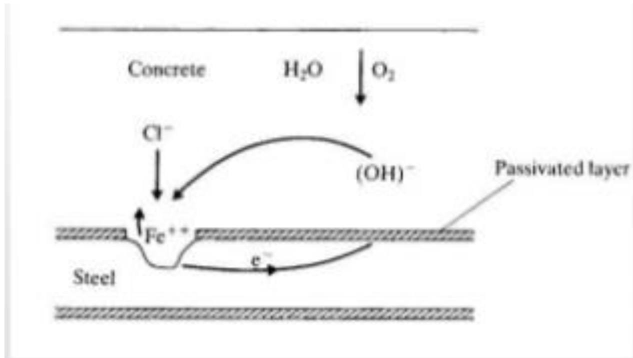

Figure 1: Chloride penetration for steel rebars, (Khan Shahzada. Presentation on Chloride Ingress.)

Figure 1 above shows the mechanism for chloride penetration in steel-reinforced concrete. Normally, a concrete pore has a pH of 13.5 due to the presence of $Ca(OH)_2$. At this pH, a chromia passive layer forms which protects the steel.. However, when the chlorides penetrate the concrete matrix, and lower the pH- the local passive layer breaks down, corrosion occurs- and those corrosion products lead to internal stresses, rebar cracks and spalls. (Apostolopoulos 2013) It's well known that the first step for any stress corrosion cracking incident starts with disruption of the passive surface film. (J. Orlikowski 2005, S. Nemat 2001, K. Ishikawa 1992, S.A. Serebrinsky 2004)

This project studies the corrosion behavior AISI 304L stainless steel in two scenarios. The first will be a test happening in concrete pore solution with no chlorides. The second test will happen in simulated concrete pore solution with 3.5% sodium chloride. The goal for this setup is to simulate chloride ingress through the concrete matrix to compare and contrast the electrochemical behavior for AISI 304L stainless steel in both scenarios.

Based on previous experiments- it was predicted that these tests would show a positive negative in the pitting potential of AISI 304L steel in the presence of chlorides. This would explain the metals increased susceptibility to localized corrosion and failure. It's also predicted that the

Concrete Pore tests with chlorides present will show a higher corrosion current density. The results of these experiments are shown in the Data and Results section of this report. (Neusa Alonso-Falleiros 2002, H. Luo 2012, S. Farjardo 2010)

Austenitic stainless steels in concrete have a passive layer that protects the bare metal. The concrete environment can change the composition of the passive layer- so there's some controversy surrounding its composition, but it is usually made of Fe, Cr, Ni, and Mo. (L Freire 2010, C.M Abreu 2004, TJ, Mesquita) In order for localized corrosion to happen (pitting or stress corrosion cracking) that passive layer has to break down. Stress corrosion cracking can happen when that localized breakdown is paired with tensile stresses that pull the pit apart and allows the crack to propagate. (K. Darowicki 2004, H. Torbati-Sarraf 2018, U. Martin 2020) Disruption of this passive layer is seen as the first step in most localized corrosion models, and the following model explains how this passive layer disruption and crack propagation happens.

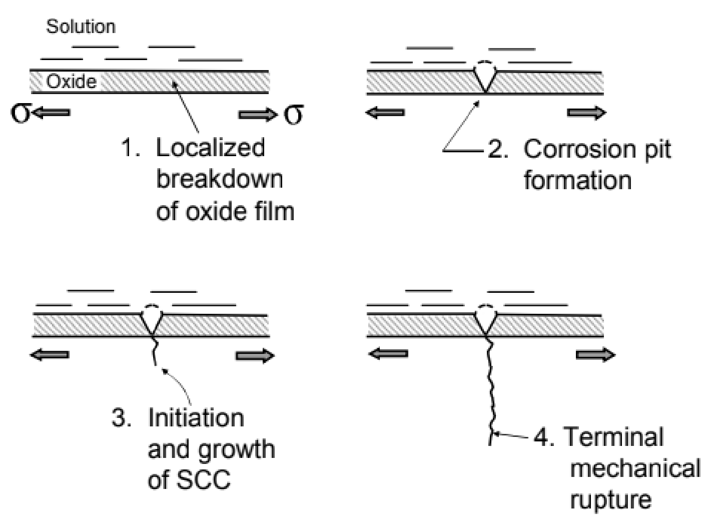

Figure 2: Stages for the initiation of stress corrosion cracks. (E. McCafferty 2010)

There are many theories for the localized corrosion of AISI 304L steel. Figure 2 above shows one of those theories which fits the mechanism for reinforcing rebar well. The process starts with localized film breakdown due to chloride attack which lowers the pH of the local solution- and takes it out of the passive region on the Pourbaix diagram. Next, this breakdown causes a corrosion pit to form. In some cases, the local pit will repassivate, and in other cases the pit will continue to grow into a crack- and the stress applied to the concrete causes growth and rupture for the Stress Corrosion Cracking process.

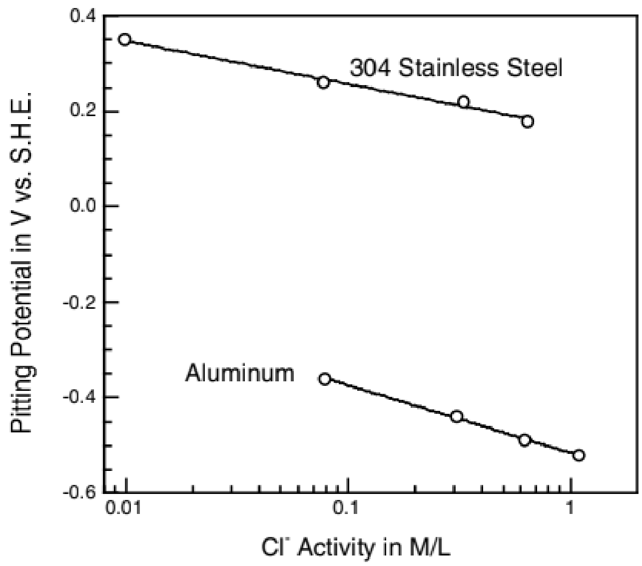

Figure 3: The relationship between chloride activity and the pitting potential of AISI 304L Stainless Steel. (Introduction to Corrosion Science)

Chloride's role in pit formation and SCC of steel is further supported by the graph in Figure 3. The chart shows that as chloride concentration increases, the pitting potential should decrease. The results for this experiment should support that theory. (E. McCafferty 2010) Other studies show that aging in chlorides promotes change in the passive film structure of the metal. More specifically, the Fe^{2+}/Fe^{3+} magnetite structure transforms into an oxidized structure with a larger concentration of Fe^{3+}. The extra Fe^{3+} ions shift the corrosion potential to more negative values, which makes pitting corrosion and general corrosion more likely. (C M. Abreu 2006.)

Other researchers have also found some stainless-steel alloys with better resistance to chloride impregnation. In this paper, the researchers tested different steel samples in a 0.1M NaCl solution but no chloride ions were detected in the film after washing and analysis. This means AISI 304L stainless steels and other alloys might offer stronger pitting corrosion resistance because the chloride ion concentration would not affect the pitting potential negatively. t. Their studies also show that chloride-induced pH drops from 13 to 9 cause a change in the passive layer for stainless steels. Their results show that the charge transfer resistance and passive film capacitance change as a result of the pH- leading to depletion of Fe(II) and Ni species in the passive layer, but enrichment of Cr(III) and Fe(III) species in the layer. (D. Addari 2008)

The good corrosion resistance of stainless-steels in simulated concrete environments might also be due to the high Cr/Fe ratio in the passive layer. However, this ratio is sensitive to the pH, so when the chlorides attack the solution decreasing the pH- the Cr/Fe ratio decreases and de-stabilizes the passive layer leading to increased susceptibility to various forms of corrosion. For instance, this teams research showed that a pH increase from 8.5 to 12.5 led to an increase in the pitting potential- their results also showed that metastable pitting and it’s incubation time are sensitive to pH too. (Hong Luo 2017)

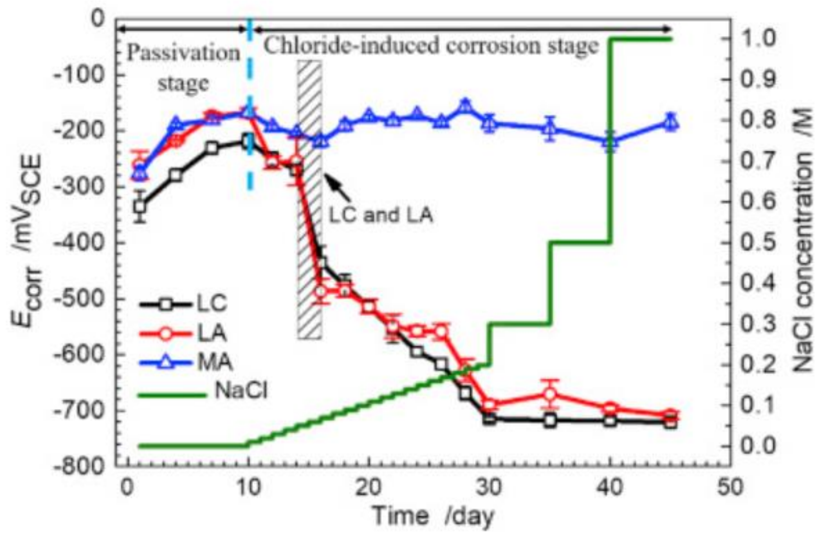

Figure 4: Corrosion potential values in saturated calcium chloride at the passivation and corrosion stages.

Another team of researchers studied the direct impact of chloride concentration on the corrosion behavior and corrosion potential of Chromium-modified reinforcing steels. Their results are seen in Figure 5 above. This plot shows how the addition of chlorides (Green line at the bottom) causes a significant decrease in the corrosion potential for the different metals. When looking at the metal lines (black, red, and blue) the first hump shows an increase in the corrosion potential indicating the metal is undergoing passivation. However, as the chlorides are introduced to the rest, all three metals undergo a significant decrease in corrosion potential indicating that the passive layer has been broken by the chlorides. (Jinjie Shi 2020, P. Ghods 2010).

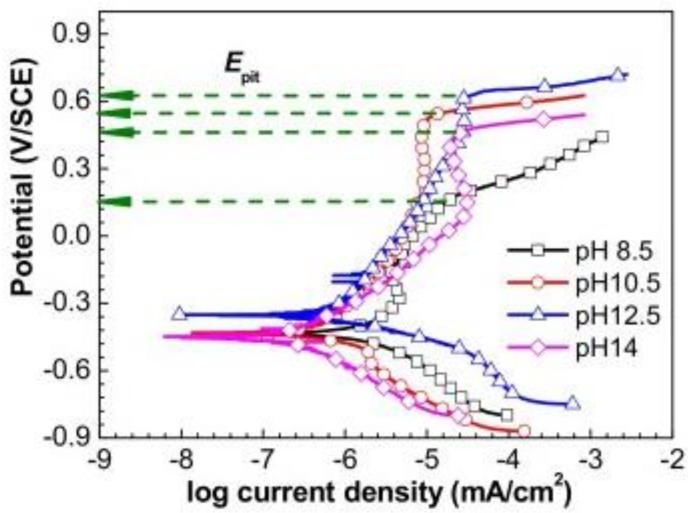

Figure 5: Potentiodynamic polarization curve of 316L stainless steel in simulated concrete pore solutions at different pH containing 3.5 wt.% NaCl.

The polarization curve shown in Figure 5 above shows how the pH affects stainless-steel corrosion behavior in a concrete pore solution. The decrease in pH clearly leads to an increate in corrosion current density, as well as lowering of the pitting potential finally leading to complete (or near complete) de-passivation of the steel. Their studies also show that hydroxides at high pH's help to stabilize the passive film protecting the metal and the chlorides destroy that passive layer. (H. Luo 2017, A.U Malik 1992)

Marketing Background

This section contains background research for the Corrosion Marketing Project. First, it was determined that the marketing strategy would be created for a real small business in Ohio called Lloyd Rebar Company. The next step was to figure out how they currently market their steel rebars. And intelligence gathered from several interviews with the owner of the company showed their primary marketing plan was outbound sales through a single salesperson on the property.

Other research found traditional marketing strategies for similar companies involve brand-advertisements in trade magazines, email, and their own website.

For a company who's single marketing or sales strategy is outbound sales- this part of the project presents a profitable opportunity. These traditional marketing channels (cold calling, websites, emails, referrals) make it difficult for a new company to find new customers. What makes the approach for this project different is the use of a direct-mail sales letter strategy. The goal is to create a personable sales letter delivered straight to the decision maker. This is powerful because popular marketing channels like email, magazine ads, and websites are saturated- so it's likely that a concrete contractor would ignore a rebar company's sales messages. Plus, this direct-mail strategy can be scaled up so you can send letters to thousands of companies each week.

This direct mail sales letter strategy is similar to many growth-campaigns used by many top companies in the past century. Although its popularity has fallen off due to the convenience of email- that might also mean that direct mail could be one of the biggest marketing opportunities for the rebar industry. For example, there's a direct-mail letter called the "Two Brothers Letter" produced by the Wall Street Journal which ran for 28 years and produced over $2 billion in sales. The strategy outlined later in this report is similar to the Wall Street Journal's campaign. (Martin Conroy)

Experimental Methods

The test used for this experiment is the cyclic potentiodynamic polarization experiment. The reason this test is used is because it's great for analyzing pitting corrosion behavior. The biggest threat to any reinforced steel concrete structure is localized pitting corrosion- and that's why the CPP test was used for this project.

For anyone wanting to reproduce this experiment, the ASTM G61 standards can be used to reproduce the tests and analyze the results. As for the physical experiment itself a Gamry Instruments Potentiostat was used. As said before, the material used for this experiment is AISI 304L stainless steel- the chemical composition is shown in the table below.

Table 1: Composition of AISI 304L Stainless Steel, wt.%(Penn Stainless)- Fe balance.

C	Mn	Si	P	S	Cr	Ni	N
0.03	2.0	0.75	0.045	0.03	18.0-20.0	8.0-12.0	0.10

There are two trials conducted for this experiment. The first is a CPP test in concrete pore solution at standard temperature and pressure. The second is a CPP test with 3.5% sodium chloride added to concrete pore solution at standard temperature and pressure. The concrete pore solution is made up of calcium hydroxide added to water to bring the solution to a pH of 13 to mimic the conditions in a concrete pore. This solution was added to an electrochemical cell for each test to conduct the CPP tests.

With the two concrete pore solutions prepared- the AISI 304L stainless steel sample was prepared by cutting a 4.9cm^2 (single faced) sample, mounting it in a two parts epoxy resin, and polished with SiC sandpaper until mirror-finished. One sample was prepared for the standard concrete pore test, and another was prepared for the 3.5 wt.% NaCl solution test. After the sample preparation- the Gamry software was used to conduct the CPP test as detailed in ASTM G-61. After this, the data was analyzed and discussed- those results are shown in the Results and Discussion section.

Results and Discussion

This section of the report contains the data for this project. What's included is a table with the electrochemical parameters found during the CPP tests, and the graphs for those tests. Each figure will have a short paragraph of comments surrounding the results for each data set. A more in depth analysis and discussion is found in the Discussion and Conclusions section.

Table 2: Cyclic potentiodynamic polarization data for AISI 304L stainless steel

	Concrete Pore Solution	**3.5 wt. % NaCl**
E_{corr} (Reverse) [mV]	−741.3	−901.2
i_{corr} (Reverse) [A/cm^2]	8.10×10^{-9}	2.59×10^{-6}
E_{corr} (Forward) [mV]	−584.4	−513.2
i_{corr} (Forward) [A/cm^2]	1.49×10^{-9}	2.81×10^{-7}
E_{pit} [mV]	−395.7	−281.2

Table 2 shows that the presence of chlorides causes an increase in corrosion potential for the forward reaction, an decrease in the corrosion potential for the reverse reaction, an increase in the corrosion current for the forward reaction, an increase in the corrosion current for the reverse reaction, and an increase in the pitting potential for 304L stainless steel. The fact that the corrosion current density increases greatly in the chloride test supports the idea that chlorides accelerate general and localized corrosion. However, during the planning phase it was predicted that the pitting potential would decrease in the presence of chlorides- but this test showed the opposite.

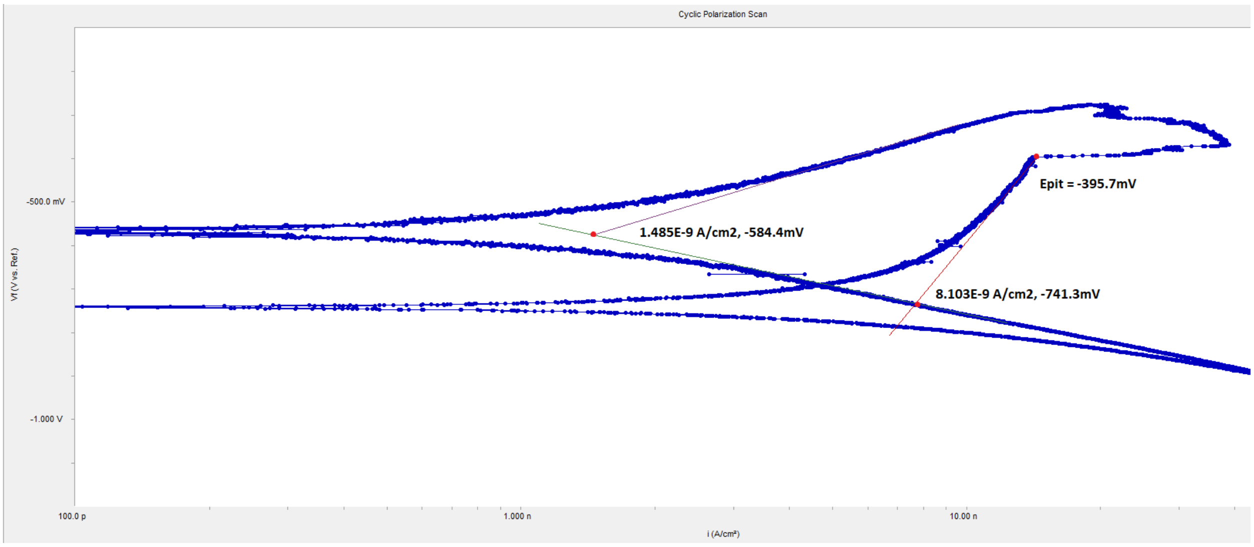

Figure 5: Cyclic potentiodynamic polarization curve for AISI 304L stainless steel in concrete pore solution.

Figure 5 shows the CPP plot for the concrete pore test for AISI 304L stainless steel. The plot shows a significant hysteresis (compared to the next plot) at the pitting potential of –395.7mV. After the hysteresis the material undergoes passivation with a new corrosion current density and corrosion potential. This plot shows a significant increase in corrosion current density for the reverse anodic curve. These results signify that localized corrosion is likely happening even without chlorides present.

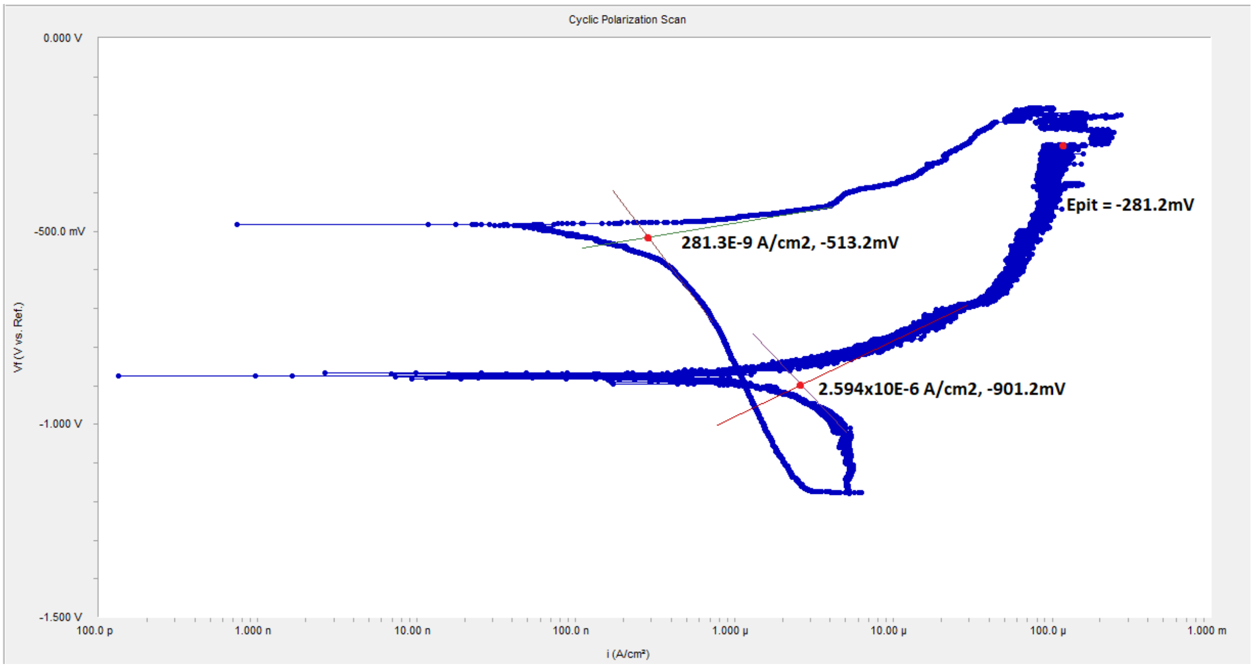

Figure 6: Cyclic potentiodynamic polarization curve for 304L stainless steel in concrete pore solution with 3.5 wt.% NaCl.

Figure 6 gives a CPP curve with more noise for the reverse sweep due to the presence of chlorides. This was expected from prior research in literature. The pitting potential was found to be more positive for this case than the solution without chlorides, which was surprising. Finally, this experiment showed a larger difference between the forward and reverse corrosion potentials due to the presence of chlorides. Most importantly, this test showed higher corrosion current densities than the test without chlorides- this means this test is undergoing a higher corrosion rate. These results are further discussed in the next section.

Conclusions

Figures 5 and 6 show that AISI 304L stainless steel is susceptible to localized corrosion, because the reverse scan shows a higher corrosion current density for the test- indicating that localized corrosion is likely to occur. (S. Tsouli 2018) The bigger the difference between the forward and reverse scans, the more susceptible the metal is to localized corrosion. Furthermore, there's a significant difference between the CPP plot for AISI 304L stainless steel with and without chlorides. First, the 3.5% NaCl graph showed a larger hysteresis (difference between forward and reverse scans) than the standard concrete pore solution test.

Also, the two graphs show much higher corrosion current density for the overall CPP plots in the presence of chlorides. For example, the corrosion current density for the reverse scan of the test without chlorides was 8.103×10^{-9}A/cm^2. And the corrosion current density for the reverse scan for the 3.5 wt.% chloride test was found to be 2.594×10^{-6} A/cm^2. That means the corrosion rate in the presence of chlorides is close to 3 orders of magnitude higher than without chlorides. All these points support the idea that chlorides accelerate general and local corrosion of AISI 304L stainless steel in a concrete pore solution.

The objective of this experiment was to study the pitting corrosion behavior of 304L stainless steel in the presence of chlorides. The polarization tests clearly support the fact that chlorides accelerate pitting corrosion for this metal. However, these test results also showed that 304L stainless steel is susceptible to pitting corrosion even without the presence of chlorides as supported by the large hysteresis seen in Figure 5- however, still- the CPP data shows that chlorides cause a corrosion current density up to 3 orders of magnitude higher. This leads to the question of whether or not the results of this experiment are precise, accurate, and valid.

For this experiment, ASTM G-61 standards were used for the interpretation of the CPP data. Those standards were also paired with the recommendations of previous researchers for interpreting CPP graphs whose research is detailed in the background section. For the analysis and research, guidelines from standard corrosion science textbooks were also followed. These standards and guidelines were followed to ensure accurate analysis of the CPP data for this project.

There are some ideas for how to improve future experiments similar to this one, (Or how researchers can build off of this test's data.) First, it would be great to have more CPP trials to compare and contrast for the CPP data. Next, it would be great to have multiple concentrations of NaCl to test: 1 wt.%, 4 wt.%, 6 wt.%, etc during the cyclic polarization tests. This would create a clearer picture of numerically, how chloride concentration affects the pitting corrosion potential, corrosion current density, and corrosion potential. Finally, it would be great to pair the CPP tests with different electrochemical tests such as a regular Potentiodynamic Polarization test, as well as a tensile test before and after chloride exposure to see how the chlorides affect mechanical behavior.

The results for this experiment clearly show a correlation between increased corrosion behavior and chloride concentration. First, the corrosion current density is up to 3 orders of magnitude higher in a concrete pore solution with 3.5 wt.% NaCl. And second, the chlorides decrease the corrosion potential of AISI 304L stainless steel (for the reverse reaction) which is a clear indicator that the chlorides are depassivating the steel leading to localized corrosion such as pitting or stress corrosion cracking.

Marketing Process & Results

This portion of the report covers the strategy and results for the stainless steel rebar marketing plan. And the first step of this project was to find the mission and purpose for this project. Here's the mission that was created after some initial research: The purpose of this project is to create a sales letter and marketing strategy for a rebar manufacturer to sell more stainless steel rebars to a concrete contractor involved in large construction projects. The goal is to create a ready-to-go sales letter and strategy a rebar manufacturer could use in business- and after the project is completed- this sales letter will be mailed to a few real rebar companies for them to test.

During the research, a company called the Lloyd Rebar Company was studied. At this time, market research was done on their steel manufacturing process, their sales process, the history of stainless steel, the concrete industry, and the psychology of the market. The marketing strategy and sales letter was created for this specific company. Some of the most relevant findings were taken from notebook paper and put into the table below:

Table 3: Market research for the stainless steel rebar company marketing project.

Problems	**Features**	**Other Facts**
Most rebar companies have one or two salesmen. This limits their growth speed.	We create 3D Designs using any program.	Lloyd Rebar Company's target market are small and big concrete contractors.
Can you bend the rebar for us?	We can handle any size project.	The story of the two bridges. One made with stainless steel the other with carbon steel.
Can you give shop drawings?	We can deal with any job site changes.	In 2015, the Chinese steel market lost about $2 billion per month.
Can you deliver the rebar on site?	We can handle estimating, detailing, fabricating, installation, project management.	Concrete contractors- interview with Tony West.

Will you deliver on time?		Contractors often build buildings, sidewalks, etc
How can we cut out many of these sub contractors?		Progreso Pier- constructed in early 1900's. Great example for stainless steel benefits.
How do I avoid costly mistakes?		
How do I find more jobs?		

After this research, there was enough information to write up the first draft of the sales letter. Next, the editing process began for the sales letter in order to improve the writing quality, and the sales conversion for the letter. This editing process involved eliminating redundant words, replacing long words with simpler easy-to-read words, rephrasing, and formatting. After all this work- the sales letter was ready to go. The final draft for this letter is found in the text below, along with yellow-highlighted commenting explaining the strategy behind the different pieces.

Figure 7: Photo of Progreso pier (Yucantán, Mexico) used for the corrosion marketing plan.

Dear Mr. Miller,

As you can see, I've attached an interesting picture to this letter. Here's why.

The bridge you see on the right is called Progreso Pier. The Mexican State of Yucatán built it in 1937- it's now the world's longest (and one of the oldest) piers in the world.

And to the left of Progreso Pier, you can see the remains of a bridge built in 1957- 20 years later than the other bridge. But for some reason, even though the Mexican state built this 20 years later, the only thing left of this bridge are the stone stumps seen in the water,

What made the difference?

For the bridge built in 1957 that didn't even last 60 years- they used carbon steel rebars to reinforce the concrete. And for the Pier that's still standing, they used stainless steel rebars.

But there's a downside. The upfront stainless steel cost is more- however, you save far more due to the long life of stainless steel. Look at the chart below to see what I mean.

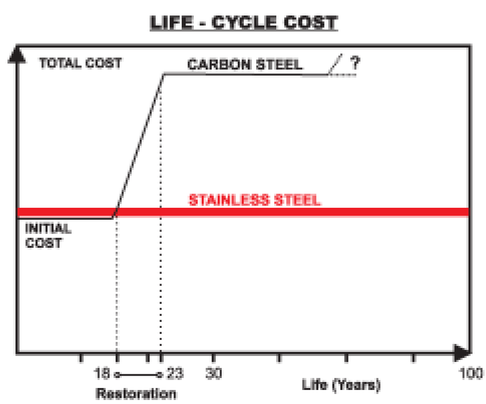

Figure 8: Total Cost Of Stainless Steel Rebar Installation vs Carbon Steel Installation

This figure shows the cost of a carbon steel installation vs stainless steel. As you can see, stainless steel is more expensive at the installation. However, several years later- that carbon steel breaks down- and you gotta replace everything.

That's when carbon steel becomes far more expensive than stainless steel.

For a concrete contractor who wants to build longer lasting structures, and land bigger higher paying jobs- then stainless steel rebars are your best choice. (Plus, they're **<u>MUCH</u>** safer)

This is why I'm writing to you today about Lloyd Rebar Company's stainless steel rebars.

If you're looking for a rebar-company who can bend rebar into any shape, deliver it straight to your job site, and handle ANY size job- then we might be the perfect fit for you. We're located in Columbus Ohio- and when you order rebars with us- you'll also get…

- Drawings for any size job.
- 3D computer designs (at your request)
- On time delivery. (Or you won't pay a dime)

Many concrete professionals and construction companies would LOVE to cut half of their subcontractors. If that's you- then you'll be happy to know we also handle all the estimating detailing, fabricating, installation- and even project management.

All so you have less stress from dealing with too many contractors- and so you can save money because you're working with only one rebar supplier.

Now, if you want to try our Stainless Steel rebars- then here's a 50% discount

Why? Because we have an over-supply of rebar sitting collecting dust in our warehouse… and if you're impressed by our services as much as our other clients- I know you'll be back for more.

So if you want your 50% discount, then call the number below.

1-234-567-8989

-Kenny Aronson

P.S. Don't wait around. Our extra rebar supply won't last long. So call as soon as possible.

The sales letter begins with a photo attached to the top of the letter. The photo should not be printed on the letter because a separate photo will give the picture of Progreso Pier a higher quality. The purpose of this photo is to first catch the attention of the reader, and provide a sales-aide that shows why stainless steel is a superior choice over carbon steel for construction. Then the sales letter opens with the story about Progreso Pier to give the photo some meaning, and in an easy to understand way, show why stainless steel rebars are a good material choice.

After the story about Progreso Pier, a reader finds a chart and a few paragraphs talking about the long-term costs of stainless steel. This part creates financial justification for why the concrete manufacturer (or construction company) would spend extra money for a higher quality rebar. The next part of the letter talks about specific benefits for working with Lloyd's Rebar Company. These benefits were based on ideas found during the market research phase and help to overcome potential objections for working with a new rebar supplier detailed in Table 3. Finally, the letter reaches the close by providing the reader with a one-time discount of 50% along with a reason for that discount. Then they'll see instructions for how to order, as well as a notice in the "P.S" to order quickly to create urgency for the sale.

The above letter is ready to ship. The next step is to find a list of concrete contractor addresses to send it to, and conduct a marketing test. Then the cost to mail and print would be compared to the total sales from the direct mail test. If profitable, the rebar company could easily scale their direct mail campaign into the millions of dollars as shown in the marketing diagram below.

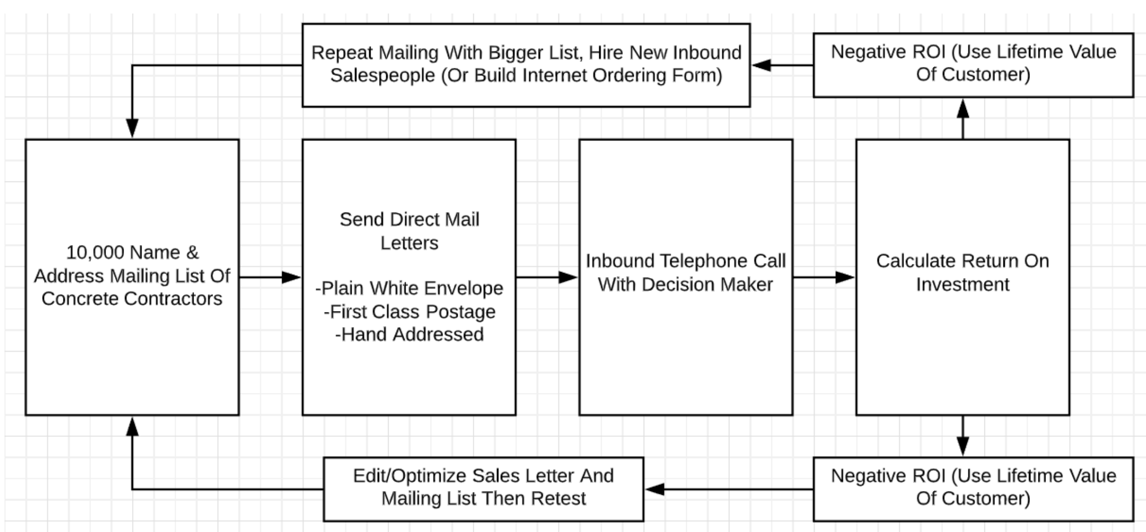

Figure 9: Marketing plan for the stainless steel rebar sales letter.

The big outcome for this project was a new strategy to market stainless steel rebars to concrete contractors. The result of all the planning, research, and editing was a ready-to-go sales letter and marketing plan for a rebar company to use. The most valuable lesson from this part of the project was figuring out how to take an innovation, a new material, or an idea and turn it into a growing business through a solid marketing plan, and a process to continually improve the return on investment.

There are countless inventions out in the world. Unfortunately, many of them never make it into the market or our society because inventors don't have a good way to bring their products to the market. A sales letter, such as the one outlined in this section, solves that problem by giving the researcher a strong way to win new customers using a marketing-medium neglected by much of the industry today.

In conclusion, this project will help me greatly in my future. The reason is I now have a better understanding of not just how to find and test a new product. But I can also take that new product and find an effective way to sell it to the marketplace. And for the Corrosion Testing portion of this project, I gained invaluable experience in planning, conducting, and analyzing experiments. I also gained a better understanding of how chloride ingress affects rebar corrosion in reinforced steel concrete.

References

1. NACE International. Highways and Bridges. https://www.nace.org/corrosion-central/industries/highways-and-bridges/

2. Lekatou A. Corrosion and protection of metals in simple words. Nermertes Publications. 2013

3. S. Tsouli, A.G. Lekatou, S. Kleftakis, T.E. Matikas, P.T. Dalla. Corrosion behavior of 304L stainless steel concrete reinforcement in acid rain using fly ash as corrosion inhibitor. Procedia Structural Integrity 10 (2018) 41−48.

4. I.G. Ogunsanya, C.M. Hansson. The semiconductor properties of passive films and corrosion behavior of stainless steel reinforcing bars in a simulated concrete pore solution. Materialia 6 (2019) 100321.

5. L. Jin, M. Liu, R. Zhang, X. Diu. Cracking of cover concrete due to non-uniform corrosion of corner rebar: A 3D meso-scale study. Construction and Building Materials 245 (2020) 118449.

6. S.A. Lee, K.P. Park, J. Kim, K.Y. Ann. Sensitivity analysis for binders in concrete mix to the corrosion risk of steel embedment in chloride bearing environments. Construction and Building Materials 251 (2020) 118944.

7. M. Liu, X. Cheng, X. Li, Z. Jin, H. Liu. Corrosion behavior of Cr modified HRB400 steel rebar in simulated concrete pore solution. Construction and Building Materials 93 (2015) 884−890.

8. S. Ahmad. Reinforcement corrosion in concrete structures, its monitoring and service life prediction- A review. Cement and Concrete Composites 25 (2003) 459−471.

9. M. Moreno, W. Morris, M.G Alvarez, G.S. Duffo. Corrosion of reinforcing steel in simulated concrete pore solutions: Effect of carbonation and chloride content. Corrosion Science 46 (2004) 2681−2699.

10. M. Serdar, L. Valek, D. Bjegovic. Long term corrosion behavior of stainless reinforcing steel in mortar exposed to chloride environment. Corrosion Science 69 (2013) 149−157.

11. H. Luo, H. Su, C. Dong, K. Xiao, X. Li. Electrochemical and passivation behavior investigation of ferritic stainless steel in alkaline environment. Construction and Building Materials 96 (2015) 502−507.

12. A. Fattah, S. Vafaeian. Influence of grain refinement on the electrochemical behavior of AISI 430 ferritic stainless steel in an alkaline solution. Applied Surface Science 360 (2016) 921−928.

13. J. Orlikowski, K. Darowicki, A. Artuonow, W. Jurczak. The effect of strain rate on the passive layer cracking of 304L stainless steel in chloride solutions based on the differential analysis of electrochemical parameters obtained by means of DEIS. Journal of Electroanalytical Chemistry 576 (2005) 277−285.

14. S. Nasser, W. Guo, D. Kihl. Thermomechanical response of Al-6XN stainless steel ofer a wide range of strain rates and temperatures. Journal of The Mechanics and Physics of Solids 49 (2001) 1823−1846.

15. K. Ishikawa, S. Tanimura. Strain rate sensitivity of flow stress at low temperatures in 304N stainless steel. International Journal of Plasticity 8 (1992) 947−958.

16. S.A. Serebrinsky, J.R. Galvele. Effect of the strain rate on stress corrosion crack velocities in face centered cubic alloys. A mechanistic interpretation. Corrosion Science 46 (2004) 591−612.

17. Khan Shahzada. Presentation on Chloride Ingress. https://www.slideshare.net/AqibAhmed21/2chloride-ingress-in-concrete

18. C.A. Apostolopoulos, S. Demis, V.G. Papadakis. Chloride-induced corrosion of steel reinforcement −Mechanical performance and pit depth analysis. Construction and Building Materials 38 (2013) 139−146.

19. N. Alonso-Falleiros, S. Wolynec. Correlation between corrosion potential and pitting potential for AISI 304L austenitic stainless steel in 3.5% NaCl aqueous solution. Materials Research 5 (2002) 77−84.

20. H. Luo, C.F. Dong, X.G. Li, K. Xiao. The electrochemical behavior of 2205 duplex stainless steel in alkaline solutions with different pH in the presence of chloride. Electrochimica Acta 64 (2012) 211−220.

21. S. Fajardo, D.M. Bastidas, M.P. Ryan, M. Criado, D.S. McPhail, J.M. Bastidas. Low-nickel stainless steel passive film in simulated concrete pore solution. A SIMS study. Applied Surface Science 256 (2010) 6139−6143.

22. L. Freire, M.J Carmezim, M.G.S. Ferreira, M.F. Montemor. The passive behavior of AISI 316 in alkaline media and the effect of pH: A combined electrochemical and analytical study. Electrochimica Acta 55 (2010) 6174−6181.

23. C.M. Abreu, M.J. Cristobal, R. Losada, X.R. Novoa, G. Pena, M.C. Perez. Comparative study of passive films of different stainless steels developed on alkaline medium. Electrochimica Acta 49 (2004) 3049−3056.

24. T. Mesquita, E. Chauveau, M. Mantel, R. Nogueira. A XPS study of the Mo effect on passivation behaviors for highly controlled stainless steels in neutral and alkaline conditions. Applied Surface Science 270 (2013) 90−97.

25. K. Darowicki, J. Orlikowski, A. Arutunow. Analysis of electrochemical parameters in time domain during the passive layer cracking occurring on 304L stainless steel in chlorides solution under tensile stress. Electrochimica Acta 49 (2004) 5069−5078.

26. H. Torbati-Sarraf, A. Poursaee. Study Of The Passivation Of Carbon Steel In Simulated Concrete Pore Solution Using Scanning Electrochemical Mircroscope (SECM). Materialia Volume 2 2018. Pg. 19-22.

27. E. McCafferty. Introduction to Corrosion Science. Springer 2010.

28. C M. Abreu, MJ. Cristobal, R. Losada, X.r. Novoa, G. Pena, M.C. Perez. Long Term Behavior Of AISI 304L Passive Layer In Chloride Containing Medium. Electrochimica Acta. Volume 51 2006. Pg. 1881-1890.

29. D. Addari, B. Elsener, A. Rossi. Electrochemistry And Surface Chemistry Of Stainless Steels In Alkaline Media Simulating Concrete Pore Solutions. Electrochimica Acta. Volume 53 Issue 27, 2008. Pg. 8078-8086.

30. Hong Luo, Huaizhi Su, Chaofang Dong, Xiaogang Li. Passivation And Electrochemical Behavior Of 316L Stainless Steel In Chlorinated Simulated Concrete Pore Solution. Applied Surface Science Volume 400 2017. Pg. 38-48.

31. Jinjie Shi, Jing Ming, Miao Wu. Electrochemical Behavior And Corrosion Products Of Cr Modified Reinforcing Steels In Saturated $Ca(OH)_2$ Solution With Chlorides. Cement And Concrete Composites. Volume 110 2020.

32. P. Ghods, O.B. Isgor, G.A. McRae, G.P. Gu. Electrochemical investigation of chloride induced depassivation of black steel rebar under simulated service conditions. Corrosion Science 52 (2010) 1649−1659.

33. A.U Malik, P.C. Kutty, N.A. Siddiqui, I.N. Andijani, S. Ahmed. The influence of pH and chloride concentration of AISI 316L steel in aqueous solutions. Corrosion Science 33 (1992) 1809−1827.

34. Martin Conroy. The Two Brothers Letter. https://swiped.co/file/wallstreet-letter-conroy/

35. ASTM G61. Standard test method for conducting cyclic potentiodynamic polarization measurements for localized corrosion susceptibility of Iron, Nickel, or Cobalt based alloys 2019.

36. Penn Stainless. AISI 304L Stainless Steel Properties. https://www.pennstainless.com/resources/product-information/stainless-grades/300-series/304-stainless-steel/

37. U. Martin, J. Ress, J. Bosch, D.M. Bastidas, Stress corrosion cracking mechanism of AISI 316LN stainless steel rebars in chloride contaminated concrete pore solution using the slow strain rate technique, Electrochimica Acta 335 (2020) 135565.