A STUDY ON UTILIZING CHEMICAL INHIBITORS IN NEW REINFORCED CONCRETE STRUCTURES

BY

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وقل رب زدني علما

THIS HUMBLE WORK IS DEDICATED TO:
MY MOTHER, MY WIFE, MY CHILDREN,
MY SISTER AND BROTHER

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Praise and thanks a lot God Almighty, for giving me the health, knowledge and patience to complete this work. I acknowledge the financial support given by Thamar University and by KFUPM's Civil Engineering Department during my graduate studies.

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THESIS ABSTRACT

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Deterioration of reinforced concrete in many industrial and non-industrial structures in the coastal areas of the Kingdom of Saudi Arabia is principally attributed to reinforcement corrosion. Corrosion of reinforcement in this environment is mainly due to the presence of chloride ions. Chloride ions may diffuse from the surrounding environment or may be contributed by concrete constituents, such as aggregates, mixing water, or admixtures.

The use of corrosion inhibitors in concrete was evaluated in this study. The effectiveness of seven types of corrosion inhibitors (Calcium Nitrate, Sika Ferrograd 901, Sika Ferrograd 903, Conplast-CN, Cemetec-CCI-S, Rheocrete-CNI, Cortec) in minimizing reinforcement corrosion was assessed. Beam concrete specimens were prepared and exposed to five commonly chloride and/or sulfate occurring zones. Further, cylindrical concrete specimens with and without chloride contamination were prepared and exposed to dry and wet cycles.

The effectiveness of inhibitors in minimizing reinforcement corrosion was assessed by measuring the corrosion potentials and corrosion current density. Moreover, accelerated corrosion test was carried out to assess the resistivity of concrete.

The results of this investigation indicated that all corrosion inhibitors were effective in minimizing reinforcement corrosion and in extending the service life of structures. However, the effectiveness of the inhibitors varied from one to another in each exposure zone. Calcium Nitrate was found to be the most effective inhibitor in all the exposure zones. Recommendations on the type of inhibitor to be used for each exposure zone are provided as an outcome of this study.

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ملخص الرسالة

الإســـــــم : **أحمد عبدالله علوي النجحي**

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يرجع تدهور الخرسانة المسلحة في العديد من المنشآت الصناعية والغير صناعية في المناطق الساحلية بالمملكة العربية السعودية بشكل رئيسي إلى صدأ حديد التسليح، وذلك بسبب وجود أيونات الكلورايد. و يمكن لأيونات الكلورايد أن تتخلل في الخرسانة من البيئة المحيطة، كما يمكن أن تكون موجودة في مكونات الخرسانة مثل الحصى أو ماء الخلط أو الإضافات.

تم في هذه الدراسة تقييم إستخدام سبعة أنواع من موانع الصدأ. وتم أعداد عينات الجسور الخرسانية وتعريضها لخمسة بيئات مختلفة من الكلورايد و/أو الكبريتات. كما تم أيضاً أعداد عينات خرسانية اسطوانية وتعريضها لدورات من الترطيب والتجفيف.

وتم تقييم فعالية الموانع في تقليل صدأ التسليح بواسطة قياس فرق جهد الصدأ وكثافة تيار الصدأ، وتم أجراء أختبار تسريع الصدأ لتقييم مقاومية الخرسانة.

تدل نتائج هذا البحث على أن كل موانع الصدأ كانت فعاله في تقليل صدأ التسليح وتطويل عمر المنشآت، لكن فعالية هذه الموانع تختلف من مانع لآخر في البيئات المختلفة. وكانت نترات الكالسيوم أكثر الموانع فعالية في كل البيئات التي تم دراستها. كما تم تقديم توصيات بشأن إستخدام النوع الأفضل من الموانع في كل بيئة من هذة البيئات المدروسة.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

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CHAPTER ONE

INTRODUCTION

1.1 General

Most of the industrial and non-industrial structures in the coastal areas of the Kingdom of Saudi Arabia are constructed of reinforced concrete. These coastal areas of Saudi Arabia are known for their aggressive environment to promote chloride-induced corrosion of steel. Sabkha soil that contains of over 15.7% Cl^- and 0.5% SO_4^{--} is one of the common soils in eastern and western Saudi Arabia [45]. The aggressivity of soil and the environment compounded by the hot and humid environment demand outmost consideration of durability of concrete construction.

Reinforced concrete in these coastal areas is exposed to this aggressive environmental conditions. Consequently, reinforcement corrosion is the primary cause that leads to the reduction in the useful service life of reinforced concrete structures in these regions. Reinforcement corrosion is principally attributed to the chloride ions that diffuse into the hardened concrete from the service environment or they may be contributed by the mix ingredients.

There are several corrosion protection measures that are taken at the design stage to minimize the effect of severe exposure conditions and to utilize the designed service life of the structures. These precautions include: coating the reinforcing steel with fusion-bonded epoxy, use of dense concrete, increased concrete cover and the use of corrosion inhibitors in the concrete.

Recently, chemical inhibitors are being utilized to minimize corrosion in new concrete structures. They are added to concrete in structures because the epoxy coating on the steel bars may be damaged during the construction work. The corrosion inhibitors prevent the electrochemical reactions associated with reinforcement corrosion. They can inhibit either anodic or cathodic reactions or both. However, the performance of corrosion inhibitors in structures exposed to real life conditions is not adequately evaluated, particularly in the aggressive exposure conditions of the Arabian Gulf.

This research was planned to assess the performance of several types of inhibitors in minimizing reinforcement corrosion in new reinforced concrete structures exposed to five different service conditions. This assessment was based on using different types of specimens; beam and cylinders. These concrete specimens were exposed to five commonly occurring exposure conditions. Reinforcement corrosion was evaluated by measuring corrosion potentials and corrosion current density. Also, accelerated corrosion test was carried out to evaluated the effectiveness of these inhibitors to retard corrosion.

The information gathered from the above tests was used for the assessment of the effectiveness of corrosion inhibitors in the selected environments.

1.2 Significance of this Study

From literature review, there are some studies that have been carried out on the use of chemical inhibitors both in the Arabian Gulf and in other countries. However, there is a need for a more detailed study to evaluate the effectiveness of inhibitors in new reinforced concrete structures, especially when exposed to local conditions. In this research, concrete specimens prepared with different types of corrosion inhibitors were exposed to five commonly occurring exposure conditions to get more detailed results. The results of this research will also be useful to update the local and international building codes.

1.3 Scope and Objectives

The overall objective of this study was to assess the benefits of using corrosion inhibitors in concrete in mitigating reinforcement corrosion in reinforced concrete structures exposed to aggressive environments. The specific objectives of this work were as follows:

1- To evaluate the corrosion protection provided by selected proprietary and generic corrosion inhibitors in minimizing chloride-induced reinforcement corrosion in concrete exposed to five commonly occurring exposure conditions;

2- To develop performance criteria for the usage of chemical inhibitors in aggressive exposure conditions; and

3- To provide recommendations for avenues of utilizing chemical inhibitors based on the data developed in this study.

1.4 Research Methodology

In order to fulfill the above objectives of this investigation, this thesis report encompassed the following phases:

1. **Literature Review (Chapter 2)**
    - I. Corrosion Mechanisms of Reinforcing Steel in Concrete.
    - II. Corrosion Protection Measures.
    - III. Corrosion Inhibitors.
    - IV. Evaluation of Corrosion Inhibitors.
2. **Experimental Program (Chapter 3)**
    - I. Commercial Inhibitors
    - II. Preparation of Concrete Specimens
        - Beam specimens.
        - Cylindrical specimens.
    - III. Curing of Concrete Specimens.
    - IV. Exposure of Concrete Specimens:
        - Atmospheric zone.
        - Tidal zone (wet and dry cycles).
        - Submerged zone.

        - Below ground zone.
        - Capillary zone.
        - Accelerated corrosion.

V. Assessing the Effectiveness of Chemical Inhibitors:

    - Corrosion Potential (E_{corr}).
    - Corrosion current density (I_{corr}).
    - Accelerated Corrosion.

3. Results and Discussions (Chapter 4)

- Corrosion Potential (E_{corr}) Results
    a) Test results on beam concrete specimens:
        - Atmospheric zone test results.
        - Tidal zone test results.
        - Submerged zone test results.
        - Below ground test results.
        - Capillary zone test results.

    b) Test results on cylindrical concrete specimens without chloride contamination in tidal zone.

    c) Test results on cylindrical concrete specimens with chloride contamination in tidal zone
- Corrosion Current Density (I_{corr}) Results:
    a) Test results on beam concrete specimens:
        - Atmospheric zone test results.

        - Tidal zone test results.
        - Submerged zone test results.
        - Below ground test results.
        - Capillary zone test results.
    b) Test results on cylindrical concrete specimens without chloride contamination in tidal zone.
    c) Test results on cylindrical concrete specimens with chloride contamination in tidal zone.
  - Accelerated corrosion test results.

4. **Conclusions and Recommendations (Chapter 5)**
    I. Conclusions.
    II. Recommendations.
5. **References.**

CHAPTER TWO

LITERATURE REVIEW

2.1 Corrosion Mechanisms of Reinforcing Steel in Concrete

Corrosion of reinforcement in concrete is mainly due to the presence of chloride ions or the reduction of pH in concrete due to the carbonation. Chloride ions may be contained in the concrete constituents, from aggregate, mixing water or admixtures; otherwise, chloride ions may diffuse from the surrounding environment [3]. In this research, these two sources for chloride ions either by surrounding environment or concrete constituents were investigated. Dissolved chloride ions in concrete destroy the passivity of the reinforcement and raise the active corrosion rate of steel. When the passive layer is destroyed, parts of the steel act as an anode and start to corrode. Ferrous ions, Fe^{2+}, are lost into the solution, which frees up electrons in the steel and raise the difference in potential. The difference between cathodic and anodic sites within the steel bar causes the current to flow in the concrete and through the metal reinforcement. The oxidation and reduction reactions at the steel-concrete interface are shown below [3]:

Oxidation Reaction: $2Fe \rightarrow 2Fe^{2+} + 4e^{-}$ (2-1)

Reduction Reaction: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$ (2-2)

At the anode, electrons are released [Eq. (2-1)] and they flow towards the higher potential (cathodic) sites, where they combine with mositure and oxygen to form hydroxyl ions. The corrosion reaction continues only if there is a cathodic reaction to accept the released electrons, so these corrosion reactions will be stopped if oxygen and water are not available at the cathodic sites on the steel. Rust is formed according to the following reactions [3]:

$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2$ (2-3)

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (2-4)

$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O$ (2-5)

When ferrous ions react with the hydroxyl ions, they react to form ferrous hydroxide, $Fe(OH)_2$, [Eq. (2-3)]. If oxygen and moisture are present, ferrous hydroxide is then further oxidized to form ferric oxide, or rust [Eqs. (2-4) and (2-5)]. Figure 2.1 shows the mechanisms of corrosion.

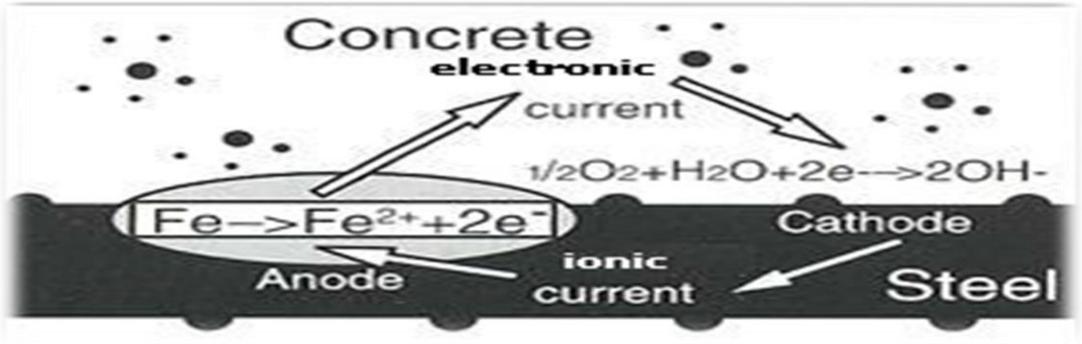


Figure 2.1 Schematic Repersentation of the Mmechanisms of Corrosion [3].

The volume of rust product due to corrosion tends to increase to much higher than that of its original steel. Therefore, tensile stresses will be developed in concrete thereby leading to cracking of concrete [3]. Also, corrosion of steel rebar decreases the cross-sectional steel area and causes local discontinuities of steel surface. The tensile strength of the steel is decreased due to the loss of steel area [50]. Furthermore, the loss of steel surface leads to a loss of bond between the steel and surrounded concrete [50].

All the effects mentioned above due to reinforcement corrosion lead to deteriorate concrete structures. Repair and maintenance of concrete structures against reinforcement corrosion will cost a lot of money and will waste time.

2.2 Corrosion Protection Measures

A number of corrosion protection measures are often utilized to extend the service life of reinforced concrete. These measures include: coating the reinforcing steel with fusion-bonded epoxy coating (FBEC), usage of dense concrete, increasing the concrete cover, usage of supplementary cementations materials, cathodic protection, and the usage of corrosion inhibitors in the concrete [1-3,51-52].

FBEC acts as a barrier between the steel and the corrosive species (i.e. chlorides, carbon dioxide, oxygen and moisture) in the surrounding concrete pore solution. However, FBEC may be damaged during construction work thereby leading to pitting corrosion [1-3].

The use of dense concrete and increasing the concrete cover will slow the ingress of chloride ions to the level of the reinforcing steel, thereby increasing the time to corrosion initiation [1-3].

The use of supplementary cementitious materials like silica fume, fly ash, ground granulated blast furnace slag (GGBFS), and natural pozzolans reduces the permeability of concrete. Therefore, they reduce the penetration of water and chlorides ions and, hence, mitigate reinforcement corrosion [51].

Cathodic protection is a recent technique used to minimize reinforcement corrosion of steel. In this technique, the steel is electrically polarized by -200 mV, and the current is forced through the interface. Therefore, the cathodic conjugate reaction will be decelerated thereby reducing reinforcement corrosion. Cathodic protection is very effective technique to reduce reinforcement corrosion if the -200 mV polarization is achieved uniformly all along the interface. Otherwise, where the interface is under polarized, the steel will continue to corrode. Cathodic protection is very expensive compared with other protection measures, where the cost of it may reach to 15% cost of the structure [52].

Currently, there is an increasing trend towards the usage of chemical inhibitors due to the drawbacks with other protection measures [1-3].

2.3 Corrosion Inhibitors

Corrosion inhibitors are chemical admixtures that hinder the corrosion of reinforcing steel. They are typically added to concrete matrix, but have also been shown to have an effect when applied to the surface of hardened concrete. The advantages of using inhibitors to provide corrosion protection are that they are uniformly distributed throughout the concrete matrix, protecting the entire steel surface; and that the concrete's low permeability prevents the inhibitor from leaching out [4]. There are many types of corrosion inhibitors that are used to minimize reinforcement corrosion. Each of these corrosion inhibitor groups may include materials which mitigate reinforcement corrosion by one of the following mechanisms:

(a) Formation of layers: Corrosion inhibitors coat the embedded steel with monocular layer which keeps the chlorides ions away from the embedded rebar [53].

(b) Oxidation by passivation of the surface: Corrosion inhibitors oxidize the ferrous oxide sites within the protective passive oxide layer into ferric oxide (+3 oxidation state), which is more stable and less reactive than the +2 oxidation state. Therefore, no reaction will occur when the chloride ions reach this ferric oxide layer [53].

(c) Inhibiting the environment in contact with the metal: Corrosion inhibitors reduce the rate of ingress of chloride ions by raising the rate of chemical binding of chlorides and/or increasing the chloride threshold value for corrosion initiation [4].

Corrosion inhibitors can be divided into the following three main types:

1) **Anodic inhibitors:** These materials have the ability to accept electrons. Anodic inhibitors usually act by forming a protective oxide layer on the surface of the steel causing a large anodic shift of the corrosion potential. This shift forces the metallic surface into the passivation region. They are sometimes referred as passivators. Sodium chromate, calcium nitrate and sodium nitrate are some examples of anodic inhibitors [4].
2) **Cathodic inhibitors:** These materials have the ability to accept protons and their actions. Cathodic inhibitors act either by slowing the cathodic reaction itself or selectively precipitating on cathodic areas to limit the diffusion of reducing species

to the surface. NaOH, NH_4OHM, and Na_2CO_3 are some examples of cathodic inhibitors which raise the pH of the concrete thereby reducing the solubility of the ferrous ions [4]

3) **Mixed inhibitors:** These inhibitors act by decreasing both the cathodic and anodic reactions. They are typically film-forming compounds which lead to form precipitates on the surface blocking both anodic and cathodic sites indirectly. Silicates and phosphates are the most common inhibitors used of this category [4].

Furthermore, there are chemical materials that are used to rehabilitate the damaged structure like migratory corrosion inhibitors (MCI). MCI are applied on concrete surface or mixed with concrete. MCI molecules diffuse through concrete pores to reach rebars and protect them from corrosion [24].

2.3.1 Evaluation of Corrosion Inhibitors

The effectiveness of chemical admixtures in inhibiting reinforcement corrosion has been reported by many studies [5-10]. Sodium nitrite, potassium chromate, sodium benzoate, stannous chloride and calcium nitrite were evaluated in these studies.

Performance of calcium nitrate exposed to aggressive environments was investigated by El-Jazairi et al. [11]. They subjected concrete specimens admixed with calcium nitrate to high chloride environments in the field and laboratory. They concluded that the use of good quality concrete is essential to get effective performance of calcium nitrate exposed to these environments. The use of adequate dosage of the corrosion inhibiting admixture based on calcium nitrate in good quality concrete is recommended to provide additional safe guard and protection to reinforcing steel in concrete exposed to aggressive environments. They mentioned that calcium nitrate-based admixture has no detrimental effect on the durability of reinforced concrete even at reduced levels [11]. It enhances the early strength development of concrete and provides long-term protection to reinforcement.

Montes et al. [12] studied the effect of calcium nitrate-based corrosion inhibitor and crack width on reinforcement corrosion in high performance concrete. They mentioned that the inhibitor alone cannot protect the reinforcing steel in the concrete from corrosion. The inhibitor failed to protect the reinforcing steel even in uncracked concrete. However, the inhibitor in good quality concrete, incorporating fly ash, was effective in reducing the effect of chloride-induced reinforcement corrosion.

Berke and Hicks [13] published long-term data to show the levels of chloride, 3.6, 5.9, 7.7, 8.9, and 9.5 kg/m^3 of concrete, that a given level of calcium nitrate, 10, 15, 20, 25, and 30 l/m^3, respectively, can protect. They also indicated that once corrosion is initiated, the rates are lower with the addition of calcium nitrate.

Justnes and Hygaard [14] used calcium nitrate as a corrosion inhibitor in their research work. The scope of their work was to determine the effect of calcium nitrate on both the chloride-binding and chloride-induced reinforcement corrosion. They concluded that the addition of 3.85% calcium nitrate to 1:3 mortars, with and without silica fume, tends to reduce the 1-day strength, but increases the compressive strength from 8 until 56 days of curing. The corrosion rate of embedded steel was, however, five times lower than that in an identical mortar without calcium nitrate.

The effectiveness of some mixed types of organic inhibitors in inhibiting reinforcement corrosion was investigated by Maeder [15]. These inhibitors were amines and alkanolamines and their salts were organic and inorganic acids. They reported that the unique feature of these inhibitors is their ability to diffuse a considerable distance through concrete because of their high vapor pressure [15]. The setting time of concrete is not delayed when these inhibitors are added to concrete. They diffuse to both the anodic and cathodic sites and provide protection to reinforcing steel. Moreover, it is reported that these inhibitors are preferable over nitrites as they are non-toxic [15].

Nmai [16] studied the multi-functional benefits of a water-based organic corrosion inhibitor. The organic inhibitor investigated consisted of amines of fatty acid esters. The time to corrosion data indicated that the inhibitor is effective in both the moderate (w/c: 0.5) and high (w/c: 0.4) quality concretes. The permeability-reducing characteristic of the inhibitor was also helpful in reducing the deterioration due to the ingress of other aggressive species, such as sulfates and sulfuric acid.

Wombacher et al. [17] investigated the effectiveness of amino-alcohol-based mixed corrosion inhibitors in reducing the rate of reinforcement corrosion. They assessed the inhibiting properties in concrete and in an alkaline electrolyte. From results, the onset of reinforcement corrosion is retarded and its rate is decreased. Also, it is reported that the inhibitor can be applied on the surface of existing concrete structures, in repair mortar or in grouts for rock bolts and anchors [17].

Jamil et al. [18] studied the corrosion behavior of reinforcing steel in the presence of a penetrating amino-alcohol corrosion inhibitor by conducting electrochemical impedance measurements. To evaluate the penetration of the inhibitor into mortar, two different electrochemical cells were used. The first consisted of two cylindrical containers separated by a disk of mortar. The second electrochemical cell consisted of only one container filled with the cement extract solution. The investigation was performed in solutions contaminated with chlorides, in the presence of the inhibitor. The electrochemical results showed that the inhibitor is able to penetrate through mortar, thereby minimizing steel corrosion.

Scott et al. [19] investigated the effectiveness of calcium nitrate, silica fume, fly ash, ground granulated blast furnace slag, and disodium tetrapropenyl succinte (DSS) in minimizing corrosion of reinforcing steel in concrete by conducting a long-term corrosion study. Mixture proportions included: single, double, and triple combinations of these admixtures. Visual inspection, macrocell readings, half-cell potentials, and destructive evaluations (autopsies) were used to evaluate non-cracked and pre-cracked slab specimens. Triple combinations of calcium nitrate, silica fume, and either fly ash or ground granulated blast furnace slag, as well as a double combination of calcium nitrate and ground granulated blast furnace slag, performed very well and were recommended in concrete mixtures exposed to severe corrosive environments. DSS outperformed the other admixtures in corrosion prevention. However, it resulted in somewhat lower compressive strength and was not fully tested for the effects on other concrete properties.

According to Qian and Cusson [20], conclusions from previous studies on the effectiveness and field performance of inhibitors on corrosion of reinforcing steel are controversial. Eight commercial corrosion-inhibiting systems were investigated by using them in a newly reconstructed barrier wall of a highway bridge. A 5-year field survey and laboratory electro-chemical study was conducted. The results showed that the anodic and cathodic reactions were reduced significantly in the presence of organic inhibitors. However, in the presence of inorganic inhibitor, these current were increased to enhance the passive film of steel. Most inhibitors presented in saturated $Ca(OH)_2$ solution (pH=12.6) can delay corrosion process on steel. Also, laboratory tests showed that coating with cementitious inhibitors applied on the steel rebar can reduce corrosion compared with the cement-coated specimens at equivalent NaCl concentration in a saturated $Ca(OH)_2$ solution.

Berke et al. [21] recommended the use of calcium nitrate corrosion inhibitor to improve the durability of reinforced concrete in the Arabian Gulf. According to them, calcium nitrate is a well tested and proven corrosion inhibitor that can provide significant improvement in corrosion-resistance if used with good quality concrete. They stated that good quality concrete alone is not enough to provide a maintenance free service-life of structures in the severe Gulf environment.

According to Matta and Berke [22], more than 100,000 m^3 of concrete incorporating calcium nitrate has been used in the United Arab Emirates to build sea walls, swimming pools, power stations, and other residential structures.

A number of studies were also conducted at King Fahd University of Petroleum and Minerals (KFUPM) to evaluate the usefulness of chemical inhibitors in the aggressive environments of the Arabian Gulf. In the earliest study conducted at KFUPM [23], the effectiveness of selected inhibitors in reducing reinforcement corrosion in concrete incorporating unwashed aggregates, brackish water or seawater was evaluated. In that study, the results showed that calcium nitrate was effective in delaying the onset of reinforcement corrosion in the concrete specimens incorporating seawater, chloride solution or chloride plus sulfate solution. In the concrete specimens prepared with brackish water or unwashed aggregates, all the inhibitors were generally effective in delaying the onset of reinforcement corrosion [23]. The time to initiation of reinforcement corrosion was also calculated by measuring the corrosion current density (I_{corr}). Corrosion was assumed to have been initiated when I_{corr} was more than 0.3 $\mu A/cm^2$. Corrosion initiation was indicated only in the control concrete specimens incorporating chloride, chloride plus sulfate or seawater, as a contamination. All the inhibitors were effective in delaying the onset of reinforcement corrosion, even in the presence of chloride or chloride plus sulfate contamination for a period of six months [23].

The performance of dimethyl ethanol amine-based and triethanol amine-based migratory corrosion inhibitors when applied on the surface of concrete was investigated by Malik et al. [24]. Reinforced concrete specimens coated with migratory inhibitors were exposed to 5% NaCl solution and to the Arabian Gulf seawater for up to 12 months. Physical examination and electrochemical measurements were used to evaluate the condition of the steel bars. From the obtained results, the corrosion inhibitors utilized were generally able to decrease the corrosion rate of steel in concrete. However, the effect of inhibitors on reinforcement corrosion was not significantly noticeable due to the small period, i.e., 12 months, of exposure.

Al-Mehthel et al. [25] studied the improvement in the corrosion resistance of chloride-contaminated silica fume cement concrete due to the use of corrosion inhibitors. They evaluated three proprietary inhibitors and one generic corrosion inhibitor for their performance in inhibiting reinforcement corrosion in the silica fume cement concrete specimens contaminated with 0.4%, 1% and 2% chloride concentration, by weight of cement. Some of the specimens were subjected to wetting and drying cycles and reinforcement corrosion was monitored by measuring the corrosion potentials and corrosion current density. Another batch of concrete specimens was partially immersed in the chloride solution and reinforcement corrosion was accelerated by impressing an anodic potential of 2V. The extent of corrosion increased with increasing the chloride contamination in the concrete specimens. Incorporation of inhibitor generally reduced the rate of reinforcement corrosion. The rate of reinforcement corrosion in the concrete specimens incorporating an organic inhibitor that was added to the concrete during mixing was lower than that in the concrete specimens without inhibitors. Further, it was noted that the accelerated impressed current technique is suitable for quickly screening the performance of corrosion inhibitors.

Pereira et al. [26] conducted a study to evaluate the efficiency of two organic corrosion inhibitors, a migratory and an admixed inhibtor, by electrochemical techniques in solutions simulating the interstitial electrolyte of concrete and on concrete slabs exposed to natural environmental conditions over a five-year period. The results indicated that organic inhibitors were effective in minimizing corrosion rates and they have some advantages, such as versatility and cost, when compared to other corrosion protection methods. However, the results of this work showed that more research is needed on the parameters influencing effectiveness of some migrating corrosion inhibitors in order to support their use.

The inhibitive action of organic substances on carbon steel in alkaline environment was studied by Ormellese et al. [27]. They investigated the effect of aminic and carboxylic groups through electrochemical potentiodynamic polarisation tests in simulated concrete pore solution in the presence of chlorides. The results showed that amines provided poor inhibition effect, with very scattered results when their volatility increased. They reported that aminoacids showed some inhibition effect, but not sufficient for industrial applications. Carboxylate substances, especially poly-carboxylates, showed very good inhibition effectiveness, making them the most promising candidates among the tested substances. However, the authors recommend confirmation tests on concrete to check the compatibility of studied inhibitors with concrete and long-term effectiveness of the organic inhibitors.

Benzotriazole (BTAH), a well known corrosion inhibitor for copper, was evaluated as a possible corrosion inhibitor of carbon steel (CA-50) in concrete by Mennucci et al. [28]. They added BTAH to a simulated pore solution of an aged concrete with addition of 3.5 wt% NaCl to imitate marine environments. The effect of BTAH in a concentration of 1.5 wt% on the corrosion resistance of CA-50 carbon steel was evaluated by electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization tests. The improvement of the corrosion resistance due to BTAH addition was superior to that associated with nitrite in similar concentration, suggesting that BTAH is a potentially attractive alternative to nitrites for inhibiting corrosion of reinforcement steel in concrete.

The role of salt contamination and corrosion inhibiting admixtures on reinforcement corrosion was evaluated by Nguyen and Shi [29]. Cement mortar specimens were prepared with NaCl and one of the three admixed corrosion inhibitors, sodium nitrite, disodium β-glycerophosphate, or N,N′-dimethylethanolamine. After 28 days of curing, all steel-mortar samples were ponded with 3% NaCl solution and electrochemical impedance spectroscopy (EIS) measurements were conducted periodically during the first 48 days. After 60 days of ponding by the 3% NaCl solution, field-emission scanning electron microscopy (FESEM) analysis was conducted on the fractured surface of the steel-mortar sample. They reported that admixed chlorides and inhibitors in fresh mortar changed the morphology and cement hydration product of hardened mortar at the steel-mortar interface [29]. The EIS data indicated that all inhibitors increased the polarization resistance of steel, implying reduced corrosion rate of the steel over the 48-day exposure to salt ponding. 0.05 M N,N′-dimethylethanolamine was reported to be the most effective corrosion inhibitor, followed by 0.5 M sodium nitrite; whereas 0.05 M disodium β-glycerophosphate was a slower and less capable corrosion inhibitor.

Song et al. [30] evaluated the influence of alkaline nitrites on the inhibition of corrosion of steel in binary and ternary cement environments. pH measurements carried out for binary and ternary cement extracts were reported to show that the alkalinity of the cement was not affected by making use of binary and ternary cements. Gravimetric measurements showed that the decrease in the corrosion rate of steel in different systems follows the order: Ternary > (Ordinary Portland cement + Portland salg cement) > (Ordinary Portland cement + Portland pozzalona cement) > (Portland pozzalona cement + Portland salg cement). Potential-time studies indicated that the ability to maintain the passivity of steel in different systems also follows the order above. Potentiodynamic polarization studies for steel in binary and ternary cement environments showed the favorable influence of the presence of higher amounts of chlorides. The authors reported that nitrites of sodium, potassium and calcium act as anodic inhibitors and they compete with chloride ions for the ferrous ions at the steel to form a film of ferric oxide [30]. An efficiency, as high as 91%, was reported for the ternary system containing 1% chloride and 0.5% nitrite. The degree of surface coverage showed a maximum value for the ternary system (>0.9) even in the presence of a higher amount of chlorides thereby indicating the better performance of the system.

The effective modes of use of an amino-alcohol based mixed corrosion inhibitor was studied by Benzina Mechmeche et al. [31]. The inhibitor was tested in fresh pore concrete simulating solutions. The effectiveness of the corrosion inhibitor was investigated through corrosion potential measurements, polarization curves and microscopic observations. The results indicated that the best inhibiting capacity was noted when the inhibitor was introduced in the solution before the contamination with chlorides [31]. The efficiency of the inhibitor was demonstrated even in the case of chloride presence.

Ann and Buenfeld [32] conducted laboratory studies to assess the effect of calcium nitrite-based corrosion inhibitors in raising the chloride threshold level (CTL) for the corrosion of steel embedded in concrete and ,hence , the time to corrosion initiation. Concrete specimens with a centrally located steel rebar were cast with 0, 1, 2, 2.5 and 5.0% nitrite by weight of cement and were cured for 4 weeks. They were then immersed in 4M sodium chloride solution and the galvanic current between the embedded steel and an external cathode was monitored. The CTL of nitrite-free specimens was reported to be typically doubled and trebled by 2.5% nitrite and 5% nitrite, respectively. It was reported that the time to corrosion depended on the cement content. Use of low cement content (282 kg/m^3) increased the CTL as the dosage of nitrite in concrete increased, but did not extend the time to corrosion because it accelerated chloride penetration. For a richer mix (350 kg/m^3), the time to corrosion increased with the dosage of calcium nitrite. After corrosion initiation, the corrosion rate for specimens containing calcium nitrite was typically two to three times higher than for nitrite-free specimens.

The effectiveness of seven corrosion inhibitors to prevent or delay the onset of corrosion in concrete made with basalt aggregate was investigated by Robertson and Newtson [46]. These inhibiting admixtures were categorized to two types. Type 1 admixtures attempt to minimize the concrete permeability: Xypex Admix C-2000, latex modifier, Kryton KIM, fly ash, and silica fume. Type 2 admixtures attempt to raise the chloride concentration threshold: Darex Corrosion Inhibitor (DCI), Rheocrete CNI, Rheocrete 222+, and FerroGard 901. After five years of half-cell potential measurements, they concluded that the control panel with lower water-cementitious materials ratio performed better than higher water-cementitious materials ratio. They also concluded that panels with Type 1 admixtures recorded lower half-cell potentials than panels with Type 2 admixtures.

Paredes et al [47] conducted a long term study to assess the effectiveness of three commercially available corrosion inhibitors for steel in concrete, Calcium nitrite, Sika FerroGard 901, and Rheocrete 222+. They concluded that calcium nitrite was the most effective of the three inhibitors in mitigating corrosion. FerroGard 901 and Rheocrete 222+ were ineffective regardless of concrete quality. None of the inhibitors were as effective as silica fume and/or fly ash in improving long term corrosion performance of embedded reinforcement in concrete. It also was concluded that these inhibitors don't affect strength, the chloride penetration, or sulfate resistance in concrete. The presence of calcium nitrite did reduce the resistivity of the concretes by about 1/3.

Both laboratory and field studies were conducted to evaluate the performance of four commercially available corrosion inhibitors, Ferrogard 901, DCI-S, Rheocrete 222+, and XYPEX C1000 [48]. All the concrete specimens were prepared according to ASTM G 109. The results showed that XYPEX C1000 provides a denser concrete, while the other corrosion inhibitors reduce the effect of the chlorides. Also, the effectiveness of these inhibitors to minimize corrosion of steel in reinforced concrete was ranked from best to worst as follows: XYPEX C1000, Rheocrete 222+, DCI-S, and Ferrogard 901.

CHAPTER THREE

EXPERIMENTAL PROGRAM

In this study, the experimental program that was planned basically aimed to assess the effectiveness of seven types of chemical inhibitors in minimizing reinforcement corrosion in new reinforced concrete structures. This assessment was based on corrosion measurements in concrete specimens exposed to five commonly occurring exposure zones in eastern Saudi Arabia. The following were the major operational tasks to achieve the objectives of this investigation:

1. Preparing two different types of concrete specimens; beam concrete specimens and cylindrical concrete specimens. Both types of concrete specimens were prepared with five corrosion inhibitors but without any dose of chlorides. In addition, cylindrical concrete specimens were prepared with the seven corrosion inhibitors and chloride contamination.
2. Placing the beam concrete specimens in the following five commonly occurring exposure zones: (i) tidal zone (wet and dry cycles), (ii) atmospheric zone, (iii) below ground zone, (iv) capillary zone and (v) submerged zone, for a duration of six months.
3. Exposing the cylindrical concrete specimens without chloride contamination to alternate dying and wetting cycles. Specimens were wetted for one day in 5% NaCl solution and dried for two days, while cylindrical concrete specimens with chloride contamination were sprayed with water once every three days.

4. Subjecting twelve beam specimens to accelerated corrosion by impressing a constant voltage of 1.5 volts for a duration of one month.
5. Periodically measuring the potential of the beam and cylindrical specimens exposed to the five commonly occurring exposure zones.
6. Periodically measuring the corrosion current density on steel in the beam and cylindrical concrete specimens exposed to five commonly occurring zones using the linear polarization resistance method (LPRM).
7. Evaluating the time to cracking of concrete by conducting accelerated corrosion test.

The details of all the above-mentioned tasks and all information about the specimen’s designations and sizes, preparation, tests procedures, and the tests set ups are discussed in the following sections.

3.1 Commercial Inhibitors

There are a number of corrosion inhibitors that have different effects on the steel or the concrete to enhance the alkalinity, block the chloride and reduce the corrosion rate. In this study, seven commercially available corrosion inhibitors were assessed. The details of these inhibitors are as follows:

(i) **Sika FerroGard 901** “is a liquid concrete admixture based on modified amino-alcohol FerroGrad technology” [37]. According to the manufacturer, Sika FerroGard 901 protects the embedded reinforcing steel from corrosion and provides a cost effective means to extend the service life of structures.

The recommended dosage rate is in the range of 3 to 4% by wt. of cement [37].

(ii) **Sika Ferrogard 903 “**is a corrosion inhibiting impregnation coating for hardened concrete surfaces” [38]. According to the manufacturer, Sika FerroGard 903 is a combination of amino-alcohols, organic and inorganic inhibitors that prevents the corrosion cell in the anodic and cathodic parts. A minimum of two coats is always recommended to achieve good protection for steel [38].

(iii) **Rheocrete-CNI** is a liquid concrete admixture based on calcium nitrite [39]. According to the manufacturer, Rheocrete-CNI protects the steel in reinforced concrete from corrosion. The recommended dosage ranges between 10 to 30 l/m^3 depending the corrosion environment severity [39].

(iv) **Conplast-CN** is a liquid concrete admixture based on calcium nitrite [40]. According to the manufacturer, Conplast-CN inhibits corrosion in steel embedded in concrete structures. The recommended dosage ranges between 7.5 to 22.5 l/m^3 [40].

(v) **Cortec** is a liquid concrete admixture based on hydroxyalkyl-amine type. According to the manufacturer, Cortec inhibits corrosion in all types of steel induced by chloride. The recommended dosage is 0.6 l/m^3 [41].

(vi) **Cemetec-CCI-S** is a liquid concrete admixture based on calcium nitrite. According to the manufacturer, Cemetec-CCI-S provides an effective barrier for chloride-induced corrosion on reinforcing steel, especially in marine concrete structures. The recommended dosage ranges between 10 to 38 l/m^3 depending upon the chloride rate [42].

(vii) **Calcium Nitrate (CN)** is a powder material that is mixed with concrete. According to literature review, calcium nitrate (CN) provides a good protection for steel from corrosion. The recommended dosage ranges between 2 to 4% by weight of cement [23].

Figure 3.1 shows the seven commercial corrosion inhibitors that were assessed in this study.

Sika901 Sika903 Rheocrete Conplast

Cortec Cemetec Calcium Nitrate

Figure 3.1 The Seven Commercial Inhibitors Used in This Investigation.

3.2 Preparation of Concrete Specimens

Two types of concrete specimens were prepared.

3.2.1 Concrete Beam Specimens

Beam concrete specimens, measuring 150 x 150 x 300 mm, with 12 mm diameter steel bars both at top and bottom, were prepared. Steel bars at top and stirrups were coated with fusion-bonded epoxy and one stainless steel bar was placed between steel bars at bottom as a counter electrode, as shown in Figure 3.2. The geometry and details of the steel for the concrete beam specimens are shown in Figure 3.3. These specimens were prepared with one dosage of the one generic inhibitor (Calcium Nitrate) and one dosage of the four proprietary inhibitors (Cemetec-CCI-S, Sika FerroGard 901, Sika Ferrogard 903 and Conplast-CN). The dosage of the proprietary inhibitors was that recommended by their manufacturers while the dosage for the generic inhibitor was ascertained from the literature. One batch of concrete specimens without any inhibitor was also prepared.

All the specimens were prepared with the following mixture composition:

- Cement content = 370 kg/m^3
- Coarse aggregate = 1112.6 kg/m^3
  1/2 in (12.5 mm) = 445 kg/m^3
  3/8 in (9.5 mm) = 445 kg/m^3
  3/16 in (4.7 mm) = 111.3 kg/m^3
  3/32 in (2.35 mm) =111.3 kg/m^3
- Dune sand = 741 kg/m^3

- Silica fume = 20 kg/m^3
- w/cm = 0.4
- Superplasticizer = 4.5 l/m^3 (It was used in the control mix, the mix for applying Sika FerroGard 903 and the mix with powder inhibitor (i.e., calcium nitrate)).
- Inhibitors that were added to mixtures are as follows:

  Liquid inhibitors (Sika FerroGard 901, Conplast-CN and Cemetec-CCI-S) = 15 l/m^3.

  Powder inhibitor (calcium nitrate) = 2.278% by weight of cementitious materials.
- Inhibitor that was applied as coating on beam specimens after casting is Sika FerroGard 903. Two layers of Sika FerroGard 903 were applied on surface of beam specimens. The second layer was applied after drying of the first layer.

Figure 3.4 shows a photographic documentation of the beam concrete specimens.

Details of the number of concrete beam specimens with each inhibitor are summarized in Table 3.1.

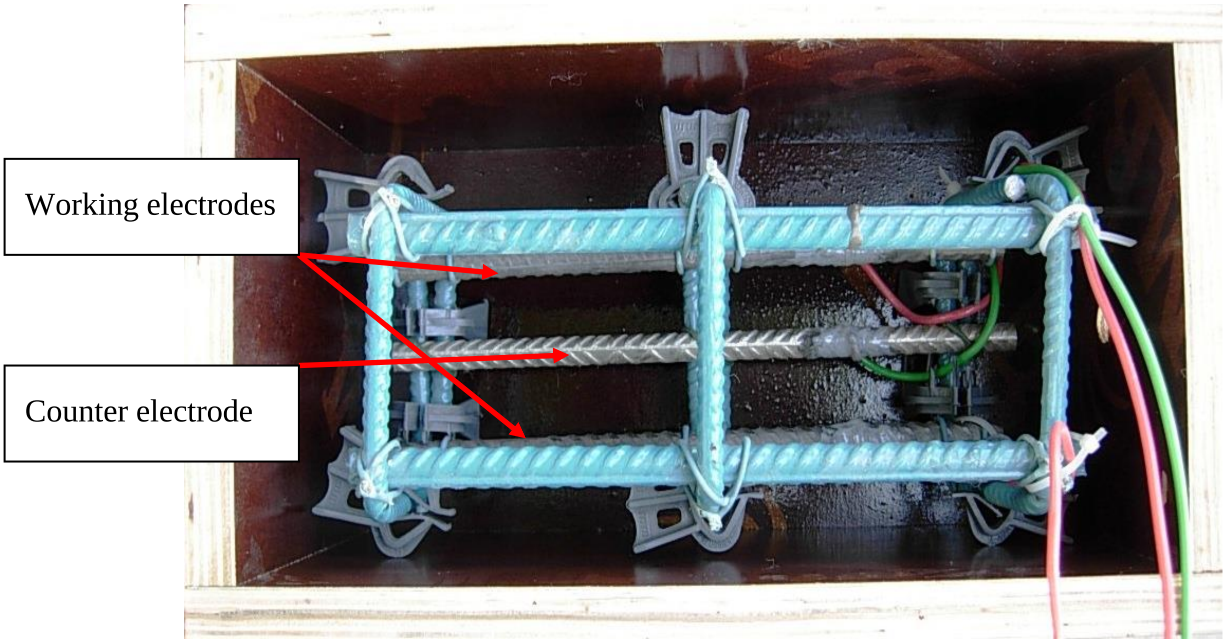
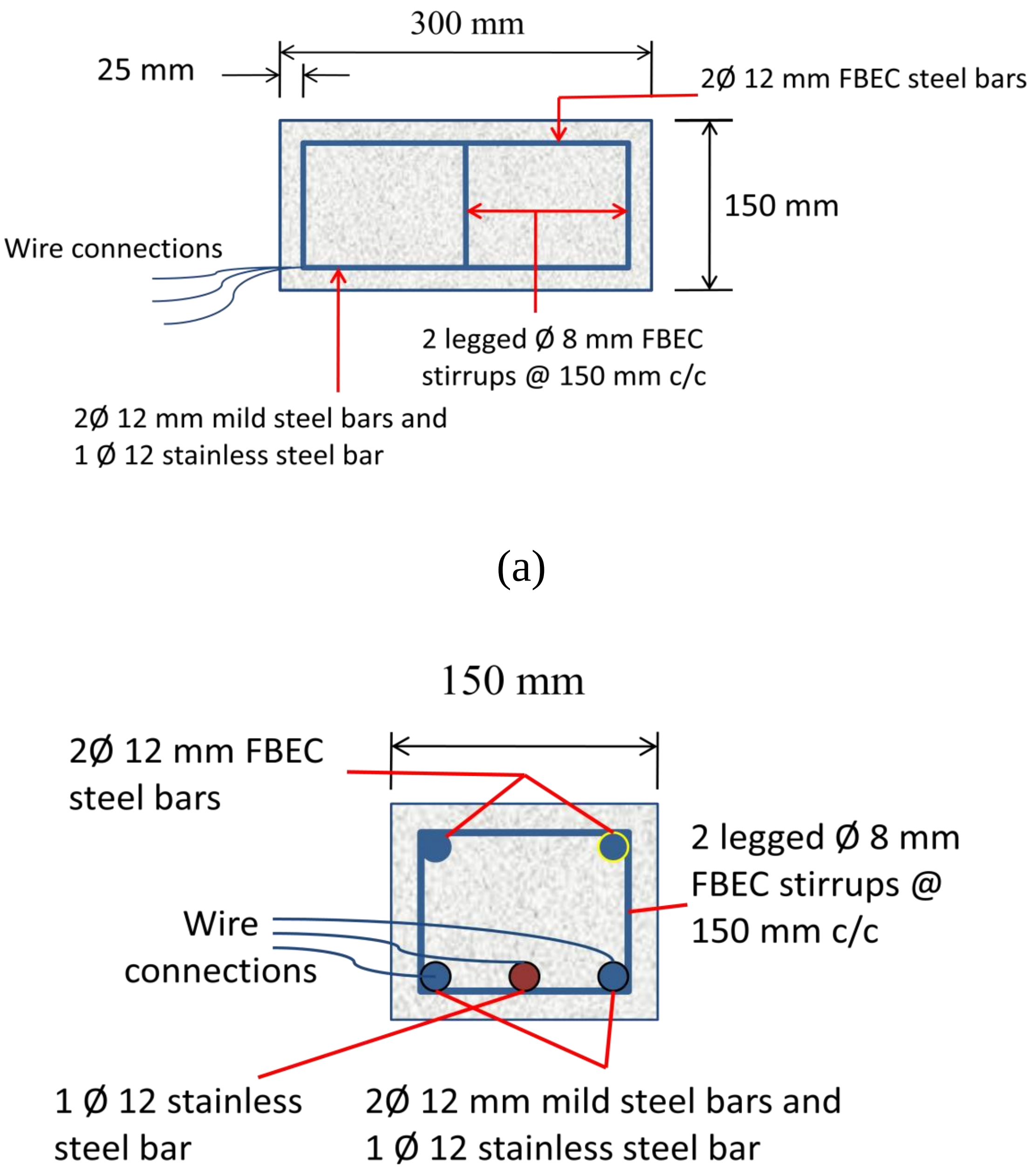


Figure 3.2 Electrodes in the Concrete Beam Specimens.



(a)

(a)

Figure 3.3: Schematic Diagram of the Beam Concrete Specimens, [(a) Elevation; (b) Cross-section].

Figure 3.4 Photographic Documentation of the Concrete Beam Specimens.

Table 3.1 Number of Beam Concrete Specimens Prepared for Each Inhibitor

Inhibitor Type	**No. of Specimens**
None	12
Sika FerroGard 901	12
Sika FerroGard 903	12
▪ Conplast-CN	12
Cemetec-CCI-S	12
Calcium Nitrate (CN)	12
Total	72

3.2.2 Concrete Cylindrical Specimens

Cylindrical concrete specimens, 75 mm in diameter and 150 mm high, with 12 mm diameter central steel bar, were prepared. The geometry and details of steel for the cylindrical concrete specimens are shown in Figure 3.5. These specimens were prepared with generic and proprietary inhibitors. The dosage of the proprietary inhibitors was that recommended by their manufacturers, while the dosage of the generic inhibitors was ascertained from the literature. Further, one batch of concrete specimens without any inhibitor was prepared.

All the specimens were prepared with the following mixture composition:

- Cement content = 370 kg/m^3
- Coarse aggregate = 1112.6 kg/m^3
  1/2 in (12.5 mm) = 445 kg/m^3
  3/8 in (9.5 mm) = 445 kg/m^3
  3/16 in (4.7 mm) = 111.3 kg/m^3
  3/32 in (2.35 mm) =111.3 kg/m^3
- Dune sand = 741 kg/m^3
- Silica fume = 20 kg/m^3
- w/cm = 0.4
- Superplasticizer = 4.5 l/m^3 (It was used in the control mix, the mix for applying Sika FerroGard 903 and the mix with powder inhibitor (i.e., calcium nitrate)).
- Inhibitors that were either added to mixtures or applied on the surface are as follows:

- **Concrete Cylindrical Specimens without Chloride Contamination**

These specimens were prepared with the following five inhibitors:

- Liquid inhibitors (Sika FerroGard 901, Conplast-CN and Cemetec-CCI-S) = 15 l/m^3.
- Powder inhibitor (Calcium Nitrate) = 2.278% by weight of cementitious materials.
- Inhibitor that was applied as coating on cylindrical specimens without chloride content specimens after casting was Sika FerroGard 903. Two layers of Sika FerroGard 903 were applied on surface of beam specimens. The second layer was applied after drying of the first layer.

- **Concrete Cylindrical Specimens with Chloride Contamination**

These specimens were prepared with the following seven inhibitors:

- Liquid inhibitors (Sika FerroGrade 901, Rheocrete-CNI, Conplast-CN and Cemetec-CCI-S) = 15 l/m^3.

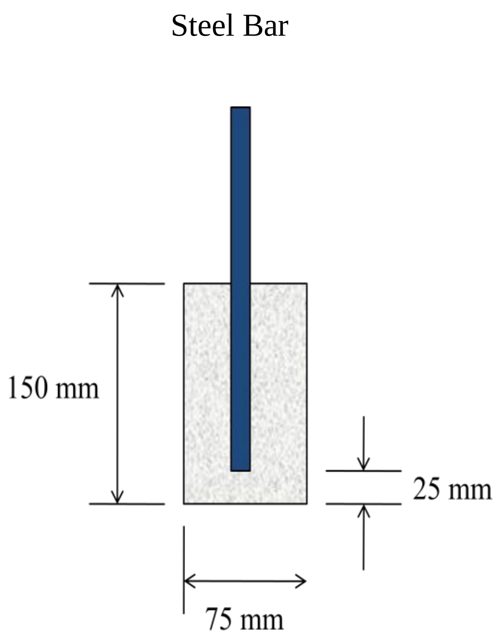
  Liquid inhibitor (Cortec) = 0.6 l/m^3.

  Powder inhibitors (Calcium Nitrate) = 2.278% weight of cementitious materials.

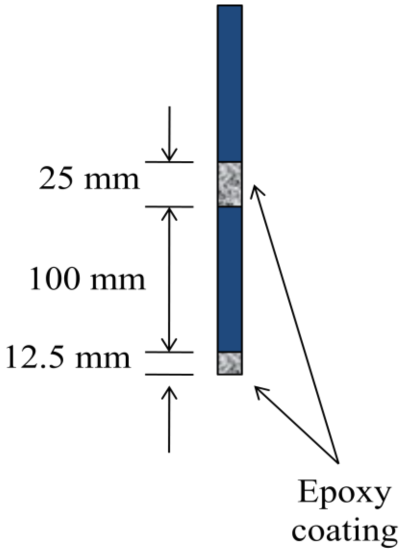
  Inhibitor that was applied as coating on concrete cylindrical specimens with chloride Content specimens after casting is Sika FerroGard 903. Two layers of Sika FerroGard 903 were applied on surface of beam specimens. The second layer was applied after drying the first layer.

Figure 3.5 depicts the schematic diagram of the concrete cylindrical specimens, while Figure 3.6 shows the concrete cylindrical specimens.

Details on the number of concrete cylindrical specimens with each inhibitor and without chloride contamination are summarized in Table 3.2, while the details on the number of concrete cylindrical specimens with each inhibitor and chloride contamination are summarized in Table 3.3.



Elevation



Steel Bar

Figure 3.5 Schematic Diagram of the Concrete Cylindrical Specimens.

Figure 3.6 Concrete Cylindrical Specimens.

Table 3.2 Number of Concrete Cylindrical Specimens Prepared without Chloride Contamination for Each Inhibitor

Inhibitor Type	**No. of Specimens**
None	6
Sika FerroGard 901	6
Sika FerroGard 903	6
Conplast-CN	6
Cemetec-CCI-S	6
Calcium Nitrate (CN)	6
Total	36

Table 3.3 Number of Concrete Cylindrical Specimens Prepared with Chloride Contamination for Each Inhibitor

Inhibitor Type	**No. of Specimens**	**No. of Specimens**			
		Chloride Content, % by Weight of Binder Content			
		0.2	**0.4**	**0.8**	**1.5**
None	12	3	3	3	3
Sika FerroGard 901	12	3	3	3	3
Sika FerroGard 903	12	3	3	3	3
Conplast-CN	12	3	3	3	3
Cemetec-CCI-S	12	3	3	3	3
Calcium Nitrate (CN)	12	3	3	3	3
Rheocrete-CNI	12	3	3	3	3
Cortec	12	3	3	3	3
Total	96	24	24	24	24

3.3 Curing of Concrete Specimens

After casting, all beam and cylindrical concrete specimens were cured by covering them with wet burlap for 14 days at the laboratory temperature (with a 22 ± 3^{o}C). After that, they were dried in the laboratory for 14 days. Figure 3.7 shows the curing of concrete specimens.

Figure 3.7 Curing Using Wetted Burlap.

3.4 Exposure of Concrete Specimens

After curing, the concrete specimens were exposed to the following five commonly occurring exposure zones:

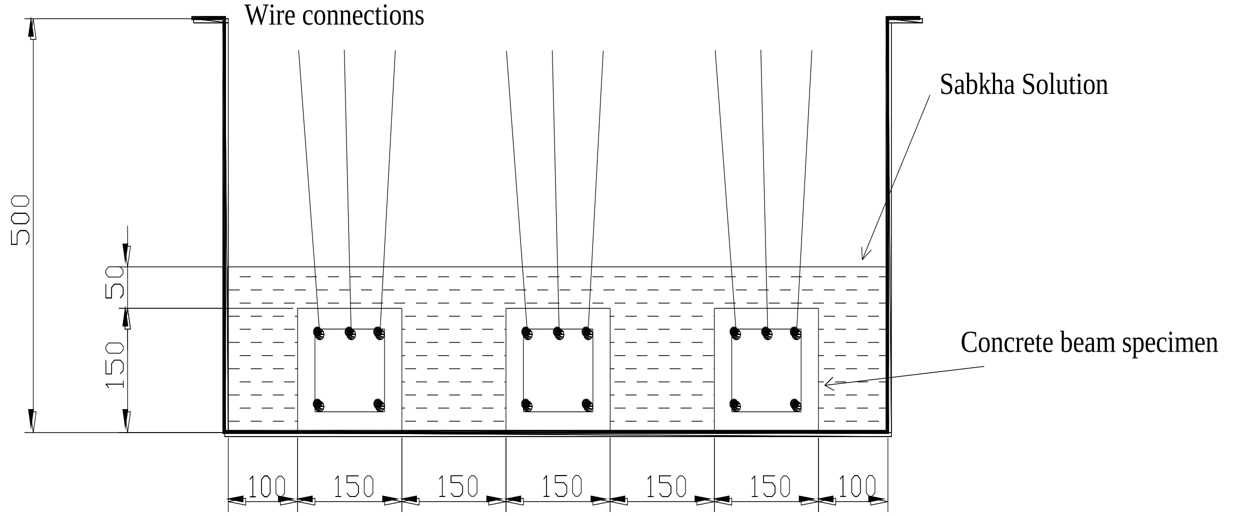
3.4.1 Atmospheric Zone

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were placed in conditions representing the atmospheric zone in eastern Saudi Arabia. They were placed outside the laboratory on some bases (so as not to be in contact with the ground) and they were sprayed with 5% NaCl solution once a week to simulate humidity and weather in the marine environment. Figure 3.8 shows the concrete beam specimens in the atmospheric zone.

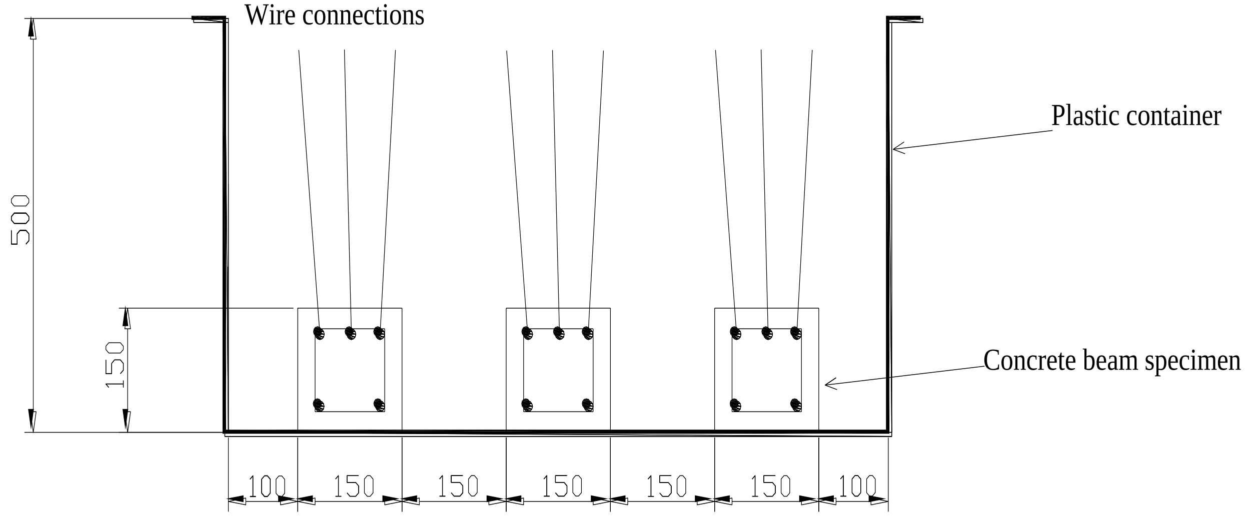
Figure 3.8 Concrete Beam Specimens in the Atmospheric Zone.

3.4.2 Tidal Zone (Wet and Dry Cycles)

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were placed in a tank with a sabkha solution (15.7% Cl^- + 0.55% SO_4^{--}) [45]. The specimens were wetted for one day and dried for two days to simulate the tidal zone in eastern Saudi sabkha exposures. Figure 3.9 shows a schematic diagram of the tidal zone for concrete beam specimens, while Figure 3.10 is a pictorial view of the concrete beam specimens placed in the tidal zone with the sabkha solution.



Wetting for one day



Drying for two days

Figure 3.9 Schematic Diagram of Concrete Beam Specimens for the Tidal Exposure.

Wetting Drying

Figure 3.10 Concrete Beam Specimens in the Tidal Zone.

- Concrete cylindrical specimens, without chloride contamination and inhibitors, were exposed to wet and dry cycles with 5% NaCl solution. The specimens were immersed in 5% NaCl solution for one day and dried for two days to simulate tidal zone in a marine environment. Figure 3.11 shows the concrete cylindrical specimens without chloride contamination in the wet and dry condition.

Wetting Drying

Figure 3.11 Concrete Cylindrical Specimens without Chloride Contamination in the Wet and Dry Condition.

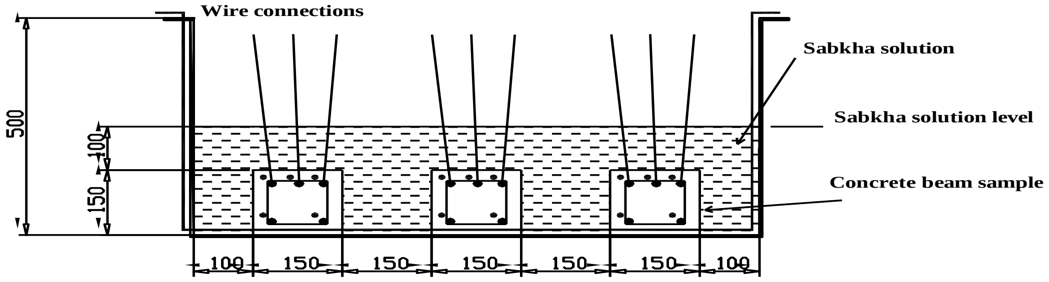
- Concrete cylindrical specimens, with chloride contamination and inhibitors, were exposed to wet and dry cycles with water. The specimens were sprayed with water once every three days because the specimens were already contaminated with chloride. Therefore, if the specimens were immersed in water for long time, chloride might leach out from the specimens. Figure 3.12 shows the concrete cylindrical specimens with chloride contamination in the wet and dry condition.

Wetting Drying

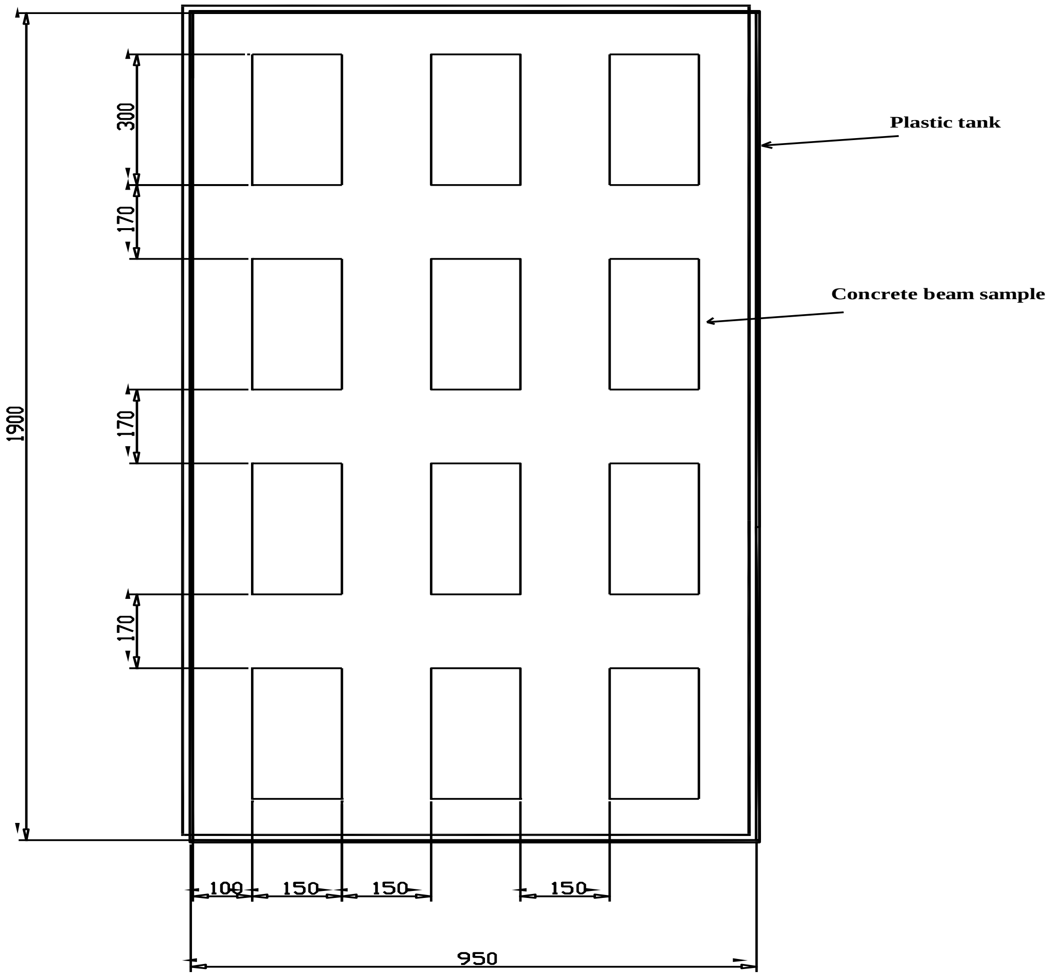
Figure 3.12 Concrete Cylindrical Specimens with Chloride Contamination in the Wet and Dry Condition.

3.4.3 Submerged Zone

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were submerged in a tank with a sabkha solution (15.7% Cl^- + 2.1% SO_4^{--}) to simulate submerged zone in eastern Saudi Arabia [45]. Figure 3.13 shows the schematic diagram of the concrete beam specimens for exposure to submerged zone, while Figure 3.14 is a pictorial view of these specimens in the submerged zone.



CROSS SECTION



PLAN ELEVATION

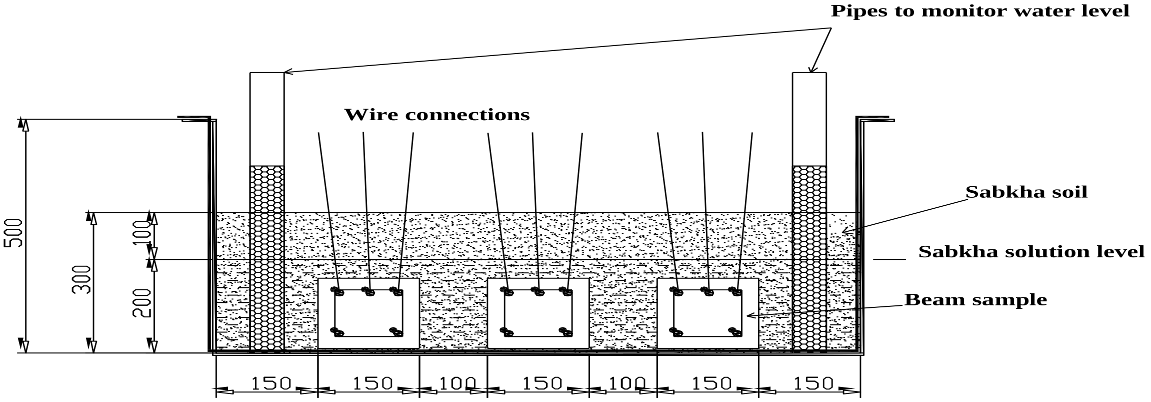
All dimensions in millimetres

Figure 3.13 Schematic Diagram of the Concrete Beam Specimens for Exposure to the Submerged Zone.

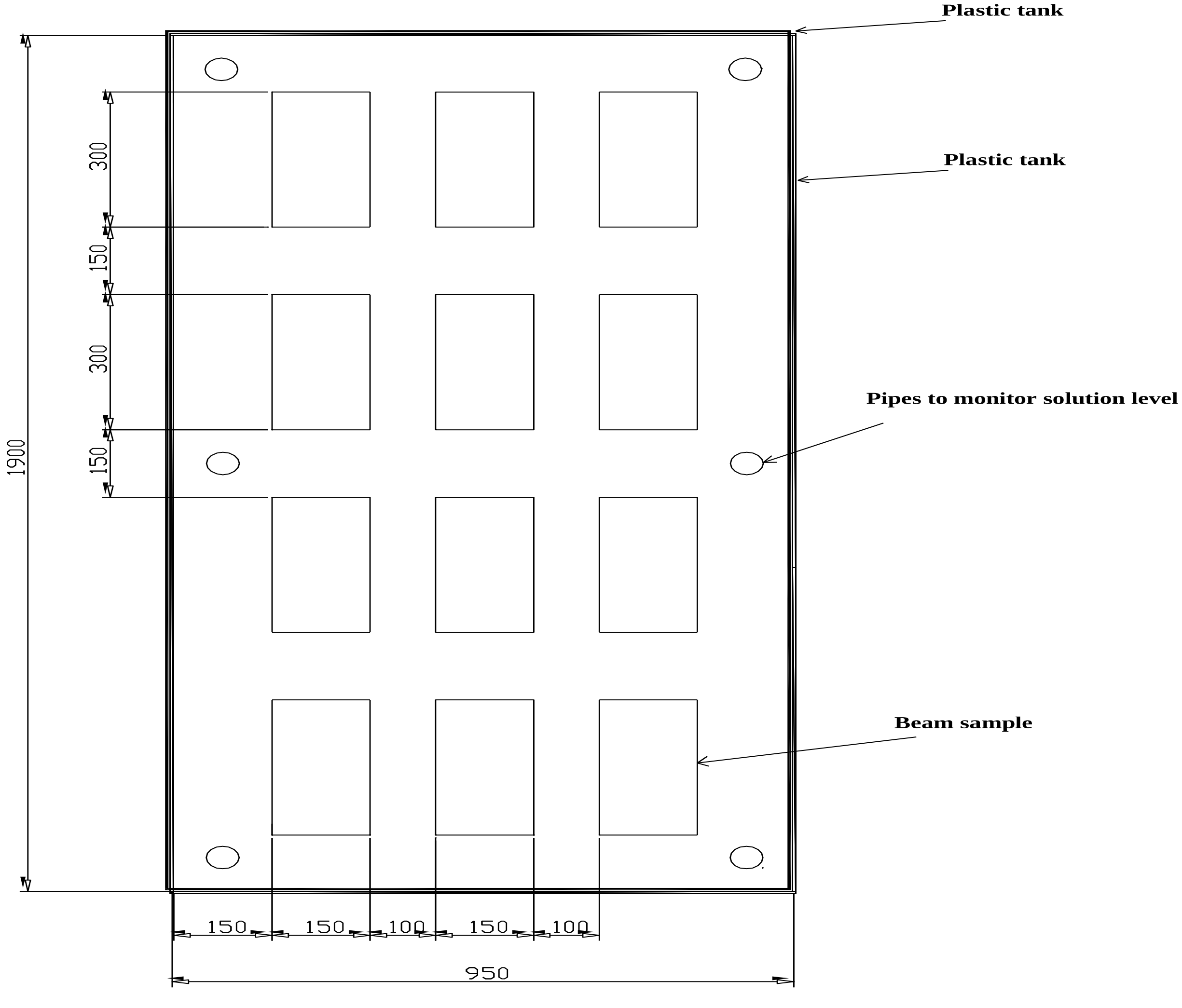
Figure 3.14 Concrete Beam Specimens in the Submerged Zone.

3.4.4 Below Ground Zone

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were buried fully in soil mixed with a sabkha solution (15.7% Cl^- + 2.1% SO_4^{--}) to simulate the below ground zone in eastern Saudi Arabia [45]. Figure 3.15 shows the schematic diagram of the below ground zone for concrete beam specimens, while Figure 3.16 is a pictorial view of these specimens in the below ground zone.



CROSS SECTION



PLAN ELEVATION

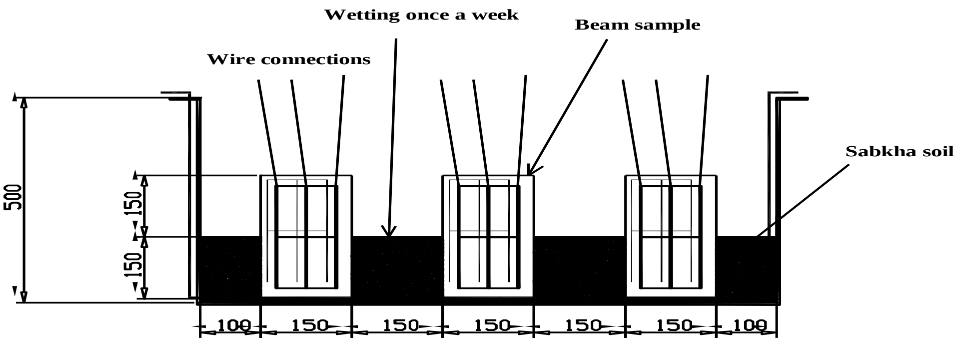
All dimensions in millimetres

Figure 3.15 Schematic Diagram of the Concrete Beam Specimens for Exposure to the Below Ground Zone

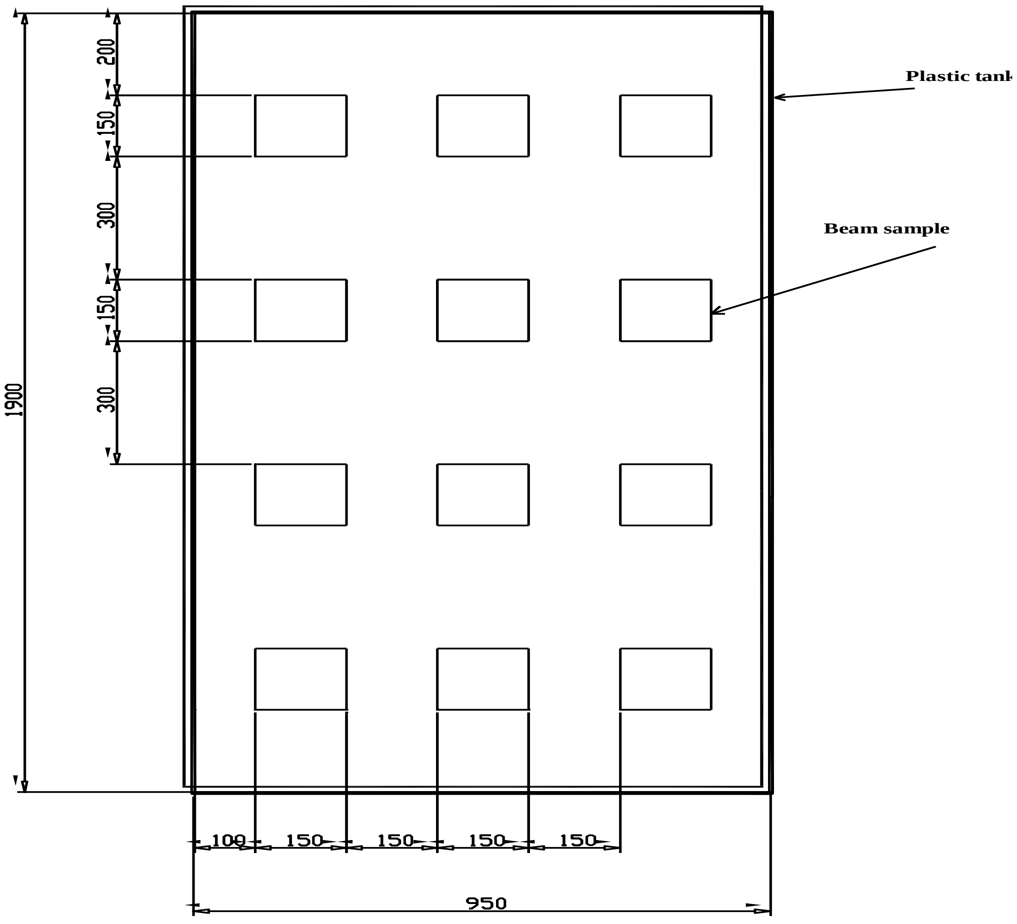
Figure 3.16 Concrete Beam Specimens in the Below Ground Zone.

3.4.5 Capillary Zone

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were half buried in soil mixed with sabkha solution (15.7% Cl^- + 2.1% SO_4^{--}) to simulate the capillary zone in sabkha environment [45]. Figure 3.17 shows the schematic diagram of the concrete beam specimens for exposure to capillary zone, while Figure 3.18 is a pictorial view of these specimens in the capillary zone.



CROSS SECTION



PLAN ELEVATION

All dimensions in millimetres

Figure 3.17 Schematic Diagram of the Concrete Beam Specimens for Exposure to the Capillary Zone.

Figure 3.18 Concrete Beam Specimens Placed in the Capillary Zone.

3.5 Tests Procedure

3.5.1 Corrosion “Half Cell” Potential (E_{corr})

Measuring the corrosion potential is the easiest electrochemical technique for monitoring corrosion of reinforcing steel in a structure. The corrosion potential (E_{corr}) is the potential at which the anodic and cathodic reactions are in balance (the currents for the reactions are equal). The current at E_{corr} is defined as the corrosion current (I_{corr}). The most common method to determine the corrosion potential of steel in reinforced concrete without having to damage the structure or the specimen is to measure corrosion potential [33]. Half-cell measurements compare the potential of the reinforcement with that of a reference electrode exposed to the same environment. Reference electrodes are made out of materials with behavior that is basically independent of the surrounding environment

According to the half-cell potential method [33], the corrosion potential for all the concrete specimens was measured every two weeks by using copper-copper sulfate reference electrode. The procedure of measurement for beam and cylindrical concrete specimens in each case of exposure was as follows [33]:

- **Beam Specimens:**
  - **Atmospheric and tidal zones:**

Before measuring the corrosion potential in these zones, the position of steel bar at the bottom of the concrete beam specimens was measured using cover meter because the position of steel bars might have been be changed during casting and compacting. Figure 3.19 shows the concrete beam specimens with the position of steel bars measured on them.

Figure 3.19 Position of Steel Bars Measured with the Help of Cover Meter.

After that, two points on surface of concrete beams for each steel bar were determined to measure the corrosion potential at these points and take the average. The procedure to measure potential in each point was as follows [33]:

1. Put a cotton piece on the reference electrode and hold it with rubber.
2. Moist the cotton piece and surface of concrete in each point with some water.
3. Put the reference electrode (copper-copper sulfate) connected to the positive terminal of the multimeter on the beam specimen at the measuring point.
4. Connect the wire lead from the steel bar to the negative terminal of the multimeter.
5. Take the measurement of the corrosion potential.

Figure 3.20 shows the methodology to measure the corrosion potential on concrete beam specimens in the atmospheric and tidal zones.

Figure 3.20 Methodology to Measure the Corrosion Potential on Concrete Beam Specimens in the Atmospheric and Tidal Zones.

- **Below ground and capillary zones:**

One reading for each working electrode inside the concrete beams in these zones was taken by using copper-copper sulfate reference electrode and multimeter. The procedure to measure potential in each beam was as follows [33]:

1. Bury half of the reference electrode in the sabkha soil beside the specimen.
2. In the capillary zone, the reference electrode was buried beside the bottom face of the specimen. In the below ground zone, the reference electrode was buried parallel to the specimen from the top.
3. Connect the reference electrode (copper-copper sulfate) to the positive terminal of the multimeter and connect the wire lead from the steel bar to the negative terminal of the multimeter.
4. Take the measurement of the corrosion potential.

Figure 3.21 shows how to measure the corrosion potential on concrete beam specimens in the below ground and capillary zones.

Below ground zone Capillary zone

Figure 3.21 Methodology to Measure the Corrosion Potential on Concrete Beam Specimens in the Below Ground and Capillary Zones.

- **Submerged zone:**

One reading for each working electrode inside the concrete beams in these zones was taken using the copper-copper sulfate reference electrode and multimeter. The procedure to measure potential in each beam was as follows [33]:

1. Immerse half of the reference electrode in the sabkha solution beside the specimen.
2. Connect the reference electrode (copper-copper sulfate) to the positive terminal of the multimeter and connect the wire lead from the steel bar to the negative

terminal of the multimeter.

3. Take the measurement of the corrosion potential.

Figure 3.22 shows how to measure the corrosion potential on concrete beam specimens exposed to the submerged zone.

Figure 3.22 Methodology to Measure the Corrosion Potential on Concrete Beam Specimens in Submerged Zone.

- **Cylindrical Specimens:**

Six readings for each concrete cylindrical specimen were taken by using the copper-copper sulfate reference electrode and the multimeter. Two faces in each specimen were determined and three readings on each face were taken. The reported corrosion potential for each specimen is the average of six readings. The procedure to measure the corrosion potential in each cylinder was as follows [33]:

1. Put a cotton piece on the reference electrode and hold it with rubber.
2. Moist the cotton piece and surface of concrete in each point with some water.
3. Put the reference electrode (copper-copper sulfate) connected to the positive terminal of the multimeter on the cylindrical specimen at the measuring point.
4. Connect the steel bar to the negative terminal of the multimeter.
5. Take the measurement of the corrosion potential.

Figure 3.23 shows the methodology to measure the corrosion potential on concrete cylindrical specimens.

Figure 3.23 Methodology to Measure the Corrosion Potential on Concrete Cylindrical Specimens.

3.5.2 Corrosion Current Density (I_{corr})

The linear polarization resistance technique is the most common method that is used to get a rapid non-destructive measurement of the corrosion rate of reinforced steel. This method was used to measure the corrosion current density (I_{corr}). In this technique, the reinforcing steel bar was polarized to ±10 mV of the open circuit potential (E_{corr}), the potential within which the current varies linearly with the applied potential.

The linear polarization resistance (R_p) can be determined from the slope of the plot of applied potential against measured current [34]. By using Stern-Geary relationship [34], the corrosion current density (I_{corr}) can be determined as follows:

$$I_{corr} = \frac{B}{R_p} \tag{3.1}$$

Where:

I_{corr} is the corrosion current density **(µA/cm^2)**,

R_p is the polarization resistance **(kΩ.cm^2)**,

$R_p = \frac{\Delta E}{\Delta I}$, ΔE is the change in the measured potential and ΔI is the change in the applied current per unit area of electrode.

B is Tafel constant,

$$B = \frac{2.3*(\beta a*\beta c)}{(\beta a+\beta c)} \tag{3.2}$$

Where:

β_a is the anodic Tafel constant,

β_c is the cathodic Tafel constant.

The values of βa and βc are determined from the Tafel plot. However, in the case of insufficient data on βa and βc for steel in concrete, a value of B equal to 52 mV for steel in passive condition and a value equal to 26 mV for steel in active condition are normally used [34].

According to the linear polarization method, the corrosion current density (I_{corr}) for all the concrete specimens was measured every month by using the copper-copper sulfate reference electrode. The procedure of measurement for beam and cylindrical concrete specimens in each case of exposure was as follows:

- **Beam Specimens:**
  - **Atmospheric and tidal zones:**
    1. Put a cotton piece on the surface of concrete along the working electrode.
    2. Moist the cotton piece with some water.
    3. Put stainless steel plate on the cotton piece to hold the reference electrode.
    4. Connect the reference electrode (copper-copper sulfate), working electrode and counter electrode (embedded stainless steel bar) to the potentiostat machine.
    5. Take the measurement of the corrosion current density.

Figure 3.24 shows the methodology to measure the corrosion current density on concrete beam specimens in the atmospheric and tidal zones.

Figure 3.24 Methodology to Measure the Corrosion Current Density on Concrete Beam Specimens in the Atmospheric and Tidal Zones.

- **Below ground and capillary zones:**

1. Bury half of the reference electrode in the sabkha soil beside the specimen.
2. In the capillary zone, the reference electrode was buried beside the bottom face of the specimen. In the below ground zone, the reference electrode was buried parallel to the specimen from the top.

3. Connect the reference electrode (copper-copper sulfate), working electrode and counter electrode (embedded stainless steel bar) to the potentiostat machine.
4. Take the measurement of the corrosion current density.

Figure 3.25 shows the methodology to measure the corrosion current density on concrete beam specimens in the below ground and capillary zones.

Below ground Zone

Capillary zone

Figure 3.25 Methodology to Measure the Corrosion Current Density on Concrete Beam Specimens in the Below Ground and Capillary Zones.

- **Submerged zone:**

1. Immerse half of the reference electrode in the sabkha solution beside the specimen.
2. Connect the reference electrode (copper-copper sulfate), working electrode and counter electrode (embedded stainless steel bar) to the potentiostat machine.
3. Take the measurement of the corrosion current density.

Figure 3.26 shows the methodology to measure the corrosion current density on concrete beam specimens in the submerged zone.

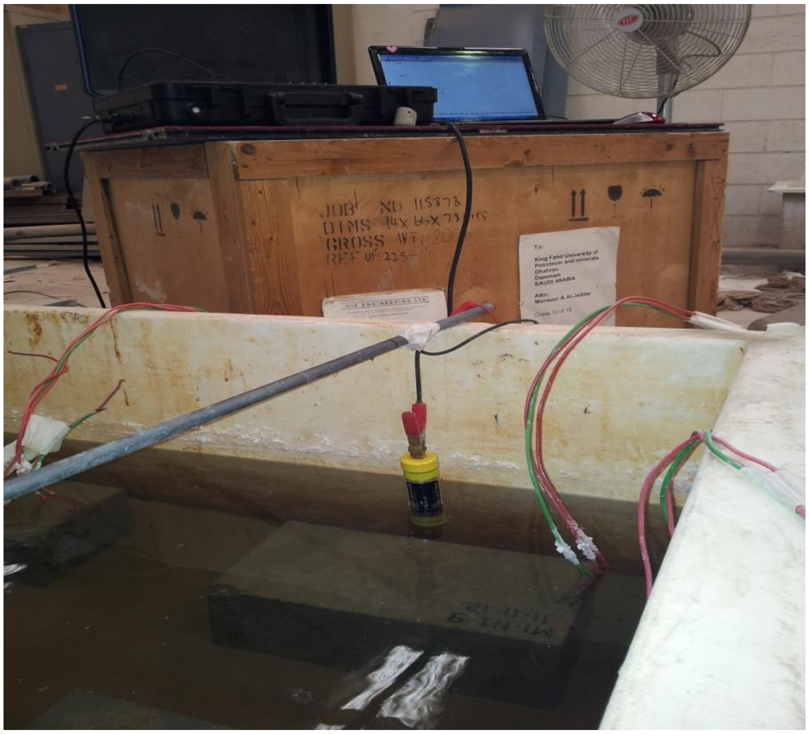


Figure 3.26 Methodology to Measure the Corrosion Current Density on Concrete Beam Specimens in the Submerged Zone.

- **Cylindrical Specimens:**
  1. Put a cotton piece on the surface of concrete along the working electrode.
  2. Moist the cotton piece with some water.
  3. Put stainless steel plate on the cotton piece as the counter electrode and to hold the reference electrode.
  4. Connect the reference electrode (copper-copper sulfate), working electrode and counter electrode (stainless steel plate) to the potentiostat machine.
  5. Take the measurement of the corrosion current density.

Figure 3.27 shows the methodology to measure the corrosion current density on concrete cylindrical specimens.

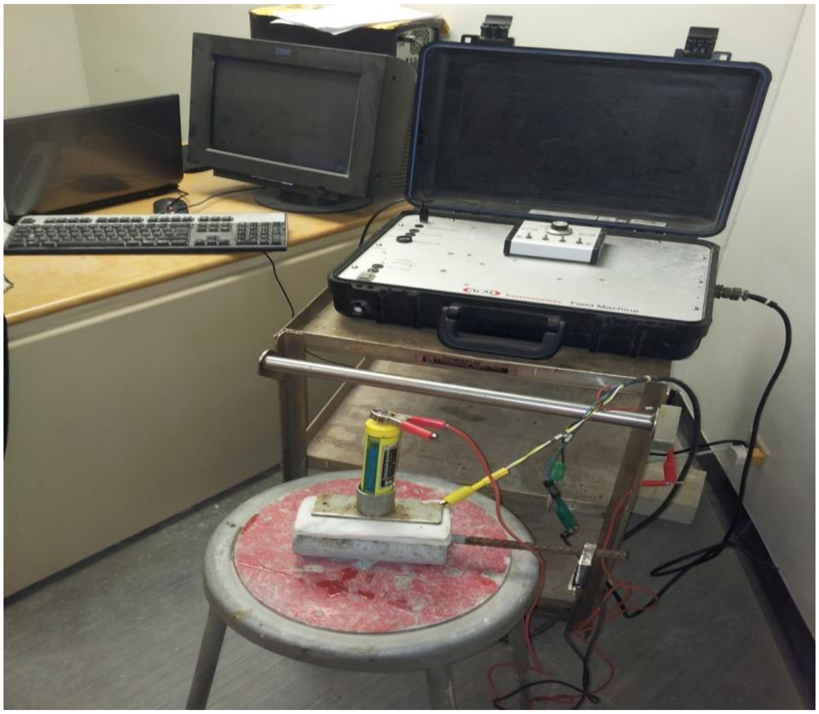


Figure 3.27 Methodology to Measure the Corrosion Current Density on Concrete Cylindrical Specimens.

3.5.3 Accelerated Corrosion Test

Twelve concrete beam specimens, each two specimens with a selected inhibitor, were subjected to a constant voltage of 1.5 volts using a power supply for a period of one month. The current was impressed through the main longitudinal rebars, which acted as the anode, while the stainless steel plate on the surface of each specimen acted as the cathode [36]. In this set-up, a wet cotton padding was inserted between the stainless steel plate and surface of beam specimen. The cotton pad was wetted with 200 ml 5% NaCl solution at the first time and with 100 ml every day. The drop in the potential was recorded by a data-logger during the entire period of the accelerated corrosion testing. Then, the corresponding currents were calculated using Ohm's law, using the constant basic resistance of the system as 10 Ω.

$$I = \frac{\mathrm{E}}{\mathrm{R}} \tag{3.3}$$

Where:

I is the current (**mA**)

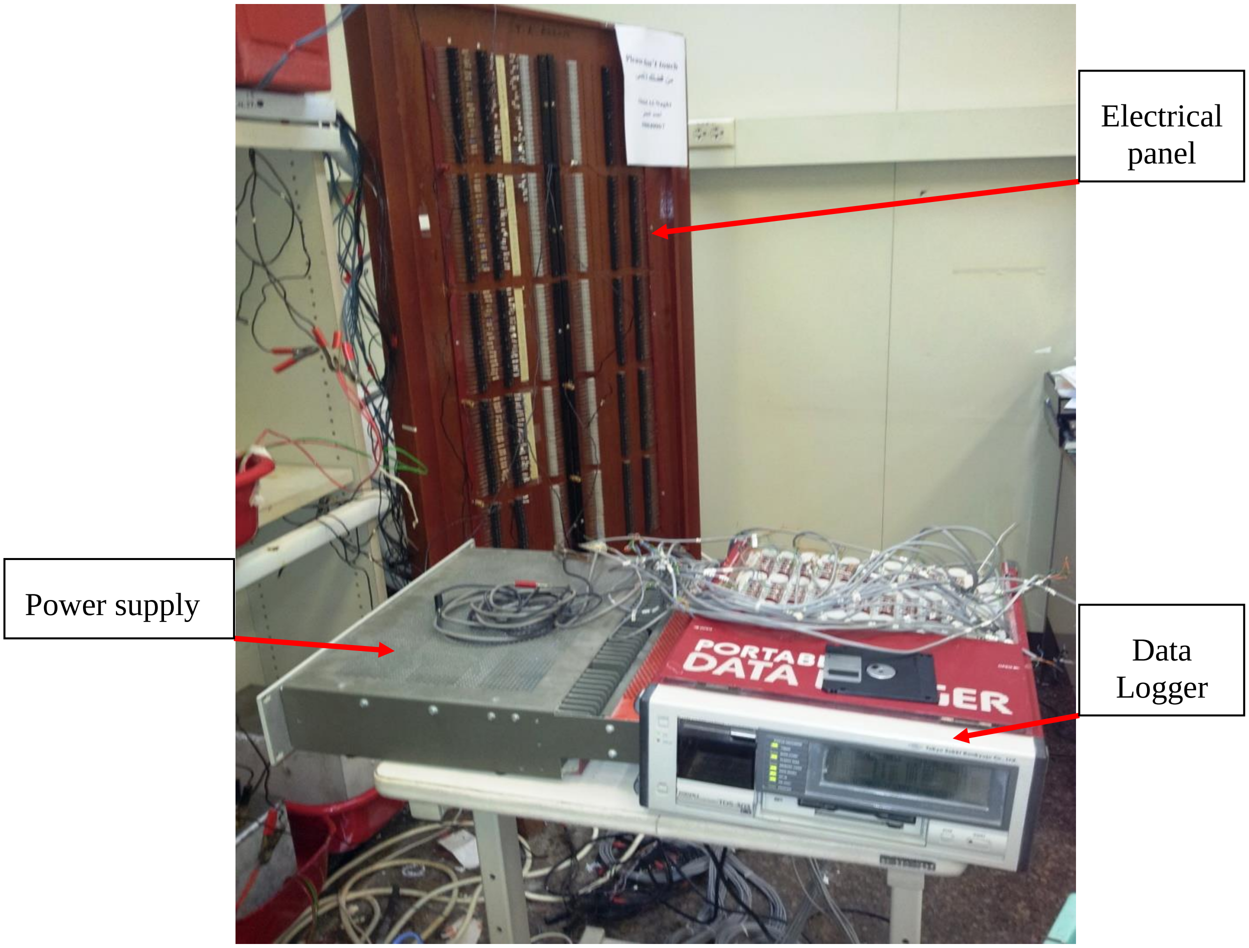
E is the potential (**mV**)

R is the resistance (**Ω**)

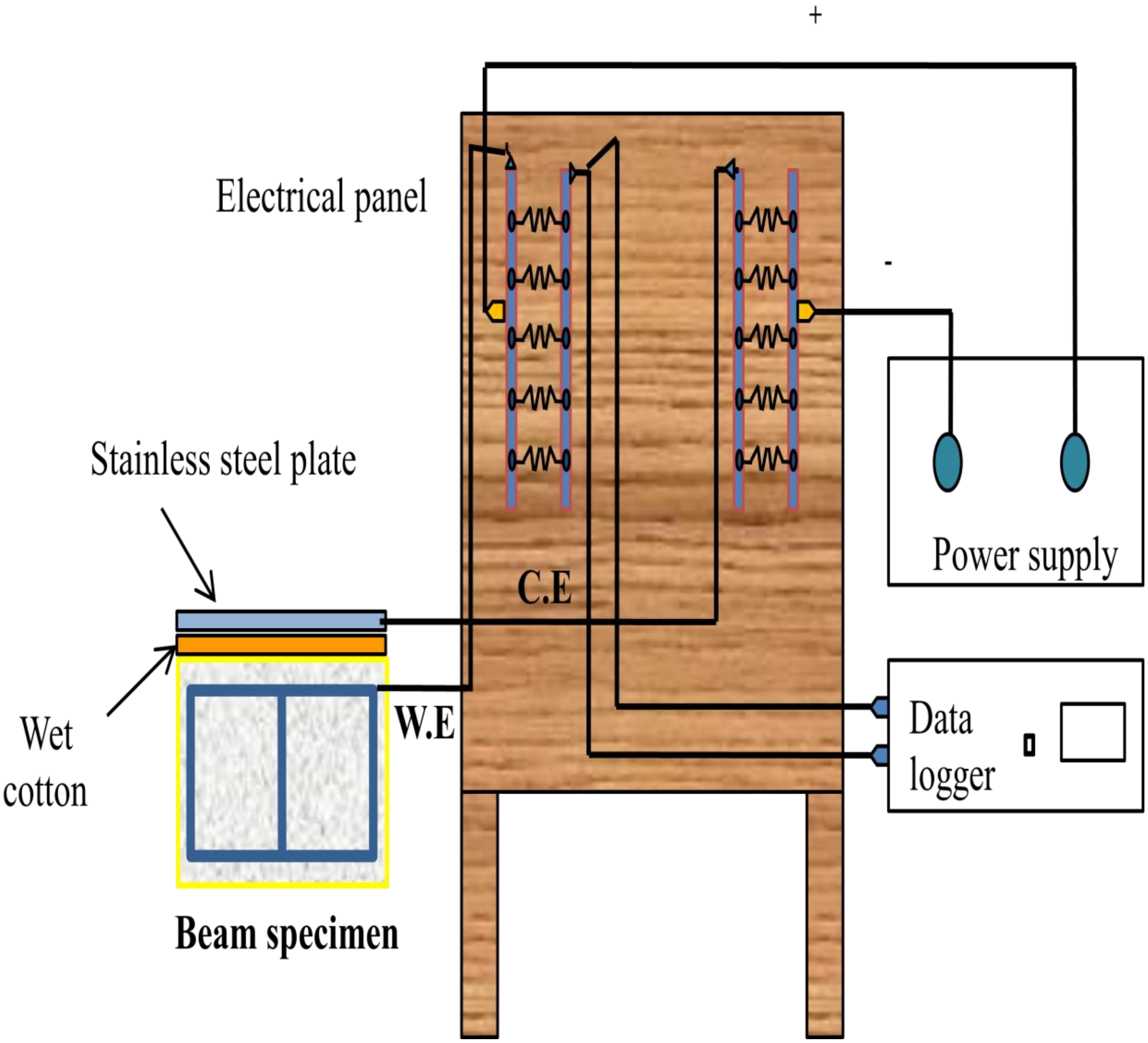
R = 10 **Ω** Then ***I*** = 0.1* E]

The plots of the current (mA) versus the corresponding time (hours) were developed. Time of cracking for all specimens was determined from the current plots and it was compared with visual inspection for specimens daily.

The accelerated corrosion test set-up and the specimens during the test are depicted in Figures 3.28, 3.29 and 3.30.



Figures 3.28 The Accelerated Corrosion Test Set-Up.



WE: Working Electrode, CE: Counter Electrode

Figures 3.29 Schmatic Diagram for the Accelerated Corrosion Test Set Up.

Figures 3.30 Concrete Beam Specimens under Test for the Accelerated Corrosion.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

As mentioned earlier, the effectiveness of corrosion inhibitors was evaluated by measuring the corrosion potentials, corrosion current density and resistance to accelerated corrosion. The results of these measurements are presented and discussed in the following sub-sections.

4.1 Corrosion Potentials

The corrosion potentials were measured every two weeks for a total period of about six months.

4.1.1Beam Specimens

As reported in Section 3.4, the beam specimens were exposed to five commonly occurring exposure zones. Therefore, the results of corrosion potentials of these specimens are presented and discussed as follows:

- **Atmospheric Zone:**

In this zone, a total of 12 beam specimens, two specimens with each inhibitor, were sprayed with 5% NaCl once a week. In each specimen, there were two working electrodes (two steel bars). The corrosion potentials were measured at two points for each working electrode, as reported in Section 3.5.1.

The average of the corrosion potentials for each working electrode and then for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are given in Table 4.1. Figure 4.1 shows the corrosion potentials on steel in the beam concrete specimens exposed to the atmospheric zone for each inhibitor.

According to ASTM 876 [33], the corrosion potentials more negative than -350 mV, with respect to copper-copper sulfate electrode (CSE), indicate the probability of corrosion activation. All the potentials in Figure 4.1 did not exceed -350 mV CSE up to six months of exposure and this indicates that the severity of this zone was low. Therefore, corrosion initiation in atmospheric zone may start after long time depending on the severity of this zone. In the concrete specimens without inhibitor, the potentials were less than those in the concrete specimens with inhibitors. This indicates that all the corrosion inhibitors were effective in delaying reinforcement corrosion. The effectiveness of the investigated inhibitors in minimizing corrosion of steel in reinforced concrete in this zone was ranked from highest to lowest as follows: Cemetec, Calcium Nitrate, Sika901, Sika903 and Conplast.

Table 4.1 Average Corrosion Potentials for Beam Specimens Exposed to the Atmospheric Zone.

Date of Exposure: 10/02/2013

Date	Duration (Days)	Average Corrosion Potentials, mV CSE					
		Control	Cemetec	Conplast	Sika901	Calcium Nitrate	Sika903
25/02/2103	15	-39	-20	-29	-30	-17	-19
13/03/2103	33	-57	-51	-76	-71	-86	-82
30/03/2013	50	-91	-22	-36	-54	-59	-84
15/04/2013	65	-106	-92	-98	-97	-89	-96
30/04/2013	80	-129	-93	-103	-106	-99	-104
14/05/2013	94	-114	-113	-120	-130	-117	-105
01/06/2013	110	-128	-119	-108	-123	-116	-111
15/06/2013	125	-147	-114	-129	-126	-126	-119
30/06/2013	140	-152	-134	-155	-120	-113	-109
25/07/2013	165	-140	-120	-105	-113	-105	-135
12/08/2013	182	-198	-150	-213	-191	-181	-193
22/08/2013	192	-249	-176	-231	-212	-205	-214

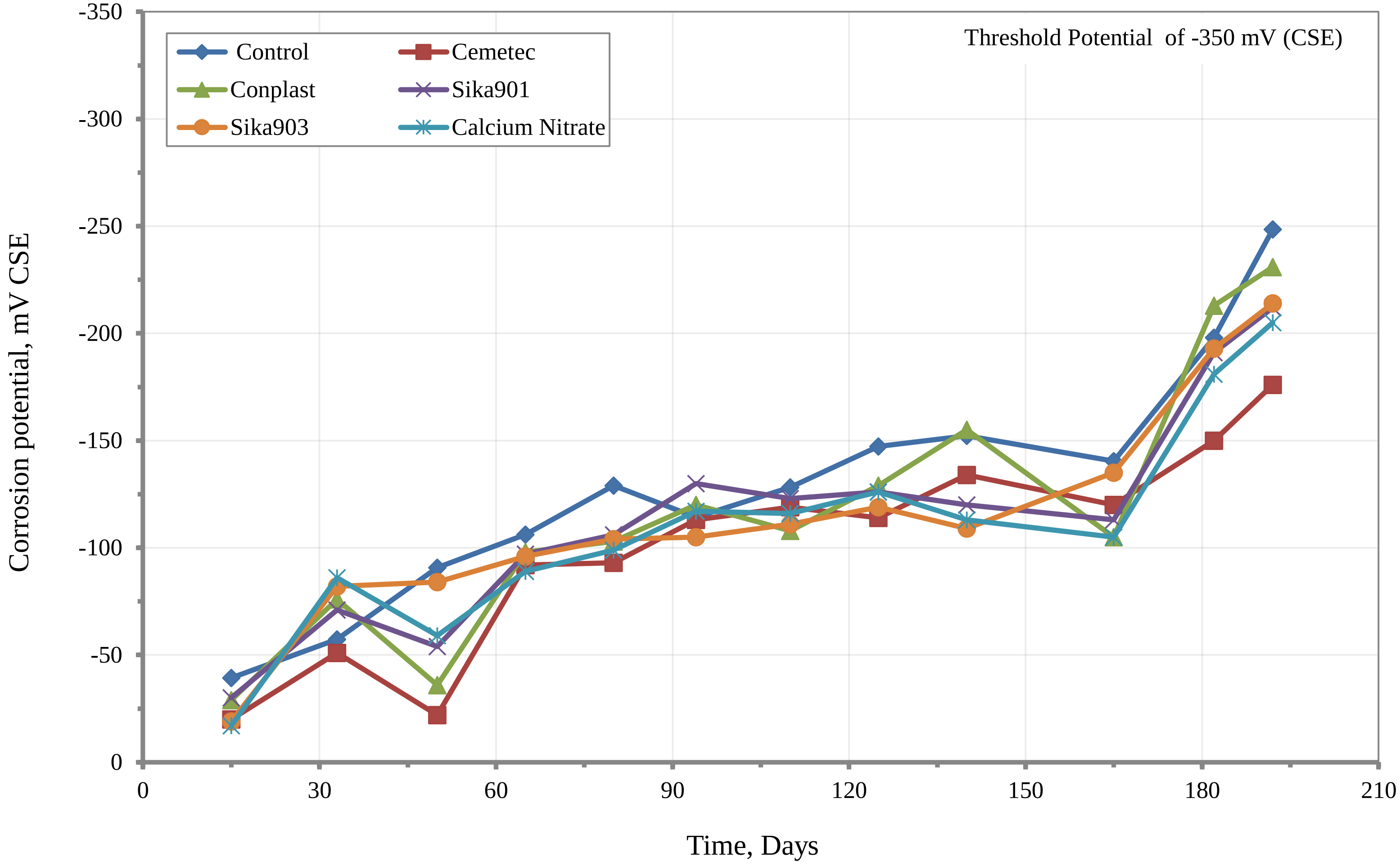


Figure 4.1 Corrosion Potentials–Time Curves for Beam Specimens Exposed to the Atmospheric Zone.

- **Tidal Zone:**

In this zone, a total of 12 beam specimens, two specimens with each inhibitor, were subjected to wet and dry cycles. Sabkha solution was used to wet the specimens. The specimens were wetted for one day and dried for two days. In each specimen, there were two working electrodes (two steel bars). The corrosion potentials were measured at two points for each working electrode every two weeks, as reported in Section 3.5.1. The average of the corrosion potentials for each working electrode and then for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.2 and schematically presented in Figure 4.2.

The corrosion potential values were more negative than the threshold value of -350 mV CSE after about 45 to 60 days of exposure. The corrosion potentials in the concrete specimens without inhibitor were less than those in the concrete specimens with the inhibitors. This indicates that the corrosion inhibitors were effective in delaying reinforcement corrosion by slowing anodic. The most effective inhibitor to retard reinforcement corrosion was Calcium Nitrate, while Cemetec, Sika901, Sika903, and Conplast have almost the same effect of retarding corrosion. This prove the efficiency of Calcium nitrate to slow the anodic reaction and protect steel against corrosion.

Table 4.2 Average Corrosion Potentials for Beam Specimens Exposed to the Tidal Zone.

Date of Exposure: 10/02/2013

Date	Duration (Days)	Average Corrosion Potentials, mV CSE					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
26/02/2103	15	-234	-229	-257	-265	-252	-226
16/03/2103	35	-265	-297	-289	-314	-269	-269
01/04/2103	50	-306	-306	-304	-344	-298	-280
16/04/2103	65	-417	-427	-413	-413	-378	-387
01/05/2103	80	-461	-472	-475	-461	-434	-429
15/05/2103	95	-443	-452	-475	-438	-394	-438
30/05/2013	110	-481	-516	-516	-502	-439	-494
16/06/2013	126	-517	-545	-543	-547	-479	-529
02/07/2013	140	-522	-534	-526	-536	-451	-515
25/07/2013	163	-531	-557	-557	-563	-513	-557
12/08/2013	180	-542	-541	-528	-549	-460	-523
23/08/2013	192	-562	-562	-544	-571	-479	-546

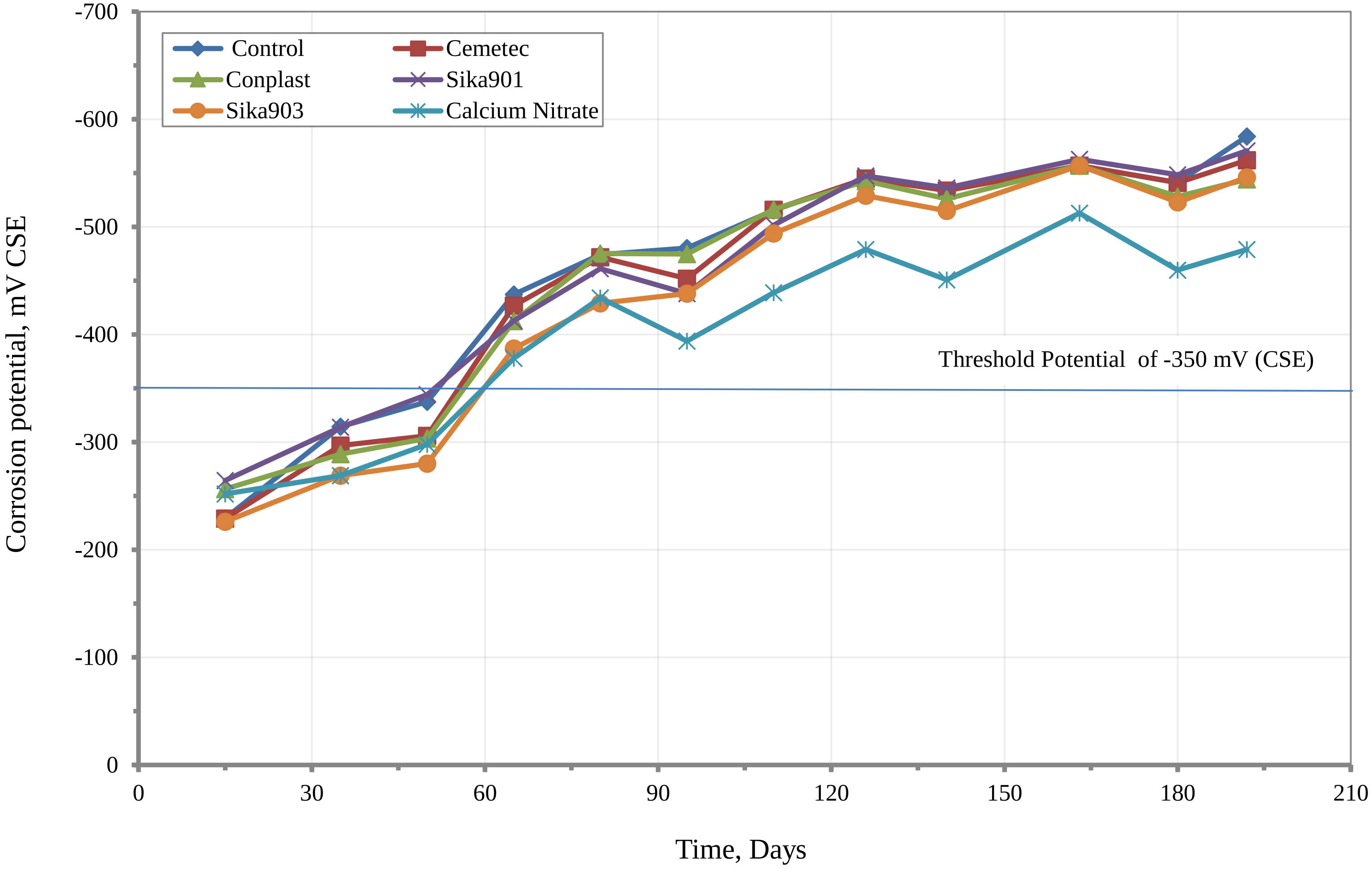


Figure 4.2 Corrosion Potentials–Time Curves for Beam Specimens Exposed to the Tidal Zone.

- **Below Ground Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were buried fully in soil mixed with sabkha solution. The corrosion potentials were measured at one point from the top for each working electrode every two weeks, as reported in Section 3.5.1. Thereafter, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.3 and plotted in Figure 4.3.

The corrosion potentials of all the reinforcing steels crossed the threshold value of -350 mV CSE [33] after about 45 days of exposure indicating corrosion initiation. After 180 days of exposure to the below ground zone, the corrosion potential values were more negative in the concrete specimens without inhibitor than those in the concrete specimens with the inhibitors. This proves that corrosion inhibitors were effective in delaying reinforcement corrosion. Calcium Nitrate was the most effective inhibitor to retard corrosion. The effectiveness of the selected inhibitors is ranked from highest to lowest as follows: Calcium Nitrate, Conplast, Sika903, Cemetec and Sika901. The corrosion potentials in these specimens, after 180 days, were -486, -546, -573, -598, -631and -636 mV CSE, respectively, as compared with -636 mV CSE for the control specimens.

Table 4.3 Average Corrosion Potentials for Beam Specimens Exposed to the Below Ground Zone.

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
21/03/2013	21	-232	-228	-220	-227	-215	-254
10/04/2013	40	-277	-276	-260	-245	-235	-295
21/04/2013	52	-378	-360	-346	-362	-347	-372
05/05/2013	66	-452	-483	-499	-434	-368	-458
19/05/2013	80	-555	-553	-567	-510	-472	-553
31/05/2013	92	-598	-573	-581	-524	-480	-574
17/06/2013	109	-602	-528	-483	-499	-402	-544
03/07/2013	125	-621	-566	-508	-572	-422	-561
17/07/2013	139	-626	-556	-512	-576	-406	-536
29/07/2013	151	-651	-559	-557	-580	-447	-586
13/08/2013	165	-629	-585	-533	-593	-428	-550
28/08/2013	180	-636	-598	-546	-631	-486	-573

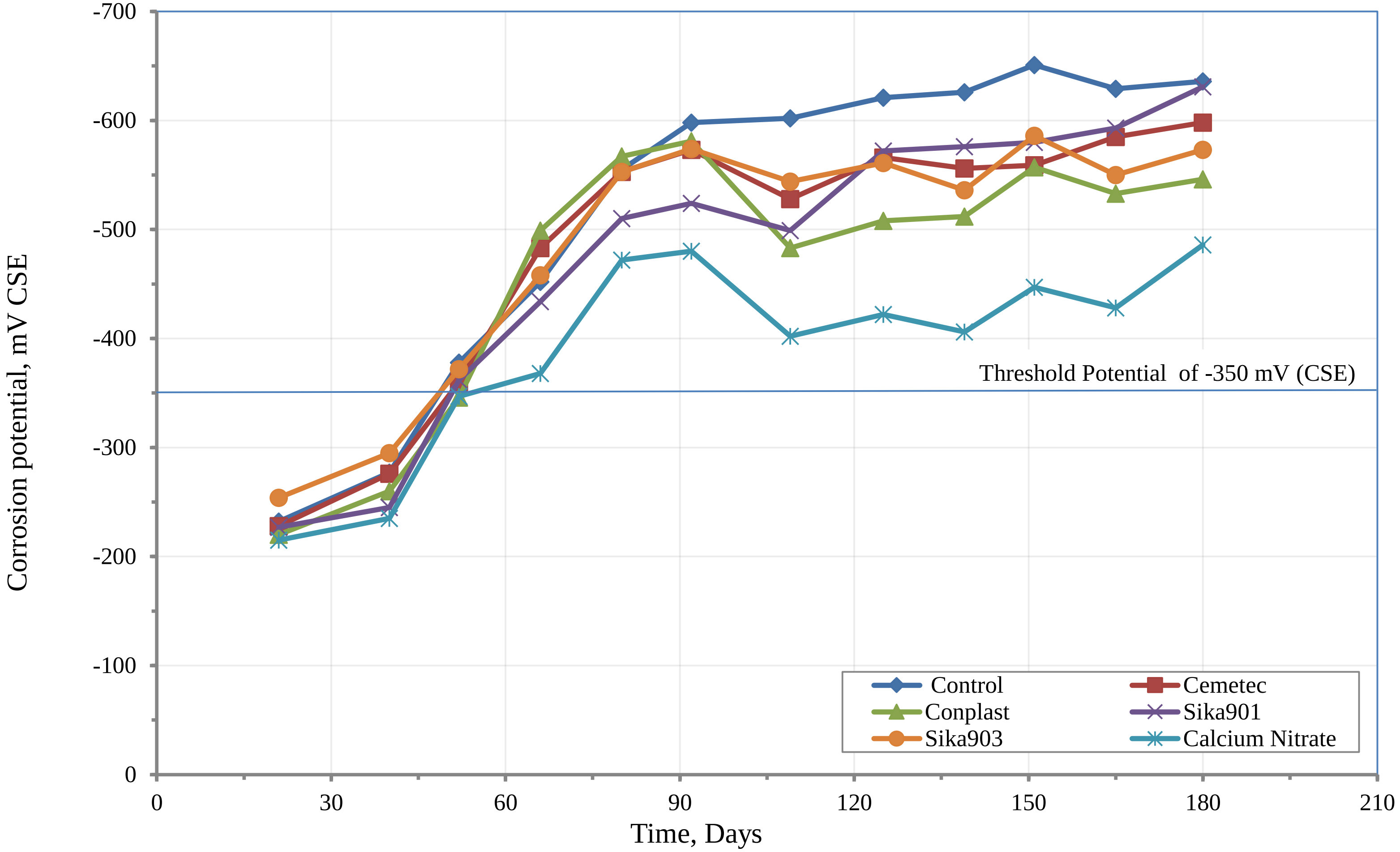


Figure 4.3 Corrosion Potentials–Time Curves for Beam Specimens Exposed to the Below Ground Zone.

- **Capillary Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were half buried in soil mixed with sabkha solution. The corrosion potentials were measured at one point for each working electrode every two weeks, as reported in Section 3.5.1. Thereafter, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.4 and plotted in Figure 4.4.

The corrosion potentials in the control specimens and with four inhibitors exceeded the threshold value of -350 mV CSE [33] after three months of exposure indicating corrosion initiation. The corrosion potentials in the specimens with calcium nitrate were below the threshold potential even after 180 days of exposure. The corrosion potentials in the control specimens and those with Conplast, Cemetec, Sik901 and Sika903 were almost the same, i.e., -500 mV CSE, after 180 days, while the corrosion potential in the concrete specimen with Calcium Nitrate was -325 mV CSE. This indicates that Calcium Nitrate was the most effective to protect the embedded steel bars by slowing the anodic reaction in the capillary zone. .

Table 4.4 Average Corrosion Potentials for Beam Specimens Exposed to the Capillary Zone.

Date of Exposure: 01/03/2013

Date	Duration (Days)	Average Corrosion Potentials, mV CSE					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
21/03/2013	21	-236	-207	-209	-206	-183	-215
10/04/2013	40	-283	-235	-227	-232	-114	-232
21/04/2013	51	-322	-277	-281	-251	-184	-291
05/05/2013	65	-327	-260	-271	-204	-110	-268
19/05/2013	79	-471	-389	-369	-468	-250	-442
29/05/2013	89	-475	-403	-369	-467	-235	-427
18/06/2013	108	-450	-424	-393	-373	-233	-416
03/07/2013	123	-463	-431	-437	-392	-245	-436
17/07/2013	137	-485	-446	-453	-415	-259	-464
28/07/2013	148	-504	-490	-488	-450	-294	-497
13/08/2013	165	-458	-470	-473	-430	-284	-478
28/08/2013	180	-511	-489	-493	-500	-332	-507

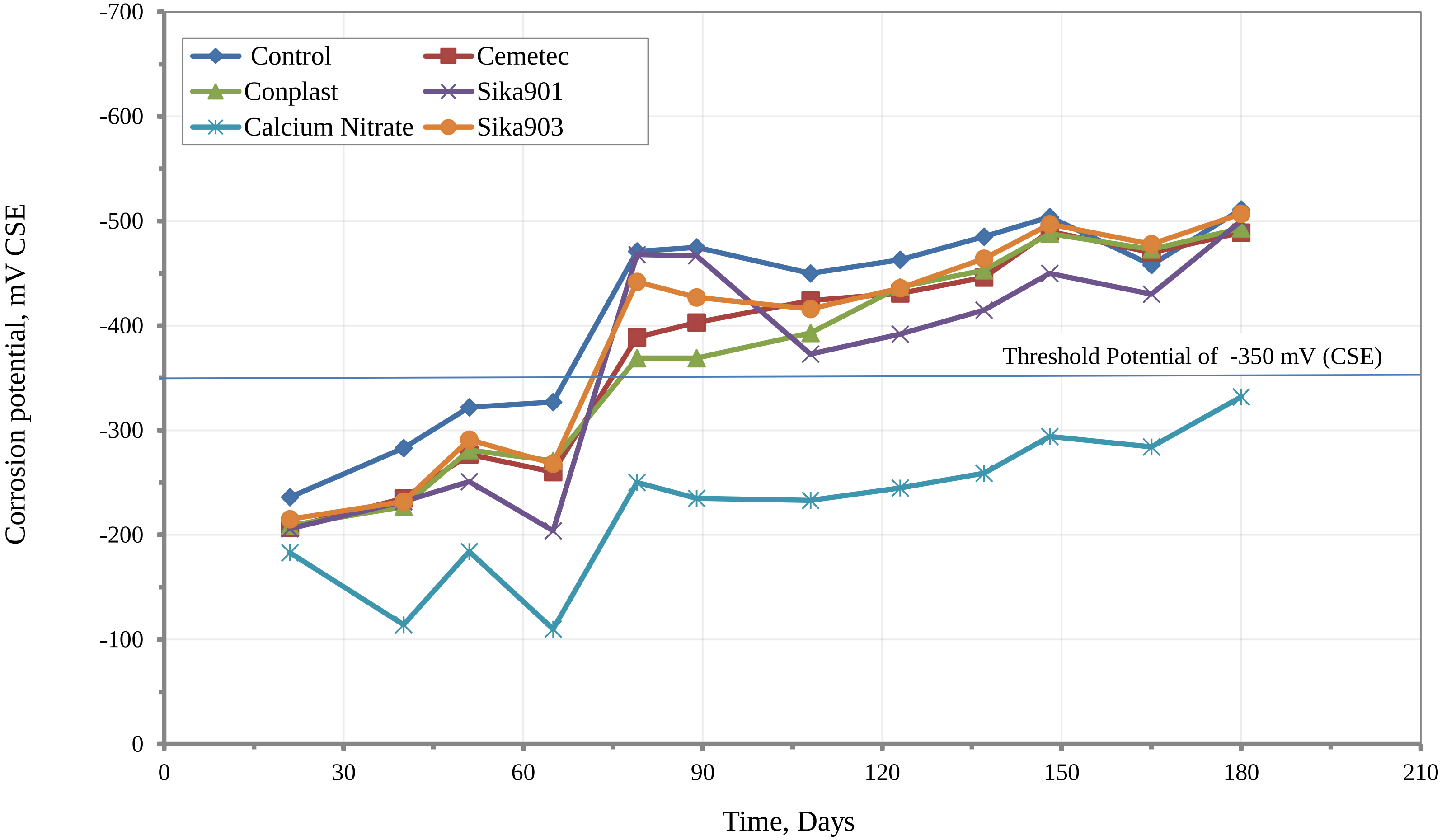


Figure 4.4 Corrosion Potentials–Time Curves for Beam Specimens Exposed to the Capillary Zone.

- **Submerged Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were submerged in sabkha solution. The corrosion potentials were measured at one point for each working electrode every two weeks, as reported in Section 3.5.1. The average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.5 and plotted in Figure 4.5.

The corrosion potentials were less than the threshold value of -350 mV CSE after 30 to 45 days of exposure [33]. After 6 months of exposure to the submerged zone, the corrosion potentials in the concrete specimens without inhibitor were more negative than those in the concrete specimens with the selected inhibitors. This indicates that the corrosion inhibitors were effective in delaying reinforcement corrosion. The most effective inhibitor to retard corrosion was Calcium Nitrate. The effectiveness of the investigated inhibitors in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Conplast, Sika903, Sika901, and Cemetec. The corrosion potentials after about 180 days in these specimens were -455, -516, -542, -543 and -594 mV CSE, respectively, as compared with -601 mV CSE for the control specimens.

Table 4.5 Average Corrosion Potentials for Beam Specimens Exposed to the Submerged Zone.

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
21/03/2013	21	-336	-260	-274	-292	-236	-270
10/04/2013	40	-335	-306	-333	-287	-243	-293
21/04/2013	51	-414	-373	-353	-375	-336	-450
05/05/2013	65	-536	-532	-491	-453	-425	-483
19/05/2013	79	-606	-626	-561	-512	-482	-510
29/05/2013	89	-618	-656	-552	-496	-490	-528
18/06/2013	108	-559	-540	-468	-441	-387	-536
03/07/2013	123	-573	-562	-497	-462	-412	-598
17/07/2013	137	-585	-576	-520	-486	-444	-573
28/07/2013	148	-607	-544	-577	-509	-489	-561
13/08/2013	165	-585	-573	-501	-456	-422	-531
28/08/2013	180	-601	-594	-516	-543	-455	-542

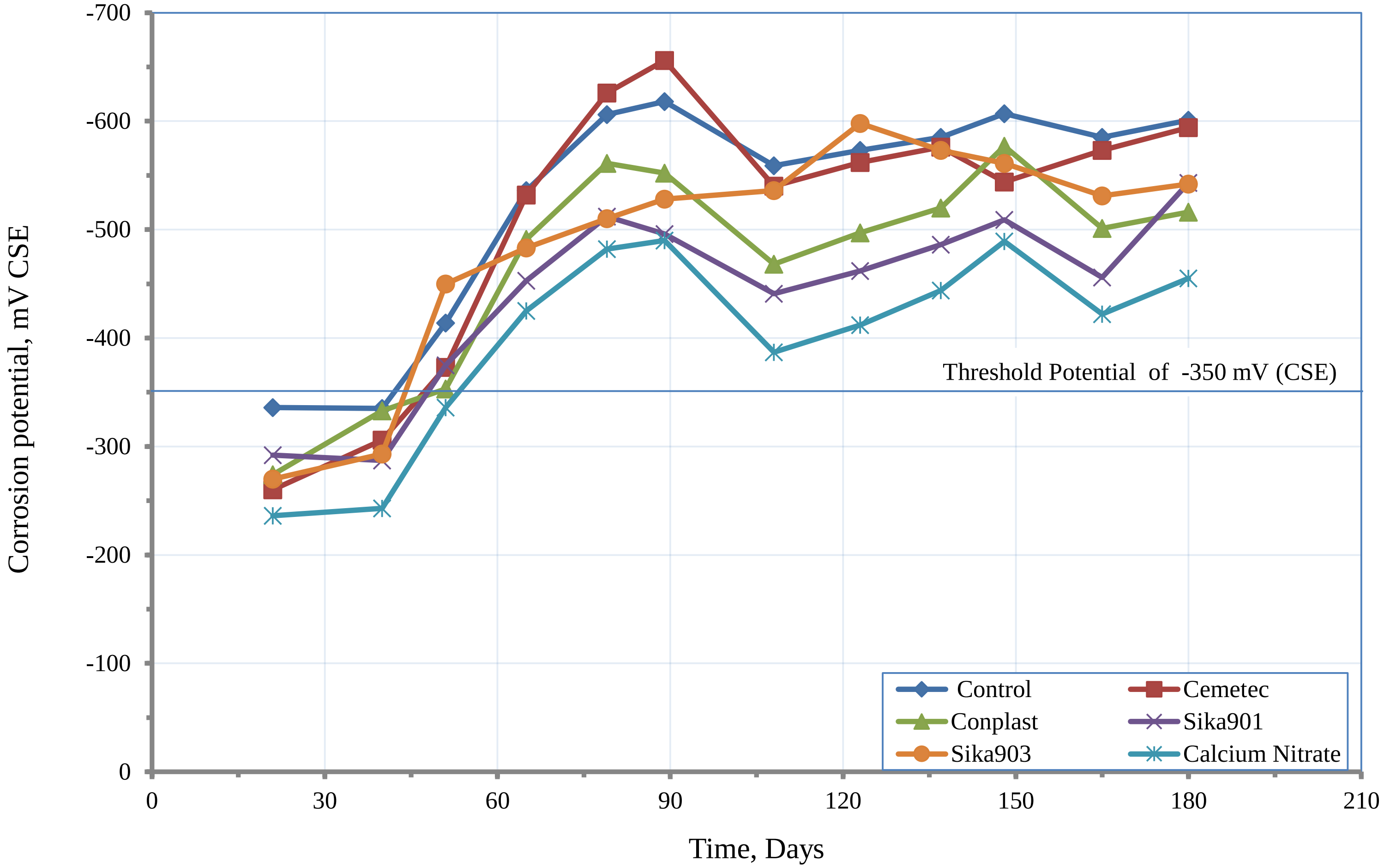


Figure 4.5 Corrosion Potentials–Time Curves for Beam Specimens Exposed to the Submerged Zone.

The time to initiation of reinforcement corrosion was also determined from the corrosion potentials–time curves plots (i.e., crossing the -350 mV CSE). Table 4.6 summarizes the time to initiation of reinforcement corrosion for each inhibitor in each of the five exposure zones.

Table 4.6 Summary of the Time to Initiation of Reinforcement Corrosion for Each Inhibitor in the Five Exposure Zones.

Zone	**Time to Initiation of Reinforcement Corrosion (Days)**					
	Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
Atmospheric	No Corrosion	No Corrosion	No Corrosion	No Corrosion	No Corrosion	No Corrosion
Tidal	50	50	55	50	60	60
Below ground	50	58	55	53	55	50
Capillary	67	75	78	72	No Corrosion	72
Submerged	43	49	51	48	55	45

From the results tabulated in Table 4.6, it can be observed that the time to initiation of reinforcement corrosion in the atmospheric zone exhibited the lowest severity as compared with the other zones because there was no initiation of reinforcement corrosion after 6 months of exposure. However, it should be noted that the time to initiation of reinforcement corrosion in other zones were less as compared with atmospheric zone because the presence of solution in these zones [49]. In the specimens with inhibitors, the time to initiation of corrosion was more than those in the control specimens. This indicates that the inhibitors were effective in minimizing reinforcement corrosion by retarding anodic, cathodic reactions. Calcium Nitrate was the most effective inhibitor to retard reinforcement corrosion, as the time to initiation of corrosion was more in the specimens with Calcium Nitrate in most of exposure zones.

4.1.2Cylindrical Specimens

As reported in Section 3.4, the cylindrical specimens were exposed to wet and dry cycles. Therefore, the results of corrosion potentials of these specimens are presented and discussed as follows:

- **Cylinders without Chloride Content:**

A total of 36 cylindrical specimens, six specimens with each inhibitor, were exposed to wet and dry cycles. The specimens were immersed in 5% NaCl solution for one day and dried for four days. The corrosion potentials were measured at six points on each specimen. The average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.7 and schematically plotted in Figure 4.6.

The data in Figure 4.6 indicate that the corrosion potentials exceeded the threshold value of -350 mV CSE after about 45 to 75 days. After 6 months of exposure to the wet and dry cycles, the corrosion potentials in the concrete specimens without inhibitor were more negative than those in the concrete specimens with the five inhibitors. This supports the fact that corrosion inhibitors were effective in minimizing reinforcement corrosion. The most effective inhibitor to retard corrosion was Calcium Nitrate. The corrosion potentials in the specimens with other inhibitors were almost similar to those in the control specimens after about 180 days of exposure.

Table 4.7 Average Corrosion Potentials for Cylinders Exposed to Wet and Dry Cycles.

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
26/02/2013	20	-182	-164	-150	-165	-152	-175
19/03/2013	43	-228	-264	-240	-258	-259	-257
03/04/2013	57	-310	-315	-339	-356	-347	-336
17/04/2013	71	-358	-333	-366	-398	-296	-365
01/05/2013	85	-369	-369	-420	-443	-373	-429
16/05/2013	100	-468	-452	-467	-514	-418	-487
01/06/2013	115	-519	-431	-508	-530	-410	-485
16/06/2013	130	-460	-434	-472	-499	-363	-453
01/07/2013	145	-469	-448	-483	-512	-373	-463
17/07/2013	161	-476	-463	-506	-528	-390	-488
03/08/2013	177	-515	-455	-493	-513	-368	-468
19/08/2013	193	-565	-545	-540	-564	-417	-527

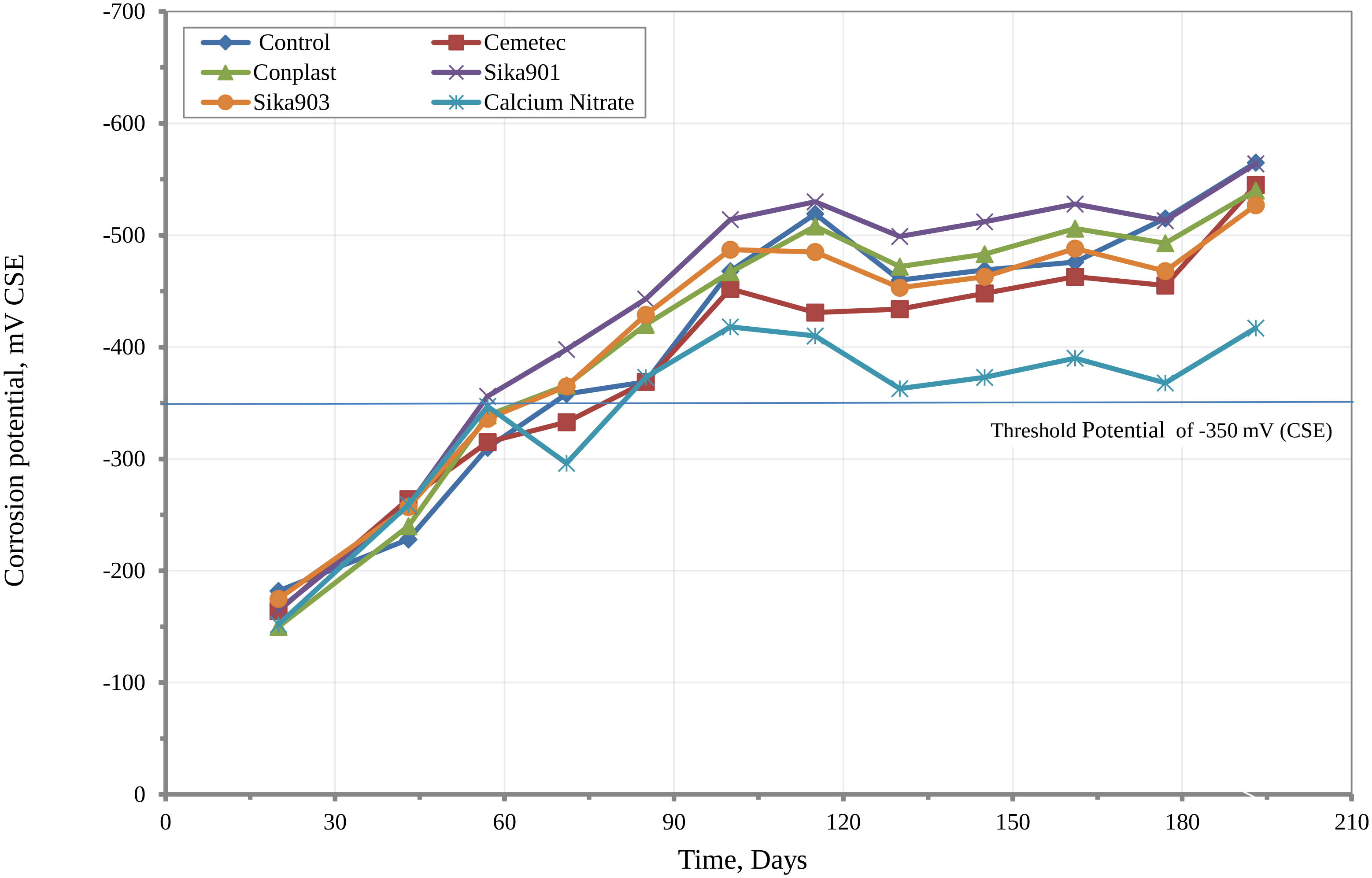


Figure 4.6 Corrosion Potentials–Time Curves for Cylinders Exposed to Wet and Dry Cycles.

- **Cylinders with Chloride Content:**

A total of 96 cylindrical concrete specimens, twelve specimens with each inhibitor, were sprayed with water once every three days for a period of five months.

- Cl^- (0.2%):

A total of 24 cylindrical specimens, three specimens with each inhibitor, were cast with a chloride contamination of 0.2% by weight of the cementitious materials. They were sprayed with water once every three days to induce reinforcement corrosion. The corrosion potentials were measured at six points on each specimen. Thereafter, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.8 and schematically plotted in Figure 4.7.

The corrosion potentials in all specimens did not exceed the threshold value of -350 mV CSE [33] up to six months probably due to the fact that 0.2% chloride contamination was relatively small to activate corrosion within this period. After 5 months of exposure to the wet and dry cycles, the corrosion potential values in the concrete specimens without inhibitors were more negative than concrete specimens with the selected inhibitors. This indicates that the corrosion inhibitors were effective in delaying reinforcement corrosion. The effectiveness of the selected inhibitors to minimize corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Sika903, Rheocrete, Sika901, Cortec and Conplast.

The corrosion potentials after about 150 days in these specimens were -201, -214, -216, -223, -226, -229 and -245 mV CSE, respectively, as compared with -268 mV CSE for the concrete specimens without inhibitors.

Table 4.8 Average Corrosion Potentials for Cylinders with a Chloride Contamination of 0.2%.

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	-138	-146	-168	-92	-131	-138	-120	-139
09/05/2013	30	-106	-90	-120	-58	-133	-90	-136	-139
24/05/2013	45	-175	-129	-98	-89	-82	-117	-73	-85
13/06/2013	64	-149	-174	-165	-119	-186	-132	-137	-110
28/06/2013	79	-179	-209	-183	-129	-201	-143	-143	-133
13/07/2013	94	-180	-191	-194	-142	-203	-158	-149	-143
23/07/2013	104	-233	-210	-214	-178	-210	-187	-179	-175
08/08/2013	119	-224	-200	-203	-151	-203	-166	-156	-168
20/08/2013	131	-243	-213	-227	-187	-214	-183	-176	-204
05/09/2013	147	-268	-223	-245	-214	-226	-201	-229	-216

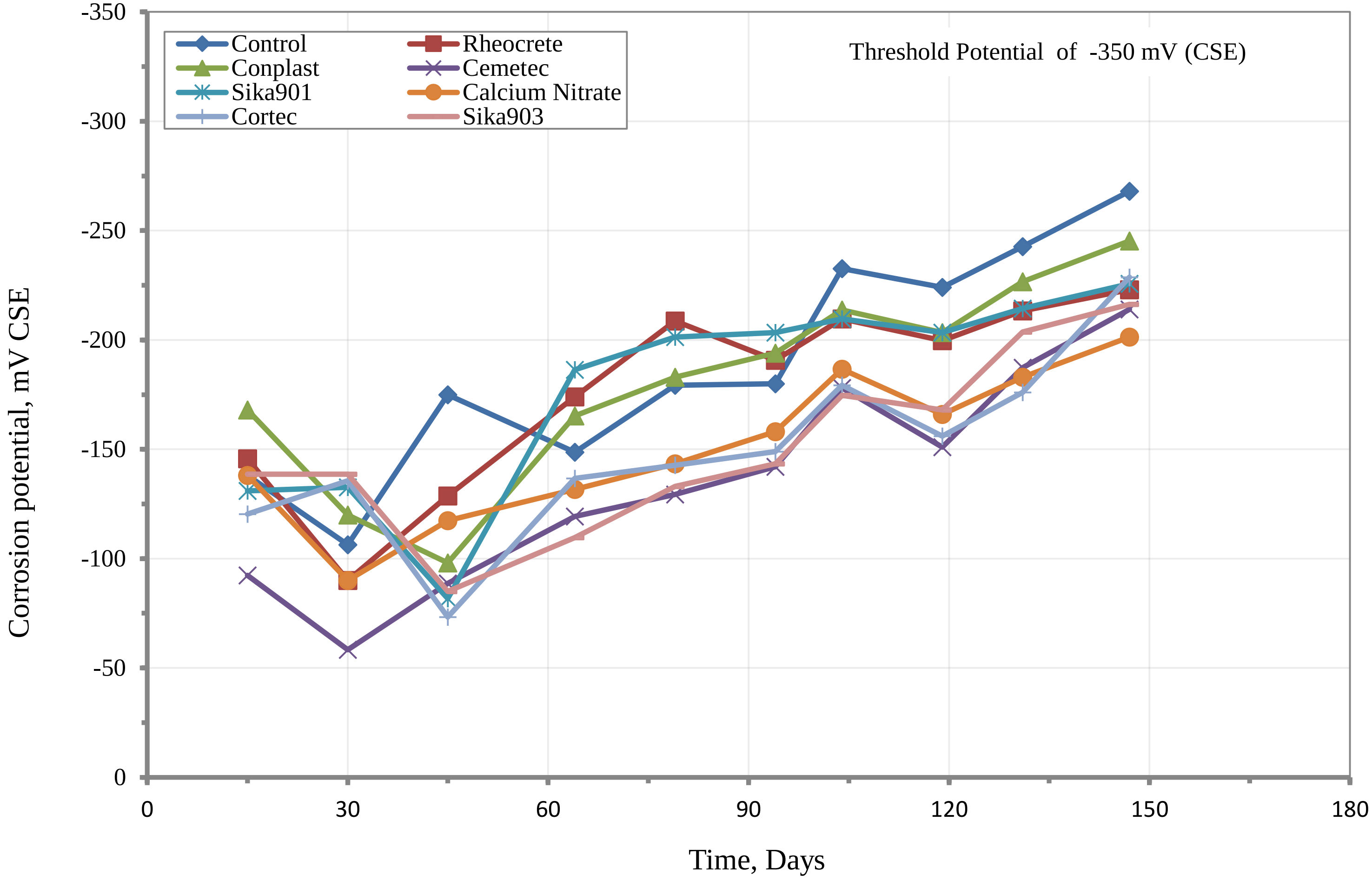


Figure 4.7 Corrosion Potentials–Time Curves for Cylinders Contaminated with 0.2% Chloride.

- **Cl^- (0.4%):**

A total of 24 cylindrical specimens, three specimens with each inhibitor, were cast with a chloride contamination of 0.4% by weight of the cementitious materials. Water was sprayed once every three days to facilitate reinforcement corrosion. The corrosion potentials were measured at six points on each specimen. After that, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.9 and schematically plotted in Figure 4.8.

The corrosion potentials in all the specimens were less than the threshold value of -350 mV CSE [33] within the period of five months probably due to the fact that 0.4% chloride contamination was small to activate corrosion in this period. However, the corrosion potentials were more negative than those with 0.2% chloride contamination. After 5 months of exposure to the wet and dry cycles, the corrosion potential values in the concrete specimens without inhibitors were more negative than concrete specimens with the selected inhibitors. This proves that corrosion inhibitors were effective in retarding reinforcement corrosion. The most effective inhibitor to retard corrosion was Calcium Nitrate. The effectiveness of the investigated inhibitors in minimizing corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Sika903, Cortec, Sika901, Rheocrete, and Conplast. The corrosion potentials after about 150 days in these specimens were -205, -229, -234, -243, -254, -265 and -272 mV CSE, respectively, as compared with -272 mV CSE for the concrete specimens without inhibitors.

Table 4.9 Average Corrosion Potentials for Cylinders with a Chloride Contamination of 0.4%.

Date of Exposure: 09/04/2013

Date	Duration (Days)	Average Corrosion Potentials, mV CSE							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	-177	-146	-185	-135	-128	-185	-231	-181
09/05/2013	30	-127	-127	-95	-96	-160	-127	-153	-147
24/05/2013	45	-145	-148	-140	-128	-150	-167	-140	-152
13/06/2013	64	-161	-157	-160	-176	-180	-140	-170	-163
28/06/2013	79	-186	-182	-159	-157	-185	-151	-174	-170
13/07/2013	94	-174	-206	-171	-173	-195	-156	-185	-179
23/07/2013	104	-202	-221	-205	-206	-224	-183	-221	-209
08/08/2013	119	-188	-230	-181	-184	-206	-167	-195	-189
20/08/2013	131	-244	-259	-224	-209	-242	-198	-237	-226
05/09/2013	147	-272	-265	-271	-229	-254	-205	-243	-234

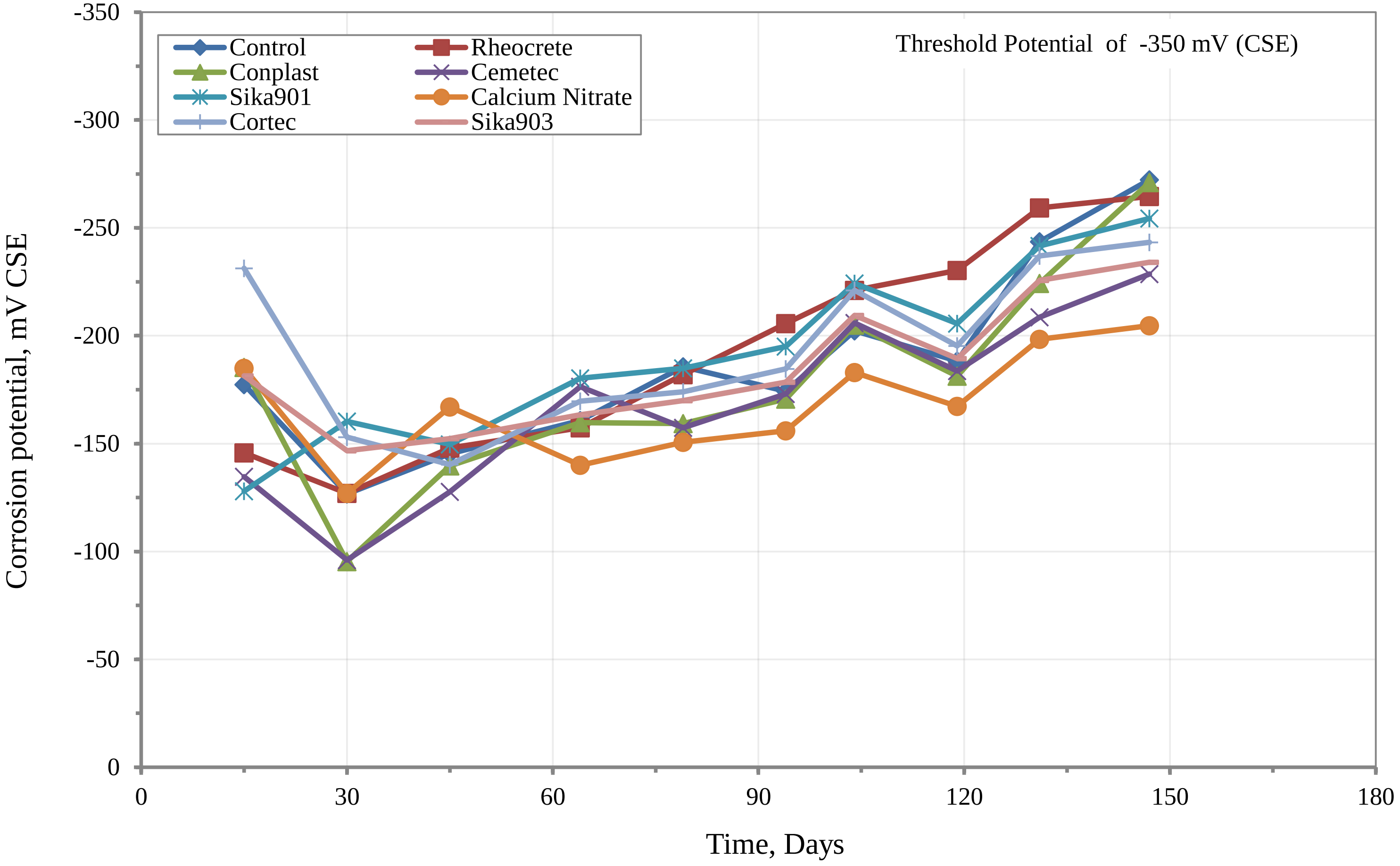


Figure 4.8 Corrosion Potentials–Time Curves for Cylinders Contaminated with 0.4% Chloride.

- **Cl^- (0.8%):**

A total of 24 cylindrical specimens, three specimens with each inhibitor, were cast with a chloride contamination of 0.8% by weight of the cementitious materials. They were sprayed with water once every three days to facilitate reinforcement corrosion. The corrosion potentials were measured at six points on each specimen. After that, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potential for each inhibitor are summarized in Table 4.10 and schematically plotted in Figure 4.9.

In all the specimens, the corrosion potentials did not exceed the threshold value of -350 mV CSE [33] even after five months of exposure. Corrosion has not been initiated after this period. However, the corrosion potentials were more negative with 0.8% chloride contamination than those with 0.2% and 0.4% chloride contamination. After 5 months of exposure to the wet and dry cycles, the corrosion potential values in the concrete specimens without inhibitors were more negative than those in the concrete specimens with inhibitors. This indicates that corrosion inhibitors are effective in minimizing reinforcement corrosion. The effectiveness of the inhibitors in minimizing corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Cemetec, Calcium Nitrate, Rheocrete, Conplast, Sika901, Cortec and Sika903. The corrosion potentials after about 150 days in these specimens were -244, -275, -276, -285,

-286, -291 and -321 mV CSE, respectively, as compared with -329 mV CSE for the concrete specimens without inhibitors.

Table 4.10 Average Corrosion Potentials for Cylinders with a Chloride Contamination of 0.8%.

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	-219	-220	-231	-211	-223	-193	-272	-236
09/05/2013	30	-218	-164	-164	-148	-176	-196	-201	-169
24/05/2013	45	-221	-218	-193	-233	-215	-204	-216	-223
13/06/2013	64	-224	-195	-186	-202	-210	-225	-211	-201
28/06/2013	79	-237	-226	-197	-183	-223	-221	-225	-213
13/07/2013	94	-230	-245	-205	-191	-232	-233	-233	-221
23/07/2013	104	-257	-278	-229	-219	-275	-249	-262	-249
08/08/2013	119	-242	-258	-216	-201	-243	-250	-242	-233
20/08/2013	131	-333	-285	-244	-230	-260	-265	-283	-281
05/09/2013	147	-329	-276	-285	-244	-286	-275	-291	-321

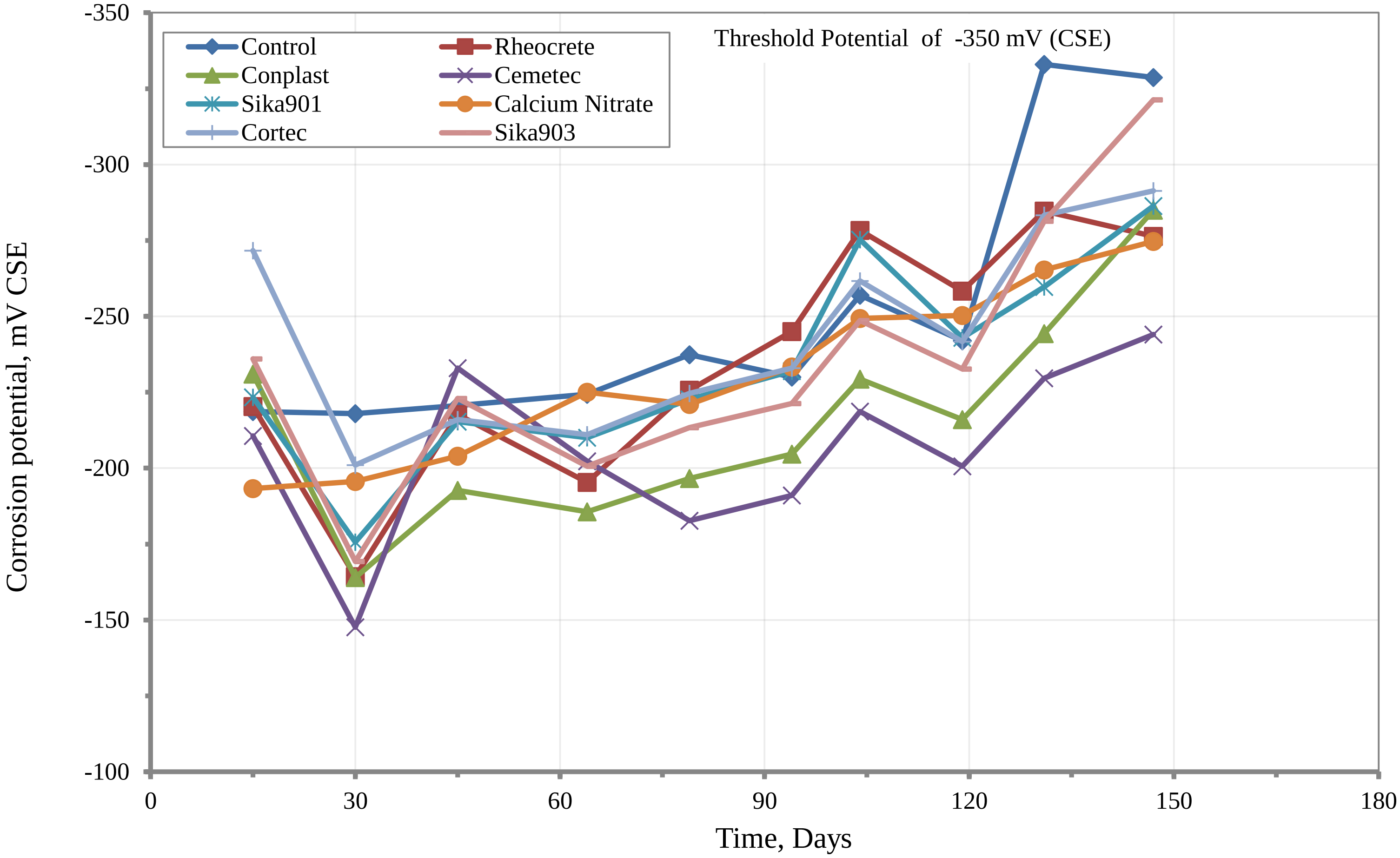


Figure 4.9 Corrosion Potentials–Time Curves for Cylinders Contaminated with 0.8% Chloride.

- **Cl$^-$ (1.5%):**

A total of 24 cylindrical concrete specimens, three specimens with each inhibitor, were cast with a chloride contamination of 1.5% by weight of the cementitious materials. They were sprayed with water once every three days to induce reinforcement corrosion. The corrosion potentials were measured at six points on each specimen. After that, the average of the corrosion potentials for each specimen was calculated, as shown in Appendix A.

The average values of the corrosion potentials for each inhibitor are summarized in Table 4.11 and schematically plotted in Figure 4.10.

The corrosion potential values in the control mix and that with Sika903 and Cortex inhibitors exceeded the threshold value of -350 mV CSE after about four months of exposure. The corrosion potentials for the mixes with other inhibitors did not exceed -350 mV CSE even after 150 days of exposure. It can observed that with the increase chloride contamination to 1.5%, accelerated the activation of corrosion more than the previous dosages (See Figures 4.7 to 4.10). In the concrete specimens without inhibitor, the corrosion potential values were more negative than those in the concrete specimens with inhibitors after 150 days of exposure to the wet and dry cycles. This indicates that corrosion inhibitors were effective in delaying reinforcement corrosion. The most effective inhibitor to retard corrosion was Calcium Nitrate. The effectiveness of these inhibitors in minimizing corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Rheocrete, Sika901, Cemetec, Cortec, Conplast and Sika903. The corrosion potentials after about 150 days in these specimens were -315, -332, -329, -357, -356, -356 and -376 mV CSE, respectively, as compared with -403 mV CSE for the concrete specimens without inhibitors.

Table 4.11 Average Corrosion Potentials for Cylinders with a Chloride Contamination of 1.5%.

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Potentials, mV CSE**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	-256	-294	-293	-270	-290	-237	-337	-334
09/05/2013	30	-287	-265	-258	-214	-222	-225	-297	-305
24/05/2013	45	-389	-337	-306	-265	-226	-287	-293	-365
13/06/2013	64	-356	-272	-283	-271	-237	-266	-290	-312
28/06/2013	79	-350	-283	-284	-277	-239	-272	-314	-322
13/07/2013	94	-335	-300	-292	-288	-251	-284	-325	-332
23/07/2013	104	-364	-330	-326	-317	-273	-310	-355	-360
08/08/2013	119	-347	-309	-306	-304	-256	-296	-337	-341
20/08/2013	131	-413	-345	-346	-344	-330	-326	-416	-413
05/09/2013	147	-403	-332	-356	-357	-329	-315	-356	-376

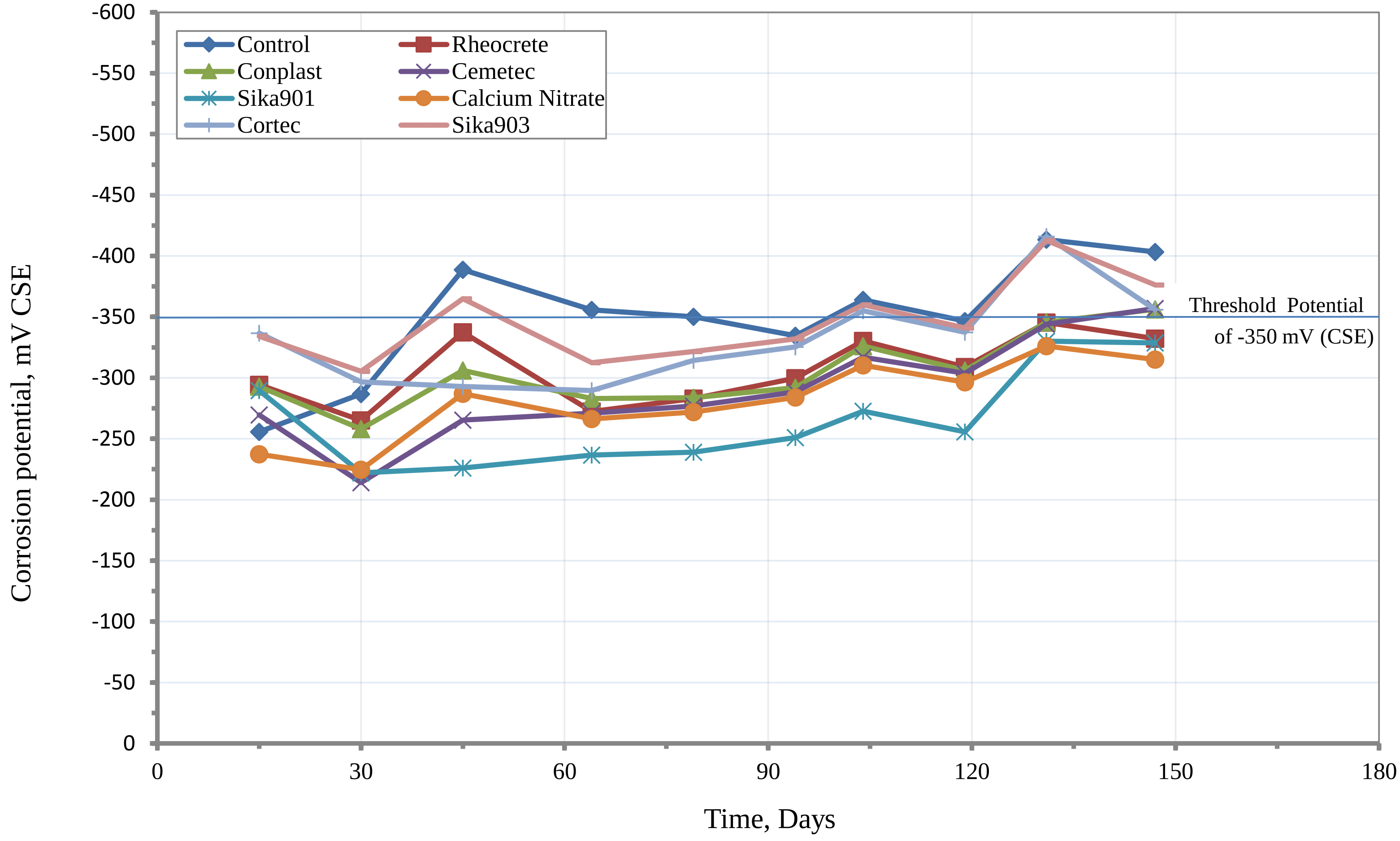


Figure 4.10 Corrosion Potentials–Time Curves for Cylinders Contaminated with 1.5% Chloride.

Table 4.12 summarizes the corrosion potentials for each inhibitor in cylinders with chloride contamination of 0.2, 0.4, 0.8 and 1.5% at the end of the exposure period.

Table 4.12 Average Corrosion Potentials for Cylinders with Various Chloride Contaminations at the End of the Exposure Period.

Chloride Concentration (%)	**Average Corrosion Potentials, mV CSE**							
	Control	Cemetec	Conplast	Sika901	Calcium Nitrate	Sika903	Cortec	Rheocrete
0.2	-268	-223	-245	-214	-226	-201	-229	-216
0.4	-272	-265	-271	-229	-254	-205	-243	-234
0.8	-329	-276	-285	-244	-286	-275	-291	-321
1.5	-403	-332	-356	-357	-329	-315	-356	-376

From the results tabulated above (Table 4.12), it is clear that the increase of chloride contamination increased the corrosion potential and accelerated the activation of reinforcement corrosion. Therefore, 1.5% chloride contamination was more aggressive and critical in activation of reinforcement corrosion as compared with the other chloride contaminations. In the control specimens, the corrosion potentials were more negative than those in the specimens with inhibitors. This proves the efficiency of inhibitors in delaying reinforcement corrosion. In all the chloride contamination percentages, the most effective inhibitor to retard corrosion was Calcium Nitrate.

4.2 Corrosion Current Density

The corrosion current density was measured for all concrete specimens, beam and cylinders, every month for a period of about six months.

4.2.1Beam Specimens

- **Atmospheric Zone:**

In this zone, a total of 12 beam specimens, two specimens with each inhibitor, were sprayed with 5% NaCl once a week. In each specimen, there were two working electrodes (two steel bars). The corrosion current density was measured for each working electrode every one month, and the average of the corrosion current density for each specimen was calculated, as shown in Appendix B.

The average values of the corrosion current density for each group of specimens are summarized in Table 4.13 and schematically plotted in Figure 4.11.

Table 4.13 Average Corrosion Current Density Values for Beam Specimens Exposed to the Atmospheric Zone

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (µA/cm^2)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
13/03/2103	33	0.01088	0.01065	0.01463	0.00984	0.011245	0.010452
15/04/2013	65	0.01606	0.01280	0.02578	0.01573	0.017900	0.014715
14/05/2013	94	0.03014	0.02197	0.03635	0.02265	0.018575	0.017453
15/06/2013	125	0.047543	0.03943	0.05198	0.02915	0.020005	0.018913
25/07/2013	165	0.07560	0.06379	0.06227	0.03704	0.021685	0.022914
22/08/2013	192	0.09759	0.07819	0.08336	0.04944	0.026235	0.043510

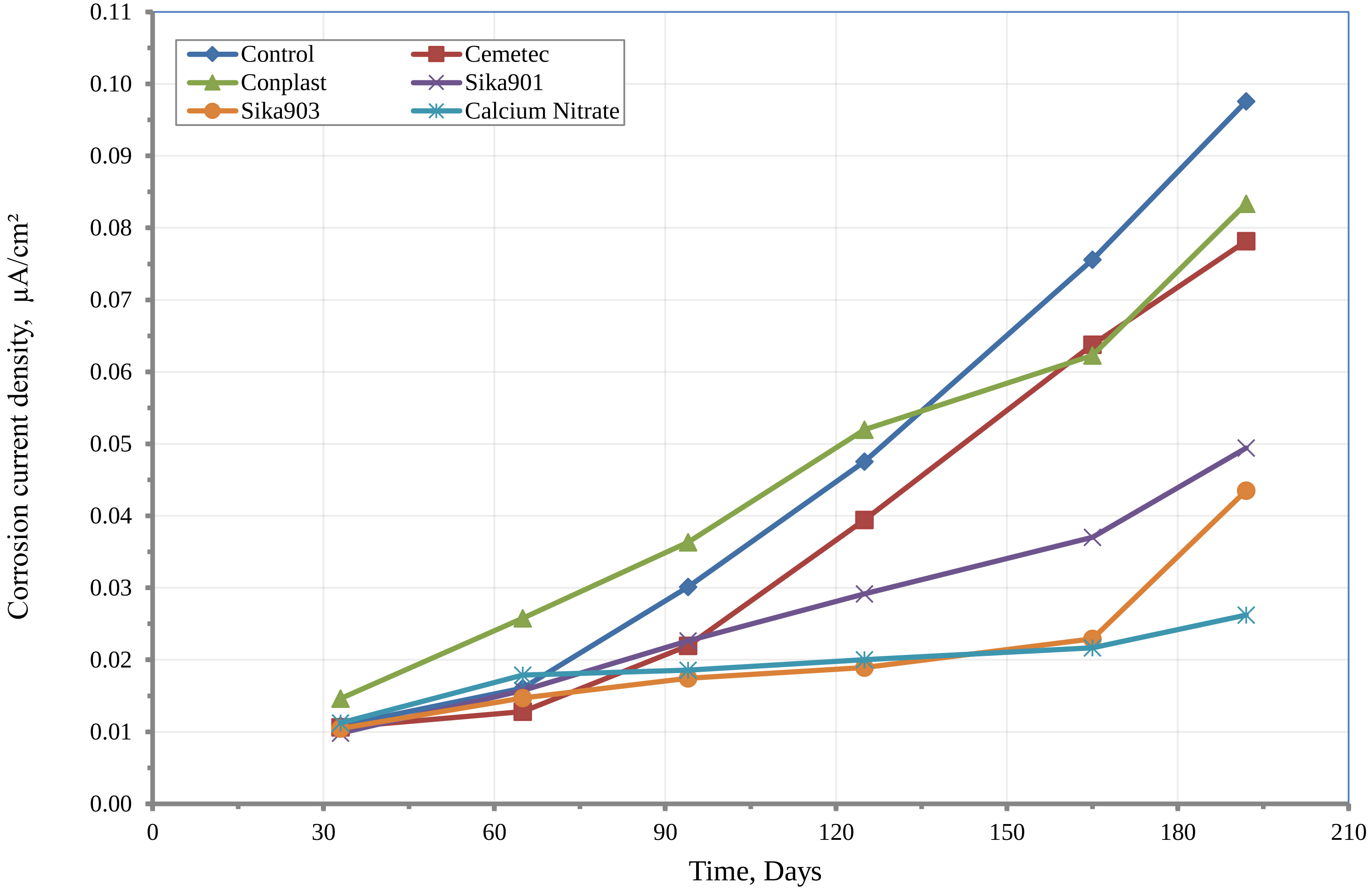


Figure 4.11 Corrosion Current Density Values–Time Curves for Beam Specimens Exposed to the Atmospheric Zone.

The data in Figure 4.11 indicate that the corrosion current density (I_{corr}) increased with time in all the specimens. Since a corrosion current density value of more than 0.3 µA/cm² indicates corrosion activation [34], it is evident that the corrosion current density values did not exceed 0.3 µA/cm² during the period of six months. However, after about 200 days of exposure, the I_{corr} values in the control specimens were more than those in the specimens with the inhibitors. In the concrete specimens without inhibitor, the corrosion current density value was more than that in the concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The effectiveness of these inhibitors in retarding corrosion of steel in reinforced concrete in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Sika903, Sika901, Cemetec and Conplast. The corrosion current density in this specimen after about 200 days was 0.026235, 0.043510, 0.04944, 0.07819 and 0.08336 µA/cm², respectively, as compared with 0.09759 µA/cm² for the concrete specimens without inhibitors.

The time–corrosion current density plot in Figure 4.11 was extrapolated to determine the time to cracking of concrete. This time was calculated as the point at which I_{corr} reaches 1.00 µA/cm² because this I_{cor} value is the practical value that indicates cracking of concrete [56].

To elucidate the extrapolation methodology, Figure 4.12 shows the time–corrosion current density plot for the control specimens in the atmospheric zone (just a typical example). The "linear" best-fit model is plotted with the genuine data for these specimens. This linear model has been extrapolated to an I_{corr} value of 1.00 µA/cm².

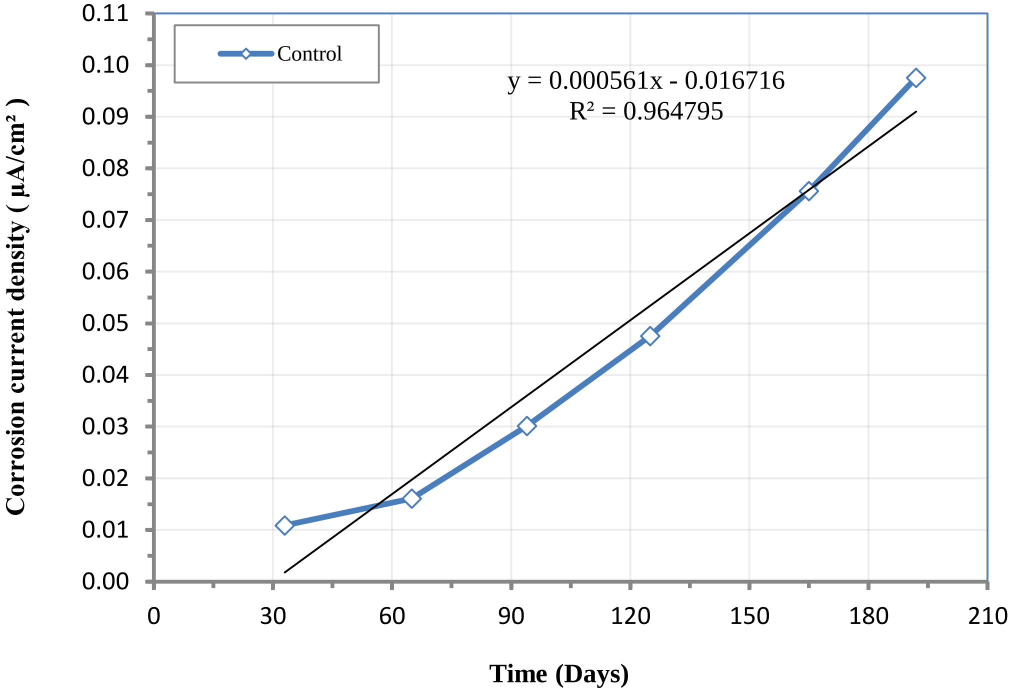


Figure 4.12 Slope of I_{corr} – Time Curve for the Control Specimens in the Atmospheric Zone.

The time to cracking of concrete x (days) was calculated by substituting the corrosion current density y = 1.00 µA/cm² in the following best-fit model:

$y = 0.000561x - 0.016716$

Where: x = Exposure time, days.

$y = I_{corr}$, µA/cm².

Now, when the best-fit model is extrapolated to an I_{corr} value of 1.00 µA/cm² (y = 1.00 µA/cm²), the time to cracking of concrete was noted to be an exposure period of 1812 days (or 5.03 years), which is the x value at y = 1.00 µA/cm².

The time to cracking of concrete in the specimens placed in the atmospheric zone (shown in Figure 4.12) is summarized in Table 4.14.

The data in Table 4.14 indicate that the time to cracking of concrete in the control specimens was 5 years as compared with 35.7 years in the specimens with Calcium Nitrate. This proves that Calcium Nitrated was very effective to slow the anodic reaction and minimize reinforcement corrosion in this exposure zone. Sika903 was effective to retard anodic and cathodic reactions by slowing the penetration of oxygen and moisture to steel bars. Also, it should be noted that the time to cracking of concrete in the specimens with other inhibitors was more than that in the control specimens.

The extension in service life of reinforced concrete structures due to the use of the selected inhibitors was also calculated by dividing the time to cracking of concrete for each inhibitor with the time to cracking of concrete of the control mix. As determined before, the time to cracking of concrete for the control specimens in the atmospheric zone was 5.03 years. Similarly, the time to cracking of concrete for the specimens with Cemetec inhibitor in the atmospheric zone was 6.2 years.

Therefore, the extension in service life of reinforced concrete structures due to the use of Cemetec inhibitor = $\frac{6.2-5.03}{5.03} * 100 = 23.2\%$

Table 4.15 shows the extension in service life (%) of reinforced concrete structures due to the use of the selected inhibitors. There is almost 25 to 600% improvement in the service life due to the use of inhibitors in the atmospheric zone.

Table 4.14 Time to Cracking of Concrete for Specimens in the Atmospheric Zone.

Inhibitor Type	**Best-fit Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.000561x - 0.016716	0.96	5.03
Cemetec	y = 0.000454x - 0.013157	0.95	6.2
Conplast	y = 0.000415x - 0.000886	0.98	6.7
Sika901	y = 0.000238x + 0.000584	0.98	11.66
Calcium Nitrate	y = 0.000077x + 0.010575	0.89	35.69
Sika903	y = 0.000169x + 0.002345	0.86	16.4

In statistical models, the relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in the best-fit equations tabulated above (Table 4.14) can be considered reliable since the value of the correlation coefficient (R^2) is 0.96, 0.95, 0.982, 0.98, 0.89 and 0.86, respectively.

Table 4.15 Extension in Service Life of the Reinforced Concrete Structure in the Atmospheric Zone by Using Each Inhibitor.

Inhibitor Type	**Extension in Service Life (%)**
Cemetec	23.26
Conplast	33.2
Sika901	131.81
Calcium Nitrate	609.54
Sika903	226.04

In the atmospheric zone, calcium nitrate was noted to be the most effective inhibitor to minimize reinforcement corrosion. It can extend the service life of reinforced concrete structures up to six times than that of the control specimens. Protection of reinforcing steel by using the other inhibitors is evident from the results. However, the effectiveness of these inhibitors is less than that of Calcium Nitrate. Sika903 was effective in slowing anodic and cathodic reactions and minimizing reinforcement corrosion by preventing chloride ions, oxygen, and moisture from penetrating concrete in this zone [38].

❖ Tidal Zone:

In this zone, a total of 12 beam specimens, two specimens with each inhibitor, were subjected to wet and dry cycles. The corrosion current density was measured for each working electrode every month. After that, the average of the corrosion current density for each specimen was calculated, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.16 and plotted in Figure 4.13.

In all the specimens, the corrosion current density values did not exceed 0.3 µA/cm² [34] after six months of exposure. The corrosion current density values increased with time. However, the I_{corr} values in the specimens with inhibitors were less than those in the specimens without inhibitor. This proves the efficiency of inhibitors in minimizing reinforcement corrosion. The effectiveness of the inhibitors in retarding corrosion of steel in reinforced concrete in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Sika903, Sika901, Conplast, and Cemetec. The corrosion current density in these specimens after 180 days was 0.165930, 0.221225, 0.2368, 0.2461 and 0.2683 µA/cm², respectively, as compared with 0.2922 µA/cm² for the concrete specimens without inhibitors.

Table 4.16 Average Corrosion Current Density Values for Beam Specimens Exposed to the Tidal Zone

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (μA/cm²)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
17/03/2103	37	0.06135	0.09726	0.08615	0.09539	0.052035	0.053790
16/04/2013	66	0.1073	0.1236	0.1320	0.1084	0.064265	0.090010
15/05/2013	95	0.1445	0.14861	0.1684	0.17995	0.116593	0.122815
17/06/2103	127	0.1921	0.1924	0.1862	0.1917	0.122491	0.168183
19/07/2103	159	0.24618	0.22600	0.20318	0.21662	0.128985	0.188545
22/08/2103	192	0.2922	0.2683	0.2461	0.2368	0.165930	0.221225

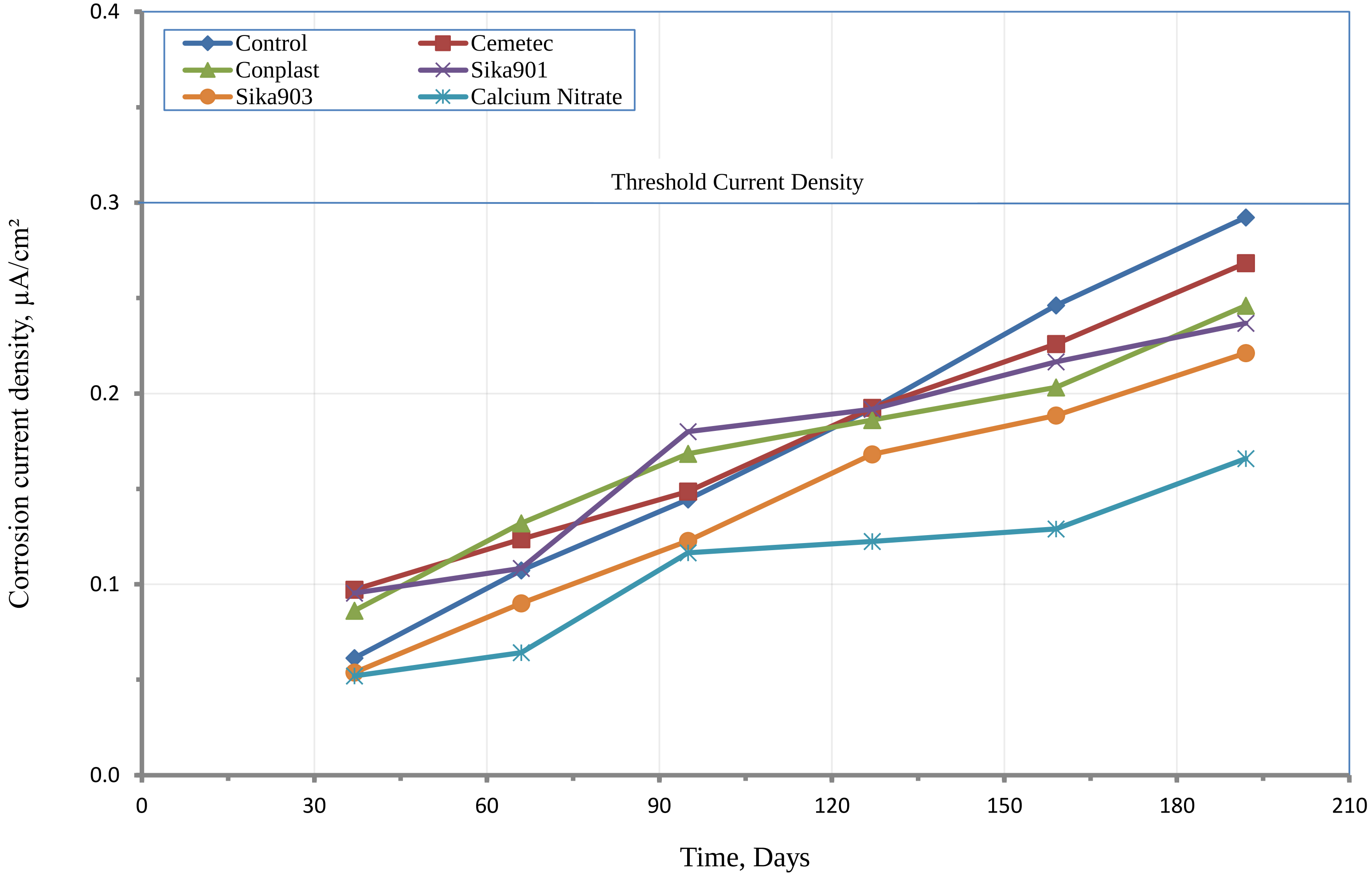


Figure 4.13 Corrosion Current Density Values–Time Curves for Beam Specimens Exposed to the Tidal Zone.

The time–corrosion current density plot in Figure 4.13 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the specimens placed in the tidal zone is summarized in Table 4.17. The time to cracking of concrete in the specimens with inhibitor was more than that in the control specimens. This indicates the efficiency of corrosion inhibitors in retarding anodic and cathodic reactions and minimizing reinforcement corrosion.

Table 4.17 Time to Cracking of Concrete for Specimens in the Tidal Zone.

Inhibitor Type	**Best-fit Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.001491x + 0.005943	1	1.85
Cemetec	y = 0.001113x + 0.050677	0.99	2.37
Conplast	y = 0.000946x + 0.063728	0.97	2.75
Sika901	y = 0.000956x + 0.063759	0.93	2.72
Calcium Nitrate	y = 0.000706x + 0.028870	0.92	3.82
Sika903	y = 0.001083x + 0.018771	0.99	2.52

The relations reported in the equations tabulated above (Table 4.17) can be considered reliable [54] since the value of the correlation coefficient (R^2) is 1, 0.99, 0.97, 0.93, 0.92 and 0.99, respectively.

Table 4.18 shows the extension in service life (%) of reinforced concrete structure due to the use of inhibitors. There is about 28 to 106% extension in the service life due to the use of inhibitors.

Table 4.18 Extension in Service Life of the Reinforced Concrete Structure in the Tidal Zone by Using Each Inhibitor.

Inhibitor Type	**Extension in Service Life (%)**
Cemetec	28.11
Conplast	48.65
Sika901	47.03
Calcium Nitrate	106.49
Sika903	36.22

Calcium nitrate can retard reinforcement corrosion and increase the service life of the structure by more than 100% in the structure without inhibitor. Conplast and Sika901 inhibitors increase the service life of the structure by about 50%, while Sika903 inhibitor may extend the service life of the structure by about 36%. Cemetec was the lowest effective inhibitor in this zone by increasing the service life of the structure by 28%.

- **Below Ground Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were buried fully in soil mixed with sabkha solution. The corrosion current density was taken for each working electrode every month. Then, the average of the corrosion current density for each specimen was calculated, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.19 and plotted in Figure 4.14.

The availability of oxygen in this zone was very low because all the specimens were placed under sabkha soil. Consequently, corrosion activation was not observed after six months of exposure as the corrosion current density values in all the specimens did not exceed 0.3 µA/cm² [34]. In the concrete specimens without inhibitor, the corrosion current density increased with time and it is more than that in concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The most effective inhibitor was Calcium Nitrate. The effectiveness of the selected inhibitors in minimizing corrosion of steel in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Sika903, Conplast, Sika901, Cemetec. The corrosion current density in these specimens after 180 days was 0.036673, 0.076278, 0.1088, 0.1338 and 0.1554 µA/cm², respectively, as compared with 0.16910 µA/cm² for the concrete specimens without inhibitors.

The time–corrosion current density plot in Figure 4.14 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the specimens placed in the below ground zone is summarized in Table 4.20. The time to cracking of concrete in the control specimens was 4.38 years, while it was 15.27 years in the specimens with Calcium Nitrate. Also, it should be noted that the time to cracking of concrete in the specimens with Cemetec and Sika901 inhibitors was less than that in the control specimens, which means that their performance was inferior to the control concrete specimens.

Table 4.19 Average Corrosion Current Density Values for Beam Specimens Exposed to the Below Ground Zone.

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (μA/cm^2)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
10/04/2103	40	0.0745	0.0352	0.0198	0.03287	0.013659	0.043390
05/05/2013	66	0.1250	0.04346	0.02338	0.0361	0.015825	0.049303
31/05/2013	92	0.13935	0.06875	0.02716	0.0414	0.020090	0.054182
03/07/2013	125	0.14753	0.1133	0.0459	0.0555	0.028055	0.063585
29/07/2013	151	0.1601	0.14368	0.07252	0.0811	0.034193	0.072195
28/08/2013	180	0.16910	0.1554	0.1088	0.1338	0.036673	0.076278

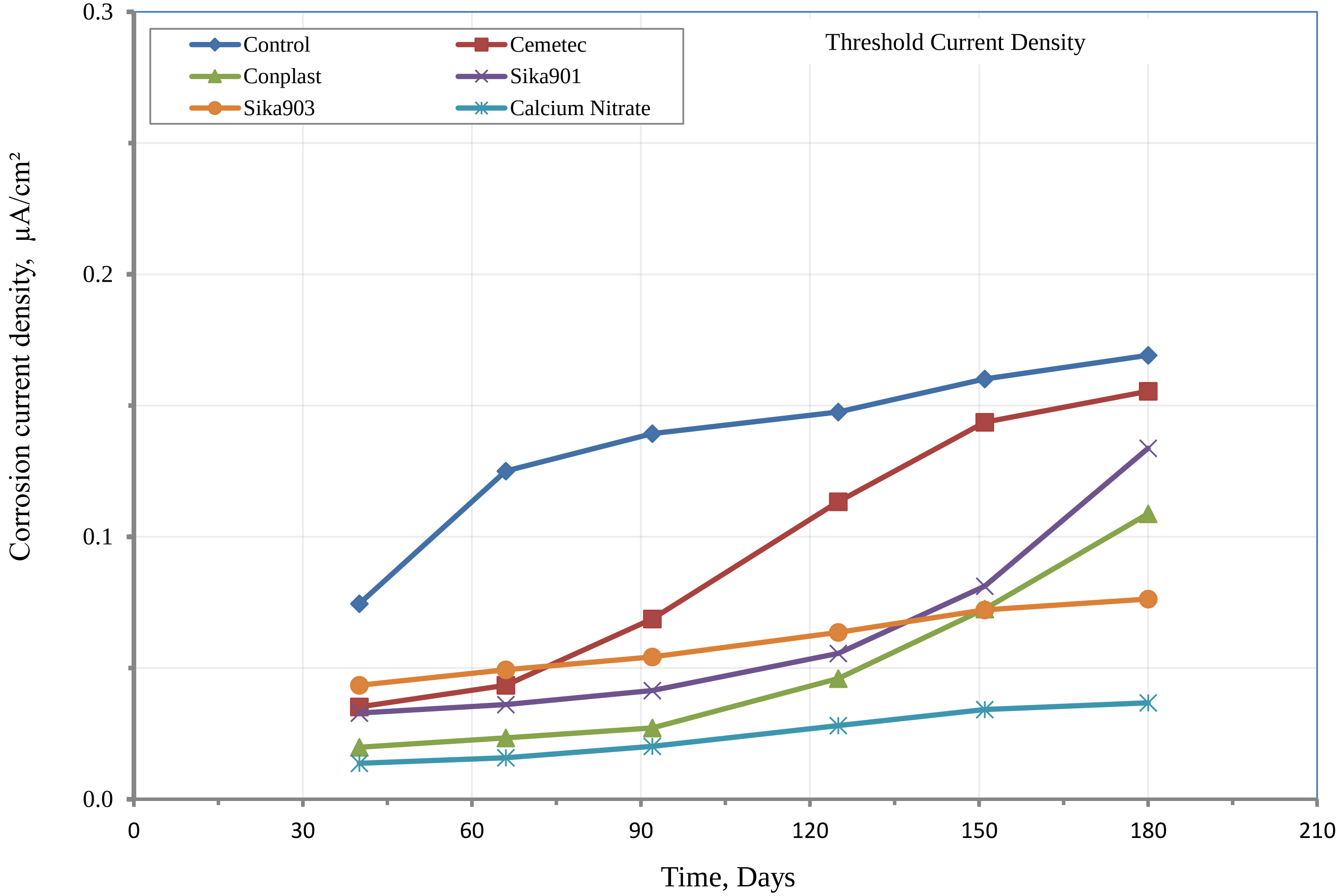


Figure 4.14 Corrosion Current Density Values–Time Curves for Beam Specimens Exposed to the Below Ground Zone.

Table 4.20 Time to Cracking of Concrete for Specimens in the Below Ground Zone.

Inhibitor Type	**Best-fit Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	$y = 0.000588x + 0.071883$	0.84	4.38
Cemetec	$y = 0.000961x - 0.011485$	0.97	2.93
Conplast	$y = 0.000622x - 0.018154$	0.88	4.55
Sika901	$y = 0.000664x - 0.008913$	0.82	4.22
Calcium Nitrate	$y = 0.000181x + 0.005039$	0.98	15.27
Sika903	$y = 0.000246x + 0.033039$	0.99	10.92

The relations reported in the equations tabulated above (Table 4.20) can be considered reliable since the value of the correlation coefficient (R^2) is greater than 0.80 [54]. The correlation coefficient (R^2) is 0.84, 0.97, 0.88, 0.82, 0.98 and 0.99, respectively.

Table 4.21 shows the extension in service life (%) of reinforced concrete structures due to the use of inhibitors. There is almost 4 to 250% extension in the service life due to the use of inhibitors. However, Cemetec and Sika901 were not effective in extending the service life.

Table 4.21 Extension in Service Life of the Reinforced Concrete Structure in the Below Ground Zone by Using Each Inhibitor.

Inhibitor Type	Extension in Service Life (%)
Cemetec	-33.11
Conplast	3.88
Sika901	-3.65
Calcium Nitrate	248.63
Sika903	149.32

The most effective inhibitor was Calcium Nitrate. The protection of steel from corrosion provided by calcium nitrate can increase the service life of the structure to more than two and a half times than the structure without inhibitor. Sika903 was also effective and it can extend the service life of the structure to about one and a half times than the structure without inhibitor. The positive effect of Conplast inhibitor to minimize reinforcement corrosion was marginal. The inferior performance of Cemetec and Sika901 inhibitors may be due to their inefficiency in such exposure condition.

- **Capillary Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were half buried in soil mixed with sabkha solution. The corrosion current density was measured for each working electrode every month. After that, the average of the corrosion current density for each specimen was calculated, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.22 and plotted in Figure 4.15.

The corrosion current density values increase with time. However, in the specimens with Calcium Nitrate inhibitor, this increment was low. On the contrary, in the control specimens and with other inhibitors, the I_{corr} values increased relatively sharply with time**.** The corrosion current density in all the specimens did not exceed 0.3 µA/cm² after six months of exposure. In the concrete specimens without inhibitor, the corrosion current density increases more than that in the concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in retarding reinforcement corrosion. The effectiveness of the inhibitors in delaying reinforcement corrosion in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Sika901, Sika903, Conplast and Cemetec. The corrosion current density in these specimen after 180 days was 0.013814, 0.1206, 0.138503, 0.1531and 0.1720 µA/cm², respectively, as compared with 0.1985 µA/cm² for the concrete specimens without inhibitors.

Table 4.22 Average Corrosion Current Density Values for Beam Specimens Exposed to the Capillary Zone.

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (μA/cm^2)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
10/04/2013	40	0.0457	0.01017	0.02418	0.02487	0.001628	0.021263
05/05/2013	65	0.05697	0.0314	0.0533	0.0308	0.003826	0.046294
29/05/2013	89	0.0808	0.0723	0.0660	0.0519	0.006664	0.077006
03/07/2013	123	0.1055	0.1033	0.1000	0.0699	0.008121	0.093766
28/07/2013	148	0.1507	0.1535	0.1343	0.0819	0.009621	0.111998
27/08/2013	180	0.1985	0.1720	0.1531	0.1206	0.013814	0.138503

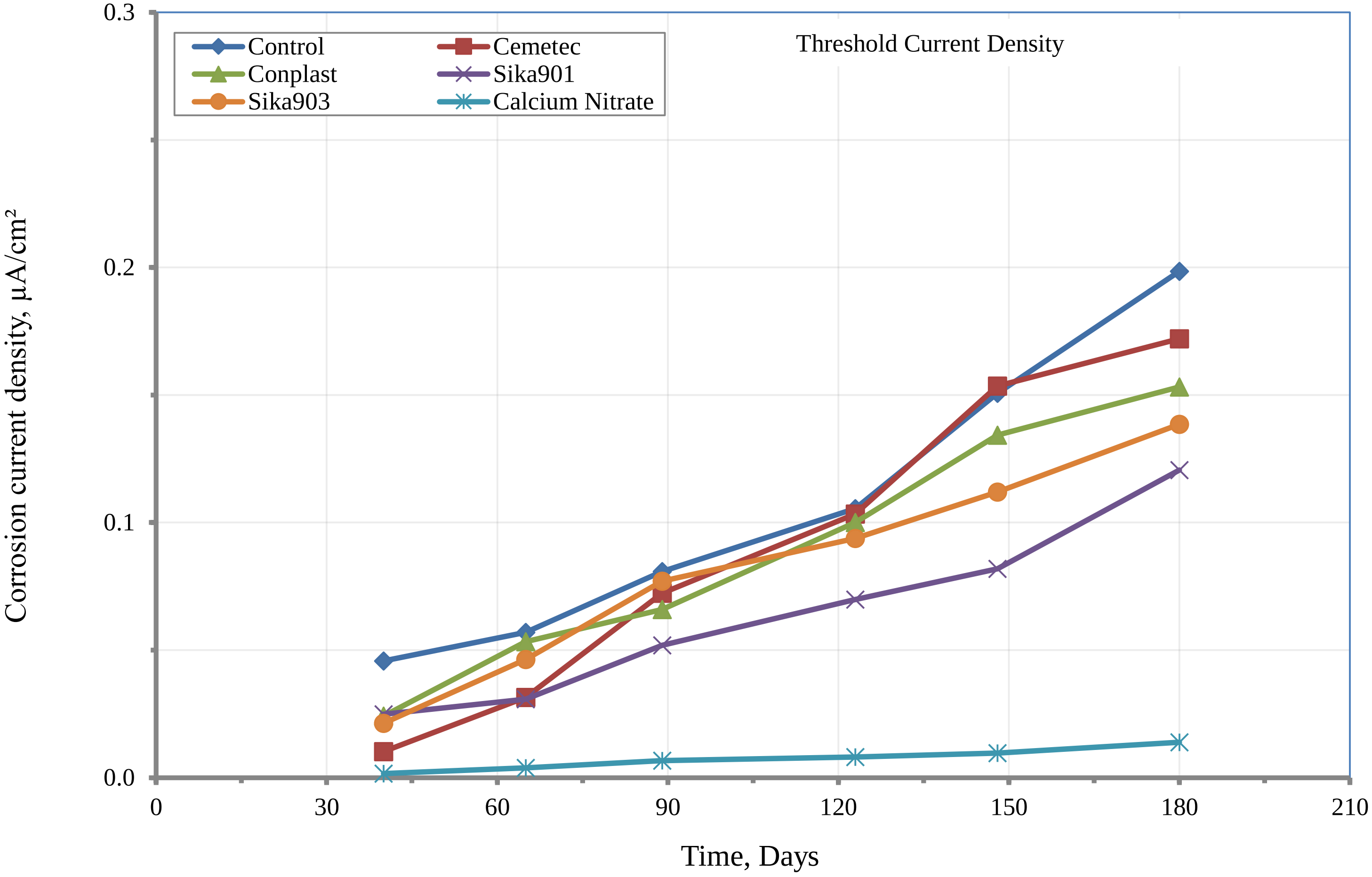


Figure 4.15 Corrosion Current Density Values–Time Curves for Beam Specimens Exposed to the Capillary Zone.

The time–corrosion current density plot in Figure 4.15 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the specimens placed in the capillary zone is summarized in Table 4.23. The time to cracking of concrete in the control specimens was 2.57 years, while it was 34.34 years in the specimens with Calcium Nitrate. Also, the time to cracking of concrete in the specimens with other inhibitors was more than that in the control specimens. However, it should be noted that the time to cracking of concrete in the specimens with Cemetec inhibitor was less than that in the control specimens.

Table 4.23 Time to Cracking of Concrete for Specimens in the Capillary Zone.

Inhibitor Type	**Best-fit Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.001093x - 0.011104	0.96	2.57
Cemetec	y = 0.001223x - 0.041020	0.98	2.36
Conplast	y = 0.000937x - 0.012275	0.99	3.00
Sika901	y = 0.000664x - 0.008092	0.96	4.22
Calcium Nitrate	y = 0.000081x - 0.001430	0.98	34.34
Sika903	y = 0.000809x - 0.005539	0.98	3.45

As mentioned earlier, the relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in the equations tabulated above (Table 4.23) can be considered reliable since the value of the correlation coefficient (R^2) is 0.96, 0.98, 0.99, 0.96, 0.98 and 0.98, respectively.

Table 4.24 shows the extension in service life (%) of reinforced concrete structure due to the use of inhibitors.

Table 4.24 Extension in Service Life of the Reinforced Concrete Structure by Using Each Inhibitor.

Inhibitor Type	Extension in Service Life (%)
Cemetec	-8.17
Conplast	16.73
Sika901	64.20
Calcium Nitrate	1237.19
Sika903	34.24

It could be noted from the results above that the use of Calcium Nitrate in reinforced concrete structures in this zone is very advantageous. Its corrosion protection can extend the service life of the structures to more than 12 times than the structures without inhibitor. Other inhibitors also are effective in minimizing reinforcement corrosion. This confirms the efficiency of inhibitors to retards the anodic and cathodic reactions. However, Cemetec was not effective in minimizing reinforcement corrosion. This adverse effect of Cemetec inhibitor may be to the quality of concrete.

- **Submerged Zone:**

In this zone, 12 beam specimens, two specimens with each inhibitor, were submerged in the sabkha solution. The corrosion current density was measured for each working electrode every month. Then, the average of the corrosion current density for each specimen was calculated as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.25 and plotted in Figure 4.16.

The corrosion current density for all the specimens increased slowly with time in this zone because the availability of oxygen was very low. The corrosion current density values did not exceed 0.3 µA/cm² after six months of exposure [34]. In the concrete specimens without inhibitor, the corrosion current density increases more than in the concrete specimens with inhibitors. This indicates that all corrosion inhibitors were effective in delaying reinforcement corrosion. The effectiveness of the inhibitors in minimizing corrosion of steel in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Conplast, Sika901, and Sika903. The corrosion current density in these specimens after 180 days was 0.039143, 0.0488, 0.0661, 0.07724 and 0.088315 µA/cm², respectively, as compared with 0.10996 µA/cm² for the concrete specimens without inhibitors.

The time–corrosion current density plot in Figure 4.16 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the specimens placed in the submerged zone is summarized in Table 4.26.

The time to cracking of concrete in the control specimens was less than that in the specimens with Cemetec, Conplast and Calcium Nitrate. However, it should be noted that the time to cracking of concrete in the specimens with Sika901 and Sika903 inhibitors was less than that in the control specimens. The coating layer of Sika903 inhibitor was not effective to prevent chloride ions and moisture from penetrating concrete. The adverse effect of Sika901 may be due to the quality of concrete.

Table 4.25 Average Corrosion Current Density Values for Beam Specimens Exposed to the Submerged Zone.

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (µA/cm^2)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
10/04/2013	40	0.0602	0.01652	0.04200	0.01563	0.011542	0.023233
05/05/2013	65	0.0664	0.0207	0.04522	0.0213	0.015947	0.036640
29/05/2013	89	0.0825	0.03094	0.04940	0.0325	0.024311	0.047343
03/07/2013	123	0.08383	0.03743	0.05323	0.04107	0.031086	0.060086
28/07/2013	148	0.08575	0.04251	0.0597	0.04857	0.034426	0.075668
28/08/2013	180	0.10996	0.0488	0.0661	0.07724	0.039143	0.088315

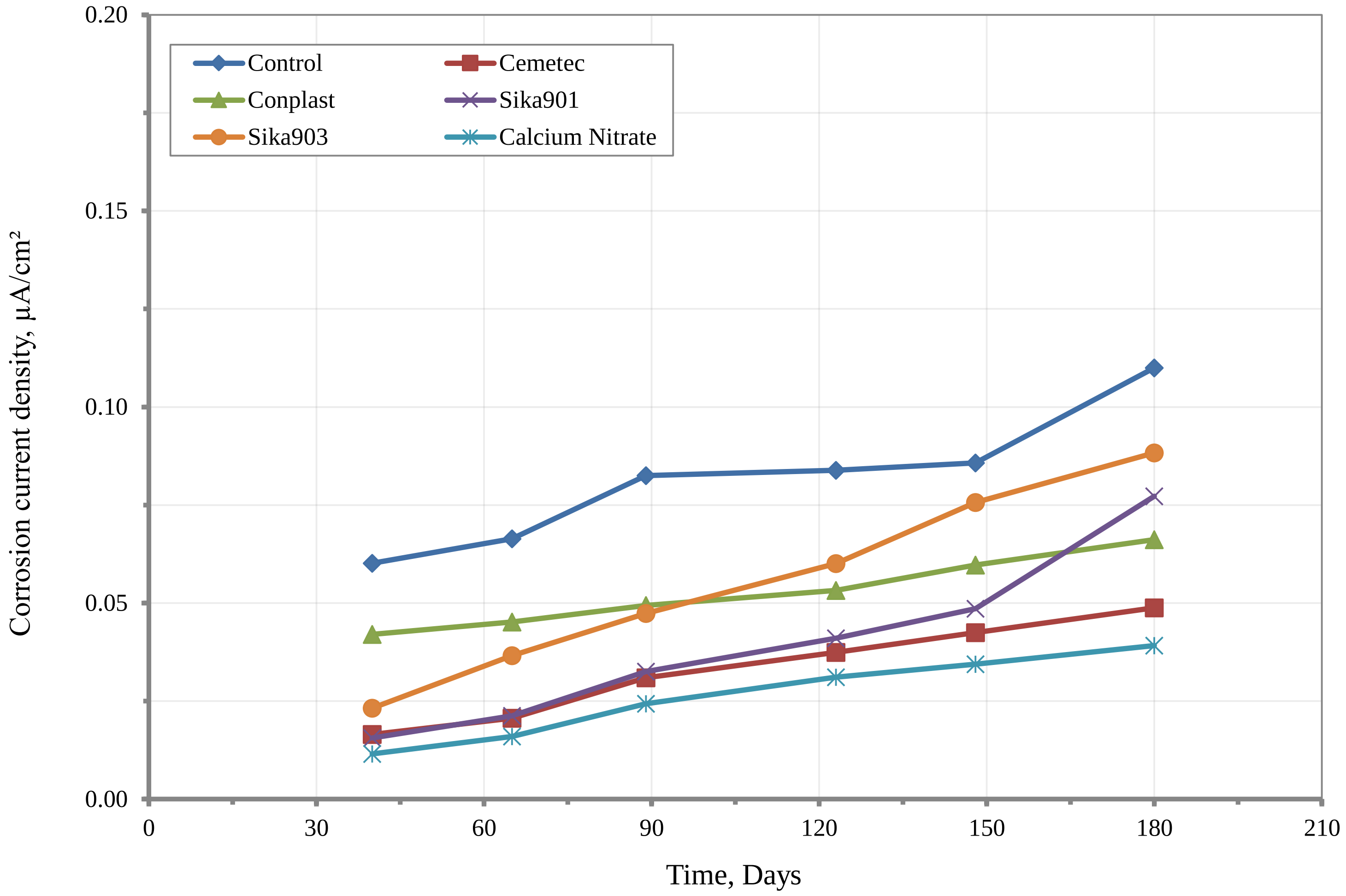


Figure 4.16 Corrosion Current Density Values–Time Curves for Beam Specimens Exposed to the Submerged Zone.

Table 4.26 Time to Cracking of Concrete for Specimens in the Submerged Zone.

Inhibitor Type	**Best-fit Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.000313x + 0.047772	0.89	8.45
Cemetec	y = 0.000236x + 0.007385	0.98	11.68
Conplast	y = 0.000171x + 0.034226	0.98	15.69
Sika901	y = 0.000408x - 0.004441	0.94	6.84
Calcium Nitrate	y = 0.000203x + 0.004272	0.98	13.63
Sika903	y = 0.000462x + 0.005528	1	5.98

The relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in the equations tabulated above (Table 4.26) can be considered reliable since the value of the correlation coefficient (R^2) is 0.89, 0.98, 0.98, 0.94, 0.98 and 1, respectively.

Table 4.27 shows the extension in service life (%) of reinforced concrete structure due to the use of inhibitors.

Table 4.27 Extension in Service Life of the Reinforced Concrete Structure by Using Each Inhibitor.

Inhibitor Type	**Extension in Service Life (%)**
Cemetec	38.22
Conplast	85.68
Sika901	-19.05
Calcium Nitrate	61.30
Sika903	-29.23

Conplast and Calcium Nitrate inhibitors were very effective in minimizing reinforcement corrosion and increased the service life of the structure by about 60 to 85%, while cemetec inhibitor could increase the service life by about 40%. Other inhibitors did not have any effect to reduce reinforcement corrosion. The adverse effect of other inhibitors may be due to the quality of concrete.

The time to cracking of concrete due to use of the inhibitors in all zones mentioned above is summarized in Table 4.28.

Table 4.28 Summary of Time to Cracking of Concrete for Specimens with Inhibitors in Each Zone.

Zone	Time to Cracking of Concrete (Years)					
	Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
Atmospheric	5.03	6.2	6.7	11.66	35.69	16.4
Tidal	1.85	2.37	2.75	2.72	3.82	2.52
Below ground	4.38	2.93	4.55	4.22	15.27	10.92
Capillary	2.57	2.36	3	4.22	34.34	3.45
Submerged	8.45	11.68	15.69	6.84	13.63	5.98

The severity of any exposure zone depends on the presence of chloride ions, oxygen and moisture. From the results tabulated above (Table 4.28), the severity of the investigated zones can be ranked from lowest to highest as follows: submerged, atmospheric, below ground, capillary and tidal. The time to cracking of concrete for specimens in the submerged zone was the highest. The highest value of time to cracking of concrete indicates that the submerged zone was the least severity in all zones despite the high chloride percentage and moisture in this zone that could not accelerate corrosion in the absence of oxygen. The tidal zone was the highest severity zone because both oxygen and moisture were available in this zone.

4.2.2Cylindrical Specimens

- **Cylinders without Chloride Content:**

A total of 36 cylindrical concrete specimens, six specimens with each inhibitor, were exposed to wet and dry cycles with 5% NaCl solution. The corrosion current density was measured for each specimen every month, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.29 and plotted in Figure 4.17.

In all the specimens, the corrosion current density values increased with time. However, there was not corrosion activation after six months of exposure because the corrosion current density values did not exceed 0.3 µA/cm² [34]. After 6 months of exposure, the corrosion current density in the specimens without inhibitor was more than that in the concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The most effective inhibitor to retard corrosion was Calcium Nitrate. The effectiveness of the inhibitors in minimizing corrosion of steel in this zone is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Sika903, Conplast, and Sika901. The corrosion current density in these specimens after 180 days was 0.026033, 0.071133, 0.085438, 0.085438 and 0.091224 µA/cm², respectively, as compared with 0.120558 µA/cm² for the concrete specimens without inhibitors.

The time–corrosion current density plot in Figure 4.17 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the cylindrical specimens placed in the wet and dry cycles is summarized in Table 4.30. The time to cracking of concrete in the control specimens was 3.83 years, while in the specimens with Calcium Nitrate it was 18.98 years. Also, it should be noted that the time to cracking of concrete in the specimens with inhibitors was more than that in the control specimens.

Table 4.29 Average Corrosion Current Density Values for Cylinders Exposed to Wet and Dry Cycles.

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (µA/cm^2)**					
		Control	**Cemetec**	**Conplast**	**Sika901**	**Calcium Nitrate**	**Sika903**
19/03/2013	43	0.003562	0.001435	0.004225	0.006790	0.002371	0.006551
17/04/2013	71	0.011755	0.012835	0.018636	0.031490	0.007274	0.021949
16/05/2013	100	0.029265	0.031898	0.036345	0.042665	0.009355	0.032558
16/06/2013	130	0.048658	0.040215	0.041356	0.052632	0.013308	0.042462
16/07/2013	160	0.072196	0.047847	0.052525	0.062745	0.017561	0.053407
19/08/2013	193	0.120558	0.071133	0.085438	0.091224	0.026033	0.083201

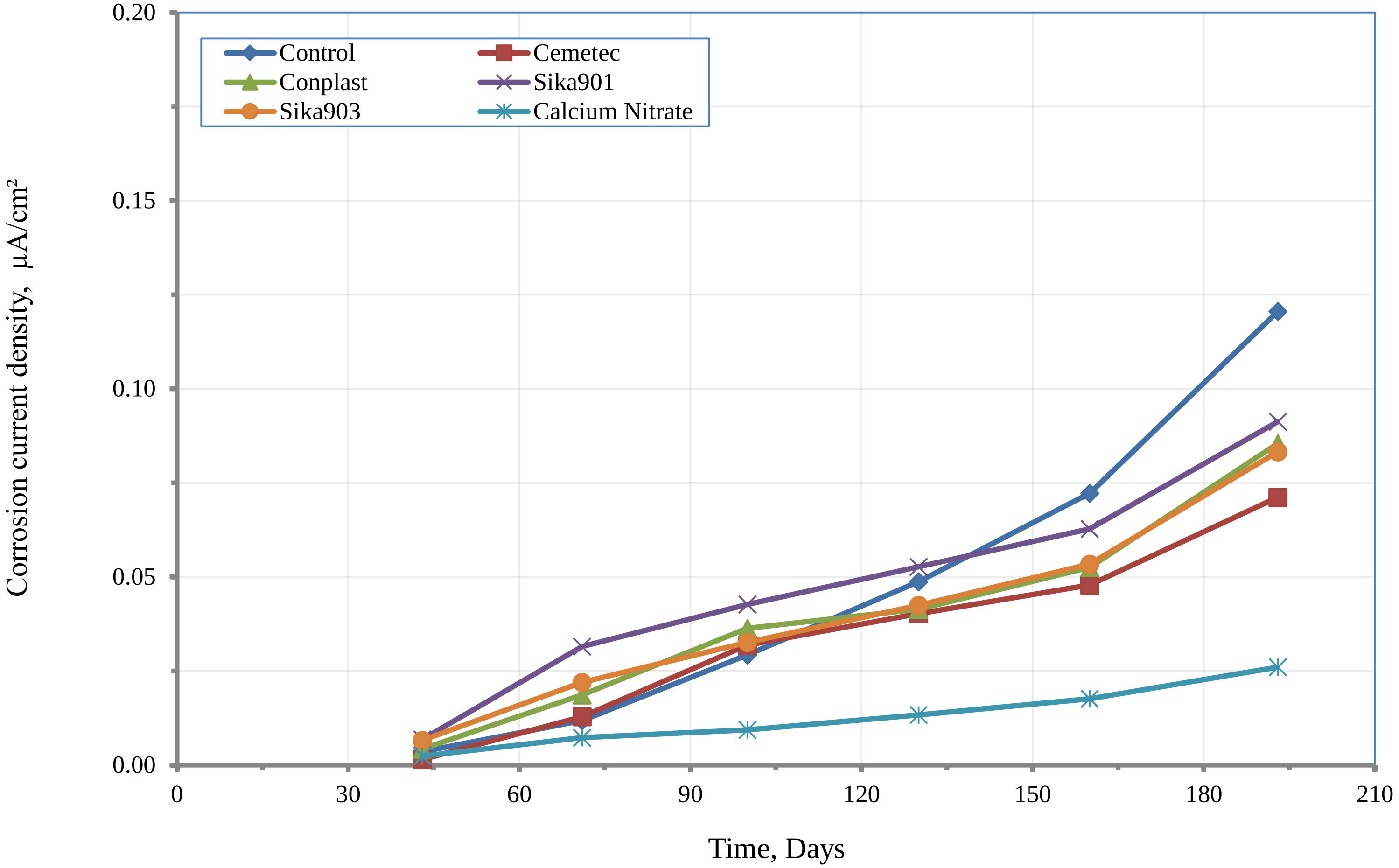


Figure 4.17 Corrosion Current Density Values–Time Curves for Cylinders Exposed to Wet and Dry Cycles.

Table 4.30 Time to Cracking of Concrete for Cylindrical Specimens.

Inhibitor Type	Slope Equation of I_{corr} – Time Curve	R^2	Time to Cracking of Concrete (Years)
None	y = 0.000755x - 0.040073	0.94	3.83
Cemetec	y = 0.000441x - 0.017060	0.98	6.41
Conplast	y = 0.000491x - 0.017329	0.95	5.76
Sika901	y = 0.000503x - 0.010479	0.96	5.58
Calcium Nitrate	y = 0.000147x - 0.004405	0.97	18.98
Sika903	y = 0.000467x - 0.014271	0.96	6.03

As mentioned before, the relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in the equations tabulated above (Table 4.30) can be considered reliable since the value of the correlation coefficient (R^2) is 0.94, 0.98, 0.95, 0.96, 0.97 and 0.96, respectively.

Table 4.31 shows the extension in service life (%) of reinforced concrete structures due to the use of inhibitors. There is about 50 to 400% extension in the service life due to the use of inhibitors because their effectiveness in retarding anodic and catodic reactions on reinforcement steels and minimizing reinforcement corrosion. The data in Table 4.31 clearly demonstrates that Calcium Nitrate superseded all the other corrosion inhibitors due to the fact that the extension in service life of reinforced concrete structures (396%) was much higher than those for all the other inhibitors (46 to 67%).

Table 4.31 Extension in Service Life of the Reinforced Concrete Structure by Using Each Inhibitor.

Inhibitor Type	**Extension in Service Life (%)**
Cemetec	67.36
Conplast	50.39
Sika901	45.69
Calcium Nitrate	395.56
Sika903	57.44

The effectiveness of inhibitors in delaying reinforcement corrosion and the increase of service life of the structure in this exposure condition is evident from the results. Calcium nitrate was the most effective by increasing the service life by almost four times, while the other inhibitors extend the service life of the structure by 45 to 70%.

- **Cylinders with Chloride Content:**

A total of 96 cylindrical concrete specimens, twelve specimens with each inhibitor, were sprayed with water once every three days for a period of five months.

- Cl^- (0.2%) :

A total of 24 cylindrical concrete specimens, three specimens with each inhibitor, were cast with a chloride contamination of 0.2% by weight of cementitious materials. They were sprayed with water once every three days. The corrosion current density was measured for each specimen, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.32 and plotted in Figure 4.18.

Corrosion activation was not observed even after six months of exposure because the corrosion current density values in all the specimens did not exceed 0.3 µA/cm² [34]. 0.2% chloride contamination was small to activate corrosion during this period. In the concrete specimens without inhibitor, the corrosion current density increases with time more than that in the concrete specimens with inhibitors. This indicates the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The effectiveness of these inhibitors to minimize corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Cortex, Sika901, Sika903, Rheocrete and Conplast. The corrosion current density in these specimens after 130 days was 0.059377, 0.065033, 0.071147, 0.077287, 0.077490, 0.097113, and 0.104567 µA/cm², respectively, as compared with 0.1365067 µA/cm² for the concrete specimens without inhibitors.

Table 4.32 Average Corrosion Current Density Values for Cylinders with 0.2% Chloride

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (µA/cm^2)**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	0.0202333	0.007015	0.008590	0.008216	0.010206	0.007713	0.015140	0.011887
24/05/2013	45	0.0500367	0.031137	0.015832	0.012685	0.021423	0.017860	0.020453	0.030721
28/06/2013	79	0.0564500	0.049633	0.034500	0.025210	0.041237	0.025887	0.039137	0.048759
23/07/2013	104	0.0864867	0.085567	0.063537	0.040987	0.067713	0.040517	0.049127	0.062407
20/08/2013	131	0.1365067	0.097113	0.104567	0.065033	0.077287	0.059377	0.071147	0.077490

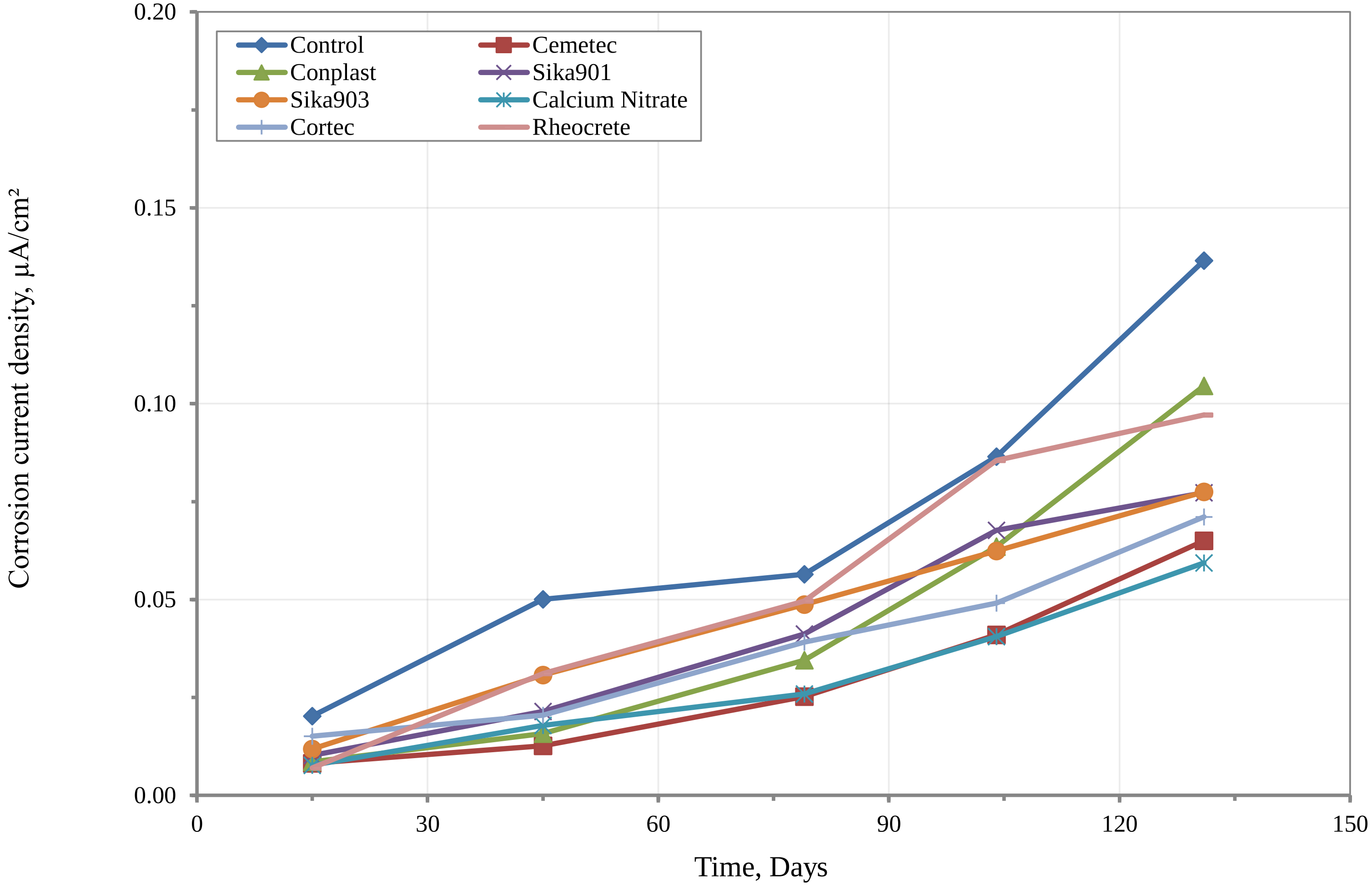


Figure 4.18 Corrosion Current Density Values–Time Curves for Cylinders with 0.2% Chloride.

The time–corrosion current density plot in Figure 4.17 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the cylindrical specimens with 0.2% chloride are summarized in Table 4.33. The time to cracking of concrete in the control specimens was less than that in the specimens with inhibitors. The time to cracking of concrete in the control specimens was 3.04 years as compared with 6.50 years in the specimens with Calcium Nitrate. This proves that Calcium Nitrated was very effective to slow the anodic reaction and minimize reinforcement corrosion in this exposure condition. Also, it should be noted that the time to cracking of concrete in the specimens with inhibitors was more than that in the control specimens. This confirms the efficiency of inhibitors in retarding reinforcement corrosion with the presence of 0.2% chloride in concrete mixture.

Time 4.33 Time to Cracking of Concrete for Cylindrical Specimens with 0.2% Chloride.

Inhibitor Type	**Slope Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.000911x + 0.001833	0.91	3.04
Cemetec	y = 0.0004814x - 0.0055810	0.92	5.80
Conplast	y = 0.000811x - 0.015290	0.91	3.48
Sika901	y = 0.000618x - 0.002624	0.97	4.51
Calcium Nitrate	y = 0.000560x + 0.004368	1	6.50
Sika903	y = 0.000428x - 0.001747	0.95	4.94
Cortec	y = 0.000481x + 0.003045	0.96	5.79
Rheocrete	y = 0.000803x - 0.005951	0.98	3.48

The relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in the equations tabulated above (Table 4.30) can be considered reliable since the value of the correlation coefficient (R^2) is 0.91, 0.92, 0.91, 0.97, 1, 0.95, 0.96 and 0.98, respectively.

Table 4.34 shows the extension in service life (%) of the reinforced concrete structure due to the use of inhibitors. There is almost 15 to 114% extension in the service life due to the use of inhibitors. Calcium nitrate was the most effective by increasing the service life by about 114%, while Cemetec and Cortec extend the service life of the structure by about 90%. The other inhibitors increase the service life of the structure by about 15 to 60%.

Table 4.34 Extension in Service Life of Concrete with 0.2% Chloride.

Inhibitor Type	**Extension in Service Life (%)**
Cemetec	90.79
Conplast	14.47
Sika901	48.36
Calcium Nitrate	113.82
Sika903	62.50
Cortec	90.46
Rheocrete	14.47

- **Cl^- (0.4%) :**

A total of 24 cylindrical concrete specimens, three specimens with each inhibitor, were cast with 0.4% chloride. They were sprayed with water once every three days. The corrosion current density was taken for each specimen, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.35 and plotted in Figure 4.19.

In all the specimens, the corrosion current density values increased with time. However, they did not exceed 0.3 µA/cm² [34] after five months of exposure. In the concrete specimens without inhibitor, the corrosion current density increases with time more than concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in minimizing reinforcement corrosion. The effectiveness of these inhibitors to minimize corrosion of steel in reinforced concrete in is ranked from highest to lowest as follows: Calcium Nitrate, Cemetec, Sika901, Cortec, Rheocrete, Conplast, and Sika903. The corrosion current density in these specimens after 130 days was 0.062367, 0.066497, 0.076037, 0.089347, 0.099877, 0.106033, and 0.132167 µA/cm², respectively, as compared with 0.1421667 µA/cm² for the concrete specimens without inhibitors.

Table 4.35 Average Corrosion Current Density Values for Cylinders with a Chloride Content of 0.4%.

Date of Exposure: 09/04/2013

Date	Duration (Days)	Average Corrosion Current Density I_{corr} ($\mu A/cm^2$)							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	0.0234500	0.007776	0.007103	0.008258	0.010063	0.012209	0.016540	0.013321
24/05/2013	45	0.0586533	0.031381	0.021513	0.012823	0.020620	0.019213	0.027260	0.032397
28/06/2013	79	0.0773033	0.051870	0.043197	0.028513	0.041203	0.030517	0.046457	0.056027
23/07/2013	104	0.1034133	0.086773	0.081827	0.043440	0.068820	0.045910	0.062484	0.078340
20/08/2013	131	0.1421667	0.099877	0.106033	0.066497	0.076037	0.062367	0.089347	0.132167

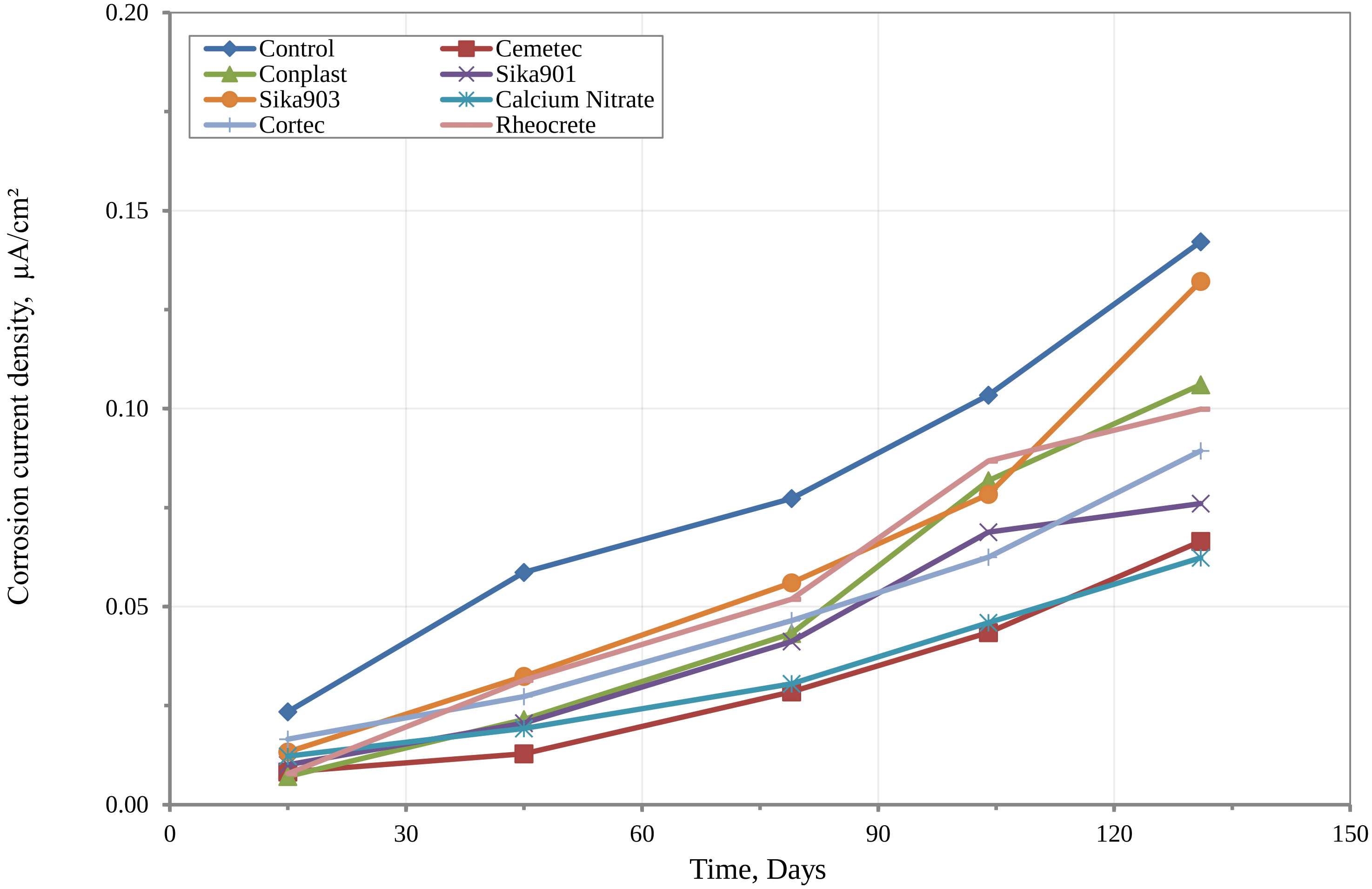


Figure 4.19 Corrosion Current Density Values–Time Curves for Cylinders with a Chloride Content of 0.4%.

The time–corrosion current density plot in Figure 4.19 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the cylindrical specimens with 0.4% chloride is summarized in Table 4.36. The time to cracking of concrete in the control specimens was less than that in the specimens with inhibitors. The time to cracking of concrete in the control specimens was 2.86 years, while it was 6.42 years in the specimens with Calcium Nitrate. Also, it should be noted that the time to cracking of concrete in the specimens with inhibitors was more than that in the control specimens. This confirms the efficiency of inhibitors in retarding reinforcement corrosion with the presence of 0.4% chloride in concrete mixture.

Table 4.36 Time to Cracking of Concrete for Cylindrical Specimens with 0.4% Chloride.

Inhibitor Type	**Slope Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.000964x + 0.008918	0.98	2.86
Cemetec	y = 0.000500x - 0.005520	0.94	5.59
Conplast	y = 0.000879x - 0.013804	0.96	3.20
Sika901	y = 0.000617x - 0.002799	0.97	4.51
Calcium Nitrate	y = 0.000432x + 0.001710	0.93	6.42
Sika903	y = 0.000964x - 0.009671	0.97	2.91
Cortec	y = 0.000617x + 0.002271	0.97	4.49
Rheocrete	y = 0.000820x - 0.005805	0.98	3.41

The relation between the variables is considered reliable if the correlation coefficient (R^2) is greater than 0.80 [54]. Hence, the relations reported in Equations tabulated above (Table 4.30) can be considered reliable since the value of the correlation coefficient (R^2) is 0.98, 0.94, 0.96, 0.97, 0.93 0.97, 0.97 and 0.98, respectively.

Table 4.37 shows the extension in service life (%) of the reinforced concrete structure due to the use of inhibitors. There is almost 2 to 125% extension in the service life due to the use of inhibitors.

Table 4.37 Extension in Service Life of Concrete with 0.4% Chloride.

Inhibitor Type	Extension in Service Life (%)
Cemetec	95.45
Conplast	11.89
Sika901	57.69
Calcium Nitrate	124.48
Sika903	1.75
Cortec	56.99
Rheocrete	19.23

Calcium Nitrate was the most effective inhibitor in protecting steel from corrosion in the concrete contaminated with 0.4% chloride. It increased the service life of structure by about 125% compared with structures without inhibitors. Cemetec was also very effective in increasing the service life by about 95%. Sika901 and Cortec extended the service life of structure by 60%, while Rheocrete and Conplast increased the service life of the structure by more than 10%, while Sika903 extended the service life by 2%.

- **Cl^- (0.8%):**

A total of 24 cylindrical concrete specimens, three specimens with each inhibitor, were cast with 0.8% chloride. They were sprayed with water once every three days. The corrosion current density was taken for each specimen, as shown in Appendix B.

The average values of the corrosion potential for each inhibitor are summarized in Table 4.38 and plotted in Figure 4.20.

It can be observed that the corrosion current density values in all the specimens with 0.8% chloride contamination were more negative than those with 0.2 and 0.4%. However, the corrosion current density values in all specimens were less than 0.3 µA/cm² after five months of exposure. In the concrete specimens without inhibitor, the corrosion current density increased with time more than the concrete specimens with inhibitors. This proves the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The effectiveness of the inhibitors in minimizing corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Sika901, Rheocrete, Conplast, Cortec, Sika903, Cemetec. The corrosion current density in these specimens after 130 days was 0.094567, 0.098310, 0.104133, 0.108213, 0.132200, 0.138367, and 0.143407 µA/cm², respectively, as compared with 0.1515500 µA/cm² for the concrete specimens without inhibitors.

Table 4.38 Average Corrosion Current Density Values for Cylinders with a Chloride Content of 0.8%.

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (µA/cm^2)**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	0.0220300	0.016100	0.014783	0.019933	0.023863	0.022636	0.028707	0.022537
24/05/2013	45	0.0554133	0.032667	0.033117	0.044137	0.031355	0.040937	0.048793	0.052350
28/06/2013	79	0.0784567	0.055193	0.044563	0.069930	0.047843	0.062113	0.062513	0.081930
23/07/2013	104	0.1085800	0.089183	0.091590	0.089570	0.073750	0.080157	0.075580	0.105577
20/08/2013	131	0.1515500	0.104133	0.108213	0.143407	0.098310	0.094567	0.132200	0.138367

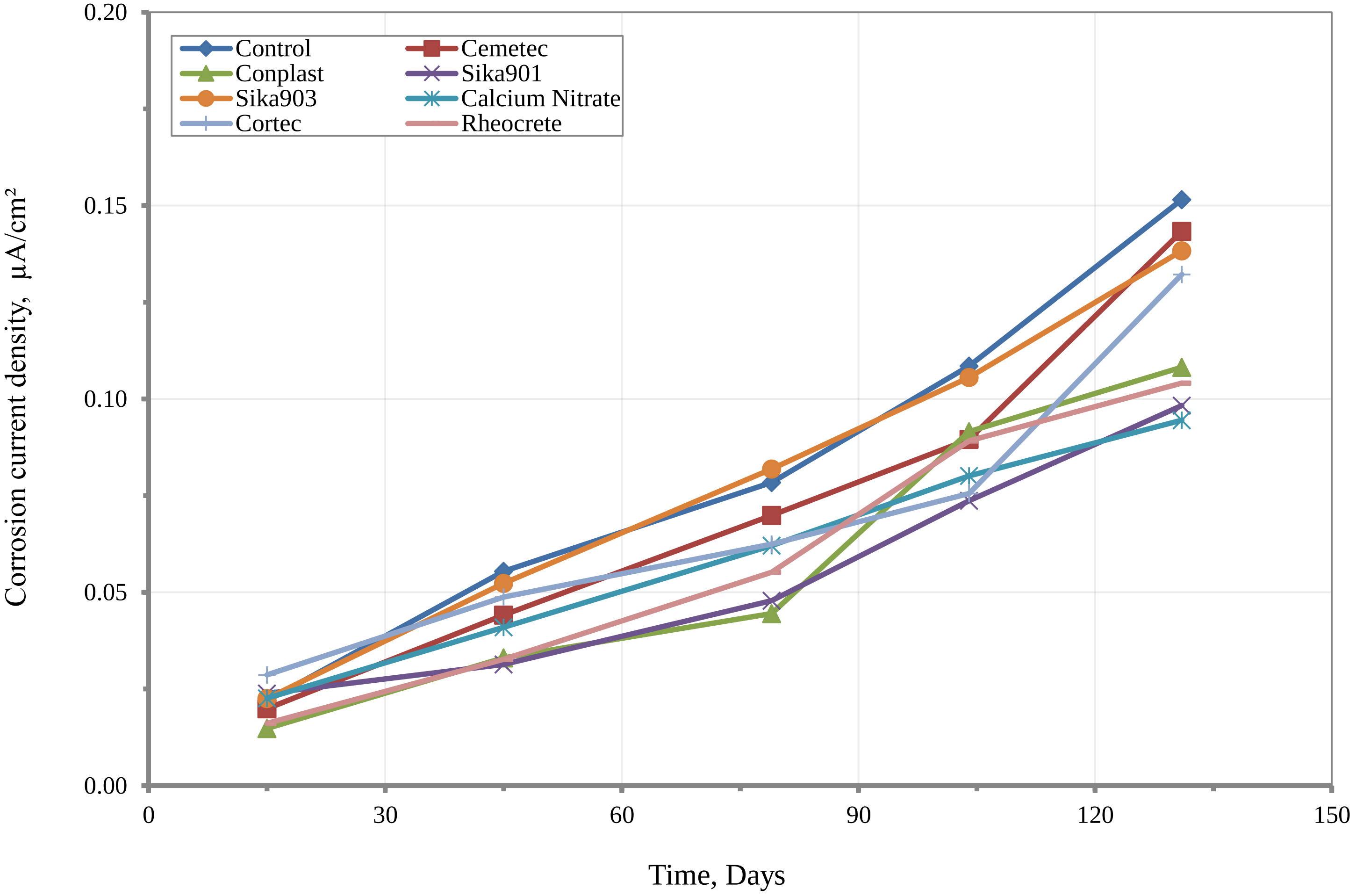


Figure 4.20 Corrosion Current Density Values–Time Curves for Cylinders with a Chloride Content of 0.8%.

The time–I_{corr} plot in Figure 4.20 was extrapolated to determine the time to cracking of concrete as discussed above. The time to cracking of concrete in the cylindrical specimens with 0.8% chloride is summarized in Table 4.39. The time to cracking of concrete in the control specimens was less than that in the specimens with inhibitors.

Table 4.39 Time to Cracking of Concrete for Cylindrical Specimens with 0.8% Chloride.

Inhibitor Type	**Slope Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.001065x + 0.003512	0.98	2.60
Cemetec	y = 0.000996x - 0.001128	0.95	2.79
Conplast	y = 0.000833x - 0.003836	0.93	3.35
Sika901	y = 0.000650x + 0.006424	0.94	4.25
Calcium Nitrate	y = 0.000977x + 0.007090	1	4.36
Sika903	y = 0.000629x + 0.013028	1	2.82
Cortec	y = 0.000792x + 0.010298	0.87	3.47
Rheocrete	y = 0.000795x - 0.000013	0.98	3.50

The correlation coefficient (R^2) is 0.98, 0.95, 0.93, 0.94, 1, 1, 0.87 and 0.98, respectively. The relation between the variables is considered reliable because (R^2) is greater than 0.80 [54].

Table 4.40 shows the extension in service life (%) of reinforced concrete structure due to the use of inhibitors. There is almost 8 to 70% extension in the service life due to the use of inhibitors.

Table 4.40 Extension in Service Life of Concrete with 0.8% Chloride.

Inhibitor Type	Extension in Service Life (%)
Cemetec	7.31
Conplast	28.85
Sika901	63.46
Calcium Nitrate	67.69
Sika903	8.46
Cortec	33.46
Rheocrete	34.62

In the concrete contaminated with 0.8% chloride, Calcium Nitrate and Sika901 were the most effective to protect reinforcement steel from corrosion. They could extend the service life of the structure by more than 60%. Rheocrete, Cortec and Conplast increased the service life of the structure by about 30%, while Sika903and Cemetec extended the service life by about 10%.

- **Cl^- (1.5%):**

A total of 24 cylindrical concrete specimens, three specimens with each inhibitor, were cast with a chloride content of 1.5%. They were sprayed with water once every three days. The corrosion current density was taken for each specimen, as shown in Appendix B.

The average values of the corrosion current density for each inhibitor are summarized in Table 4.41and plotted in Figure 4.21.

In all the specimens, the corrosion current density values increased with time. However, they did not exceed 0.3 µA/cm² after five months of exposure. In the concrete specimens without inhibitor, the corrosion current density increased more than in the concrete specimens with inhibitors. This gives us indication that all corrosion inhibitors were effective in minimizing reinforcement corrosion. The effectiveness of these inhibitors in delaying corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Sika901, Rheocrete, Conplast, Cortec, Cemetec and Sika903. The corrosion current density in these specimens after 130 days was 0.119717, 0.129133, 0.140700, 0.182167, 0.217233, 0.218667 and 0.259700 µA/cm², respectively, as compared with 0.284080 µA/cm² for the concrete specimens without inhibitors.

Table 4.41 Average Corrosion Current Density Values for Cylinders with a Chloride Content of 1.5%.

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Average Corrosion Current Density I_{corr} (μA/cm^2)**							
		Control	**Rheocrete**	**Conplast**	**Cemetec**	**Sika901**	**Calcium Nitrate**	**Cortec**	**Sika903**
24/04/2013	15	0.115677	0.034323	0.052477	0.020073	0.038180	0.034823	0.074643	0.079320
24/05/2013	45	0.175700	0.058970	0.083667	0.046407	0.078083	0.061313	0.095650	0.103223
28/06/2013	79	0.212800	0.071783	0.095153	0.071830	0.082780	0.073000	0.117373	0.137680
23/07/2013	104	0.257000	0.089947	0.123500	0.122760	0.095683	0.098297	0.151900	0.196837
20/08/2013	131	0.284080	0.140700	0.182167	0.218667	0.129133	0.119717	0.217233	0.259700

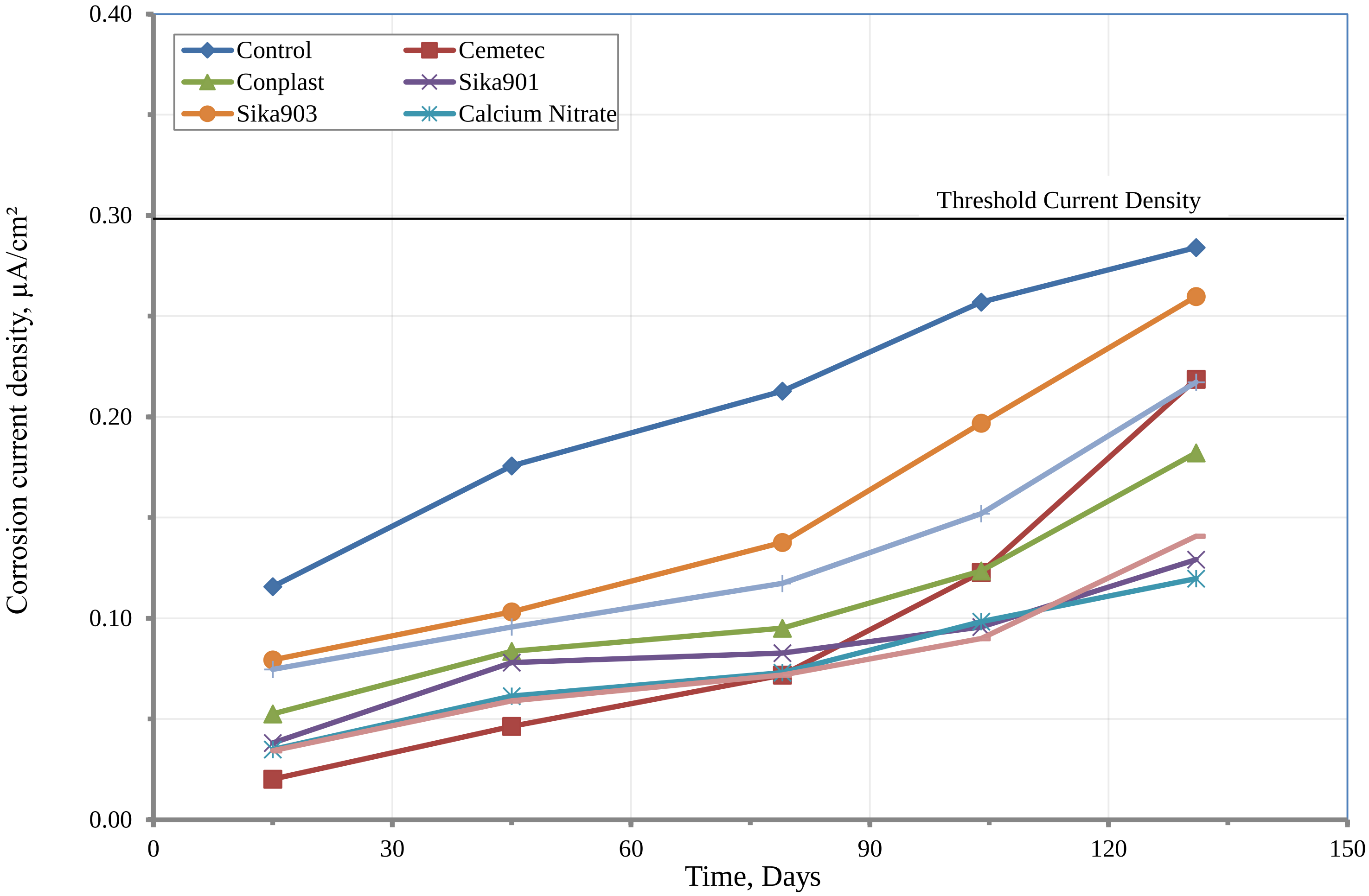


Figure 4.21 Corrosion Current Density Values–Time Curves for Cylinders with a Chloride Content of 1.5%.

The time–corrosion current density plot in Figure 4.21 was extrapolated to determine the time to cracking of concrete as discussed before. The time to cracking of concrete in the cylindrical specimens with 0.8% chloride is summarized in Table 4.42. The time to cracking of concrete in the control specimens was less than that in the specimens with inhibitors. This proves the efficiency of inhibitors in minimizing reinforcement corrosion.

Time 4.42 Time to Cracking of Concrete for Cylindrical Specimens with 1.5% Chloride.

Inhibitor Type	**Slope Equation of I_{corr} – Time Curve**	**R^2**	**Time to Cracking of Concrete (Years)**
None	y = 0.001438x + 0.101511	0.99	1.74
Cemetec	y = 0.001600x - 0.023764	0.89	1.78
Conplast	y = 0.001014x + 0.031541	0.91	2.65
Sika901	y = 0.000682x + 0.033787	0.92	3.94
Calcium Nitrate	y = 0.000706x + 0.024626	0.94	3.84
Sika903	y = 0.001543x + 0.039960	0.98	1.73
Cortec	y = 0.001157x + 0.044845	0.91	2.29
Rheocrete	y = 0.000827x + 0.017268	0.911	3.30

Table 4.43 shows the extension in service life (%) of reinforced concrete structure due to the use of inhibitors. There is almost 3 to 130% extension in the service life due to the use of inhibitors.

Table 4.43 Extension in Service Life of Concrete with 1.5% Chloride.

Inhibitor Type	Extension in Service Life (%)
Cemetec	2.30
Conplast	52.30
Sika901	126.44
Calcium Nitrate	120.69
Sika903	-0.57
Cortec	31.61
Rheocrete	89.66

Sika903 has almost no positive effect to minimize reinforcement corrosion with the increase in the percentage of chloride to 1.5%. However, Sika901, Calcium Nitrate and Rheocrete were effective in delaying reinforcement corrosion. Their effect in retarding anodic reaction was advantageous with this percentage of chloride contamination. They extended the service life of the structure by about 100% compared with the structure without inhibitors. Also, Conplast extended the service life by more than 50%, while Cortec increased the service life by more than 30%. Cemetec has a small effect in retarding reinforcement corrosion.

The time to cracking of concrete due to use of the inhibitors for each chloride percentage is summarized in Table 4.44.

Table 4.44 Time to Cracking of Concrete with inhibitors and Chloride Contamination.

Chloride Concentration (%)	**Time to Cracking of Concrete (Years)**							
	Control	Cemetec	Conplast	Sika901	Calcium Nitrate	Sika903	Cortec	Rheocrete
0.2	3.044	5.803	3.478	4.506	6.503	4.939	5.792	3.481
0.4	2.856	5.586	3.203	4.514	6.419	2.908	4.492	3.408
0.8	2.6	2.792	3.347	4.247	4.364	2.822	3.472	3.497
1.5	1.736	1.778	2.653	3.936	3.839	1.728	2.294	3.3

From the results tabulated above (Table 4.44), it can be observed that the time to cracking of concrete decreased with the increase in the chloride contamination for all the specimens because the increase of chloride contamination percentage raises corrosion activation.. However, the time to cracking of concrete in the specimens with inhibitors was more than that in the control specimens. This confirms the efficiency of inhibitors in minimizing reinforcement corrosion. Calcium Nitrate was generally the most effective inhibitor in all the chloride contamination percentages. Sika901 was also very effective in chloride contamination of 1.5%. The effectiveness of Rheocrete and Sika901 does not change too much with the increase of chloride contamination as compared with the effectiveness of other inhibitors.

4.3 Accelerated Corrosion Test Results

In this test, twelve beam specimens, two specimens with each inhibitor, were subjected to the accelerated corrosion test by impressing a constant voltage of 1.5 volts for duration of 40 days.

For all beam specimens, the values of current passing in the accelerated corrosion circuitry as a result of the applied voltage, were recorded every two hours for a period of 40 days, and are typically plotted in Figures 4.22 through 4.31. Table 4.45 shows the time to cracking of concrete specimens determined from the time-current plots and by visual inspection.

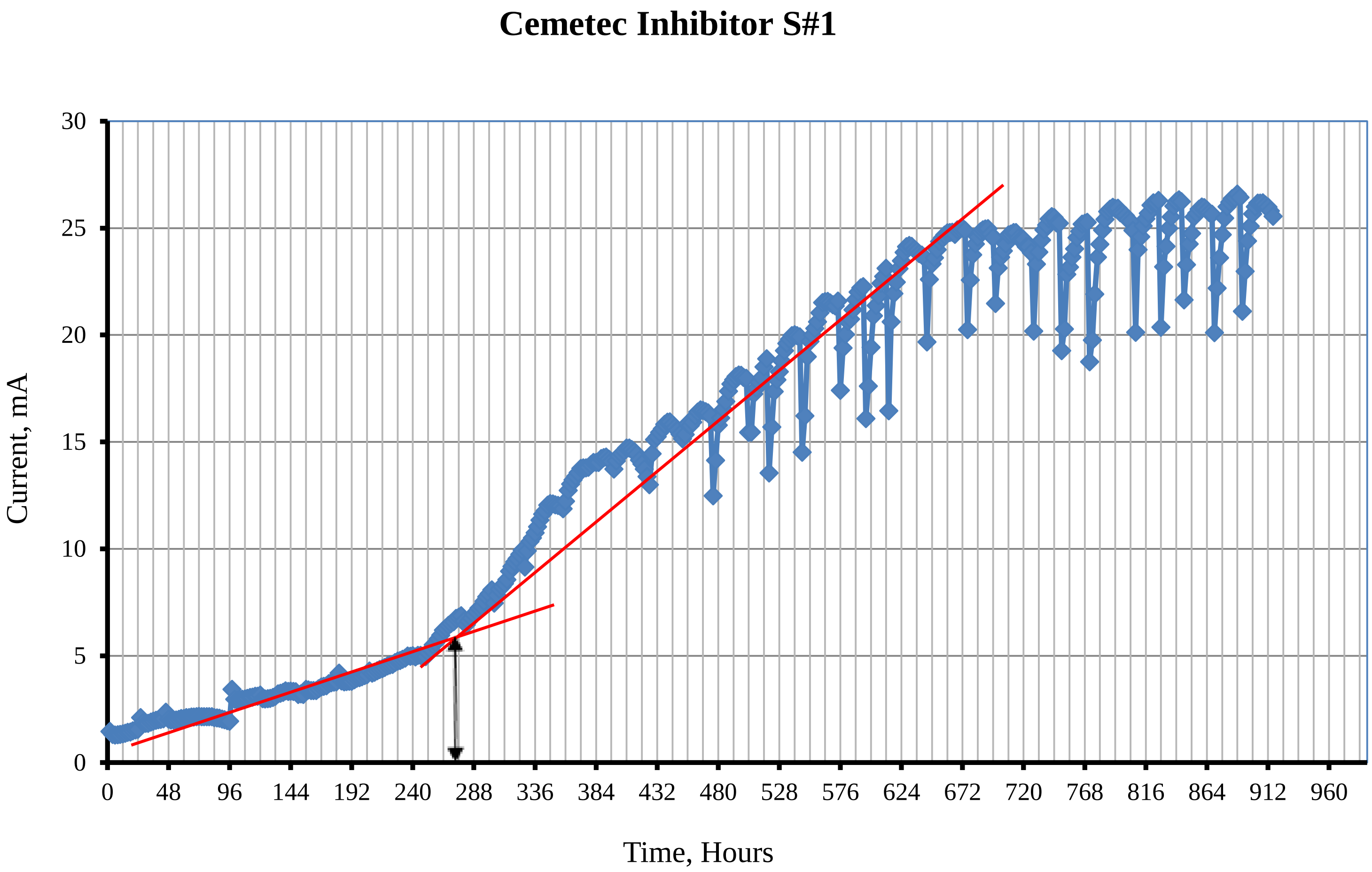


Figure 4.22 Current versus Time Plot for Specimen with Cemetec Inhibitor (Specimen #1).

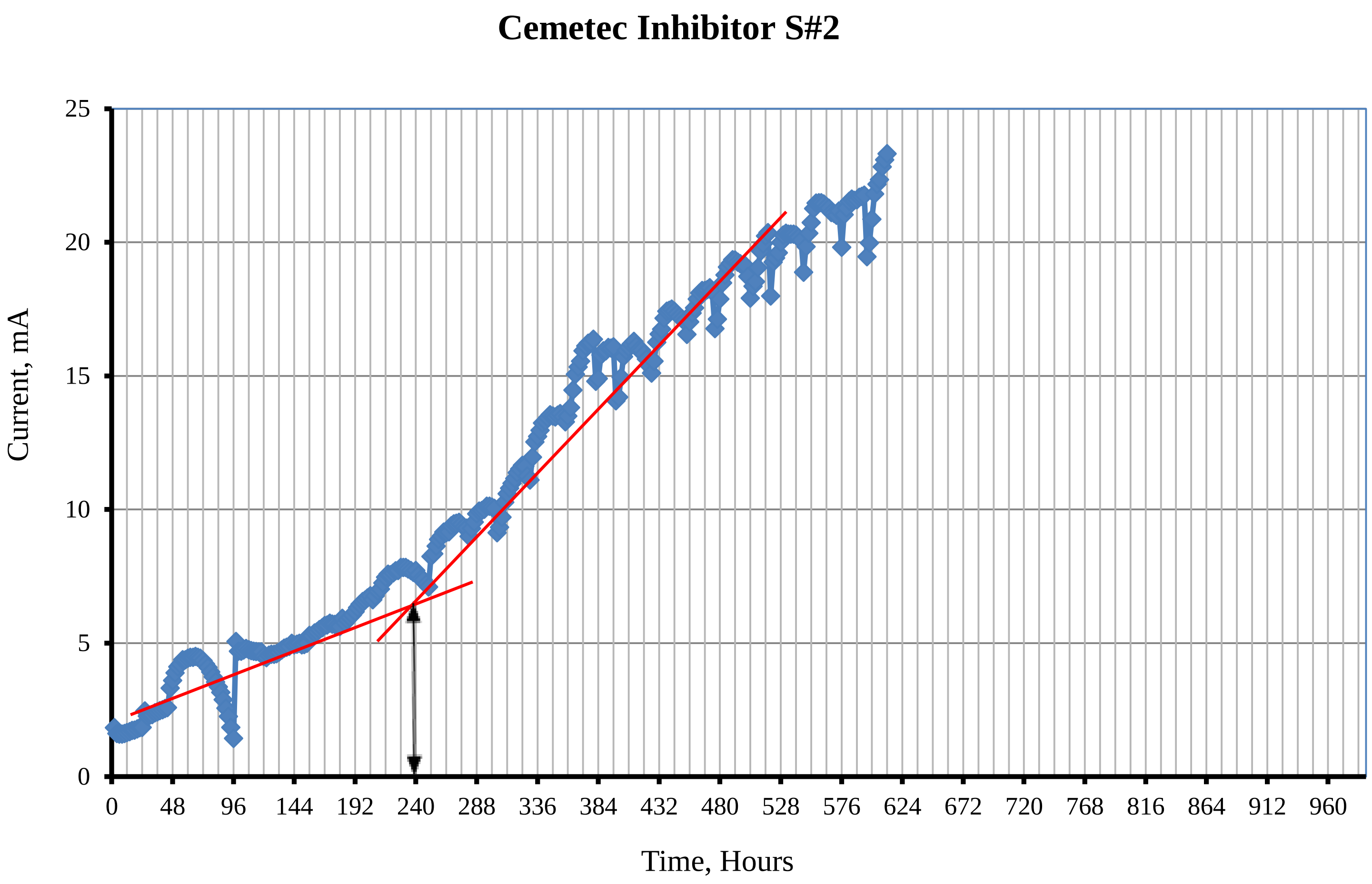


Figure 4.23 Current versus Time Plot for Specimen with Cemetec Inhibitor (Specimen #2).

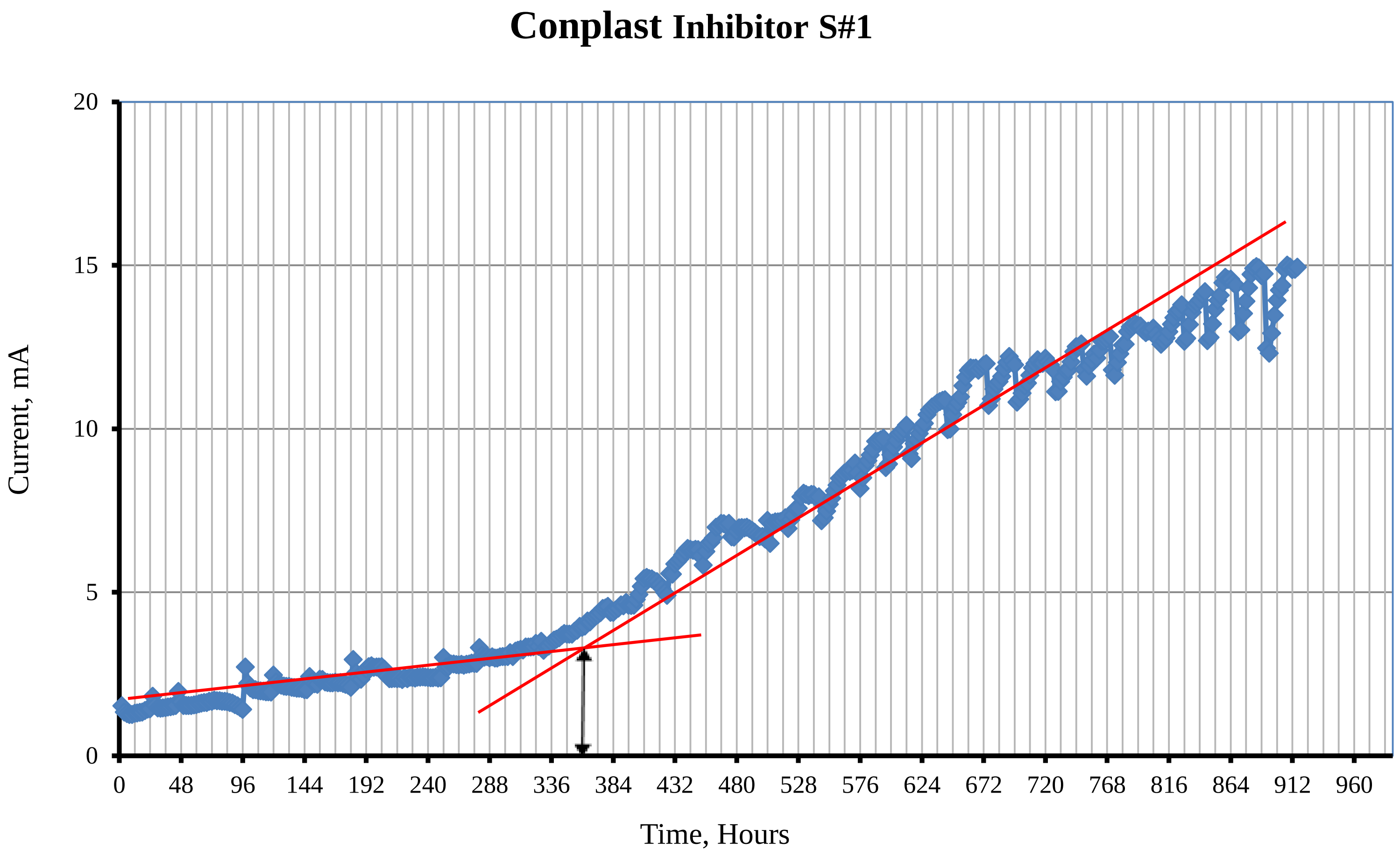


Figure 4.24 Current versus Time Plot for Specimen with Conplast Inhibitor (Specimen #1).

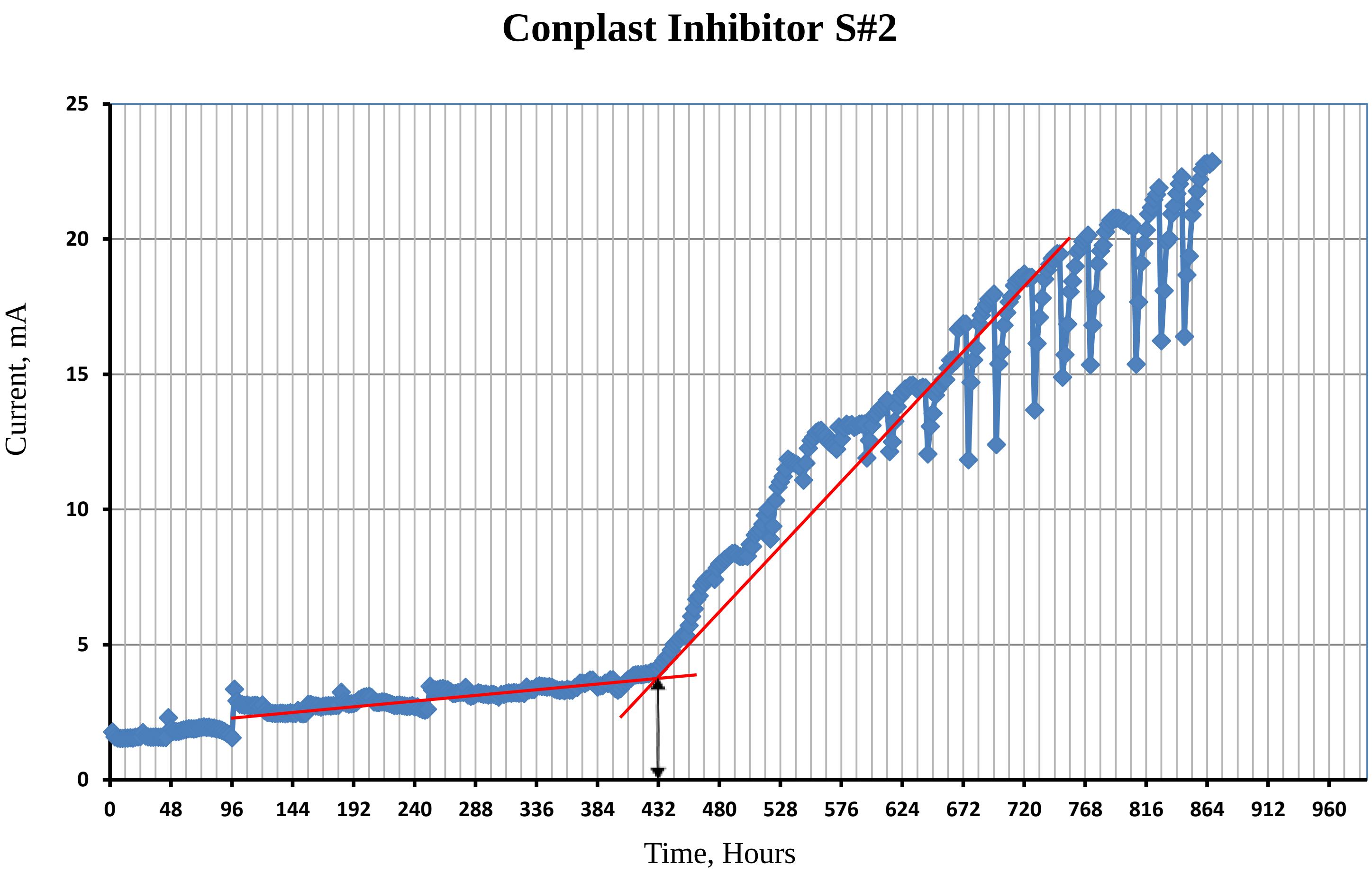


Figure 4.25 Current versus Time Plot for Specimen with Conplast Inhibitor (Specimen #2).

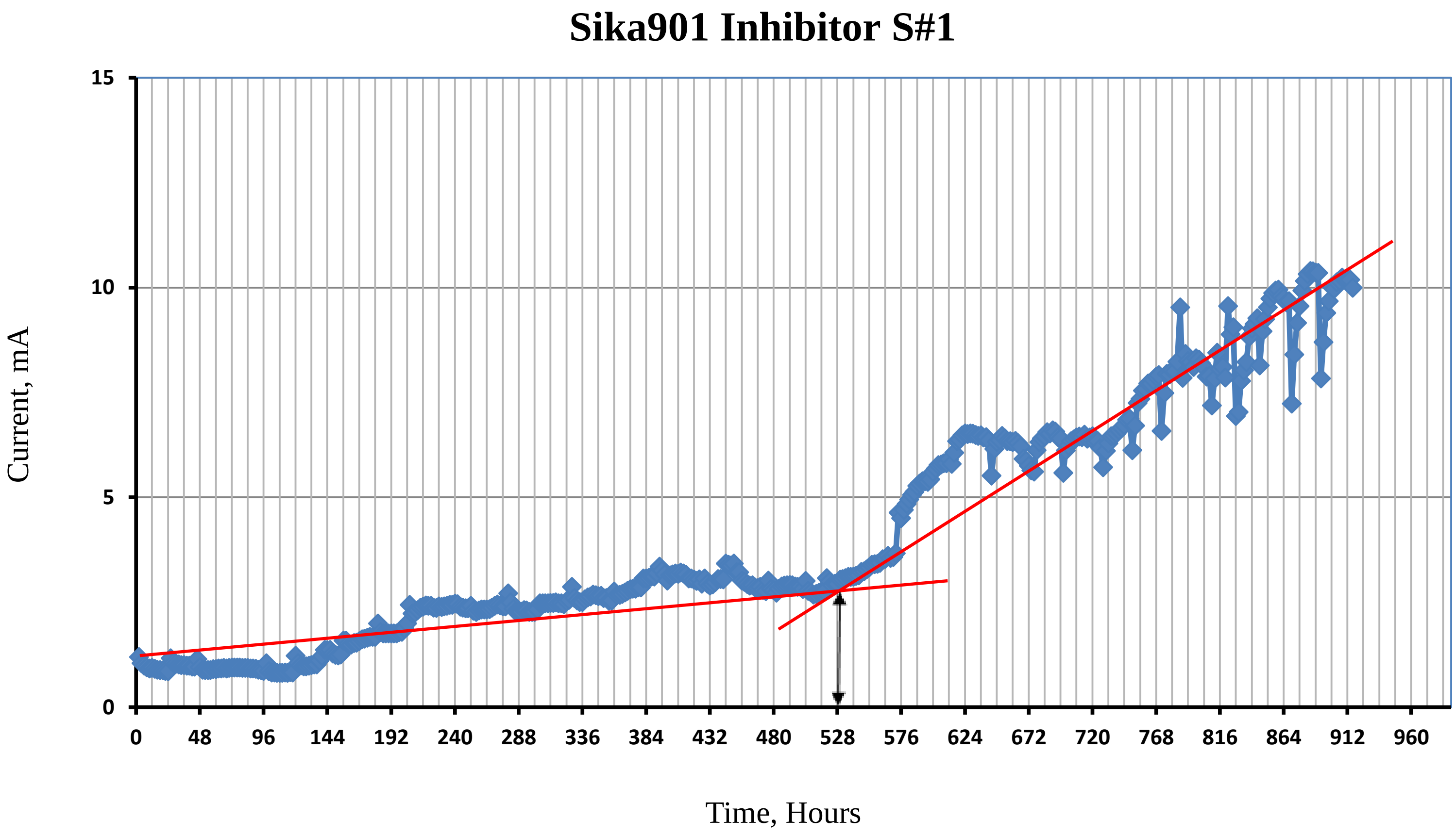


Figure 4.26 Current versus Time Plot for Specimen with Sika901 Inhibitor (Specimen #1)

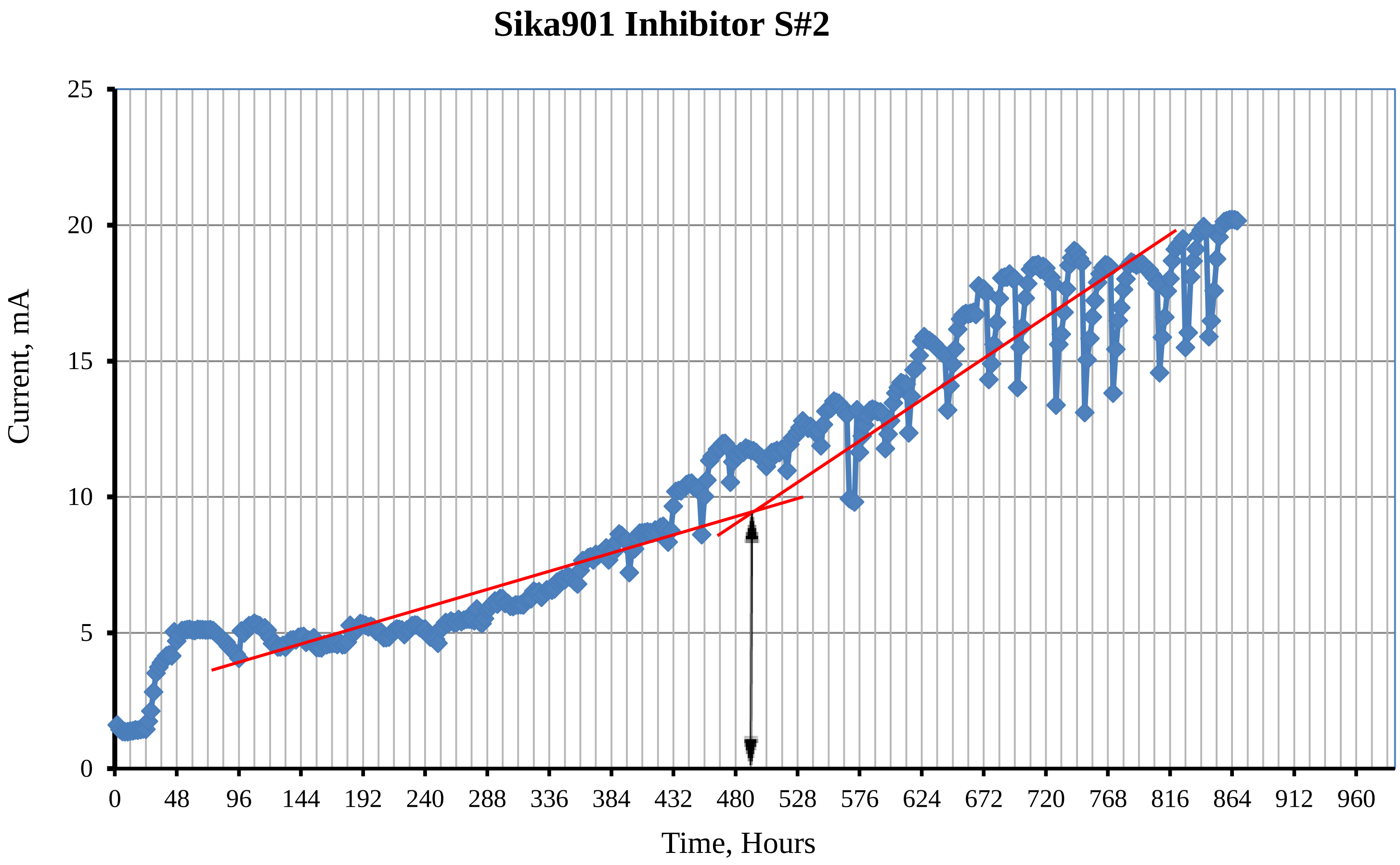


Figure 4.27 Current versus Time Plot for Specimen with Sika901 Inhibitor (Specimen #2).

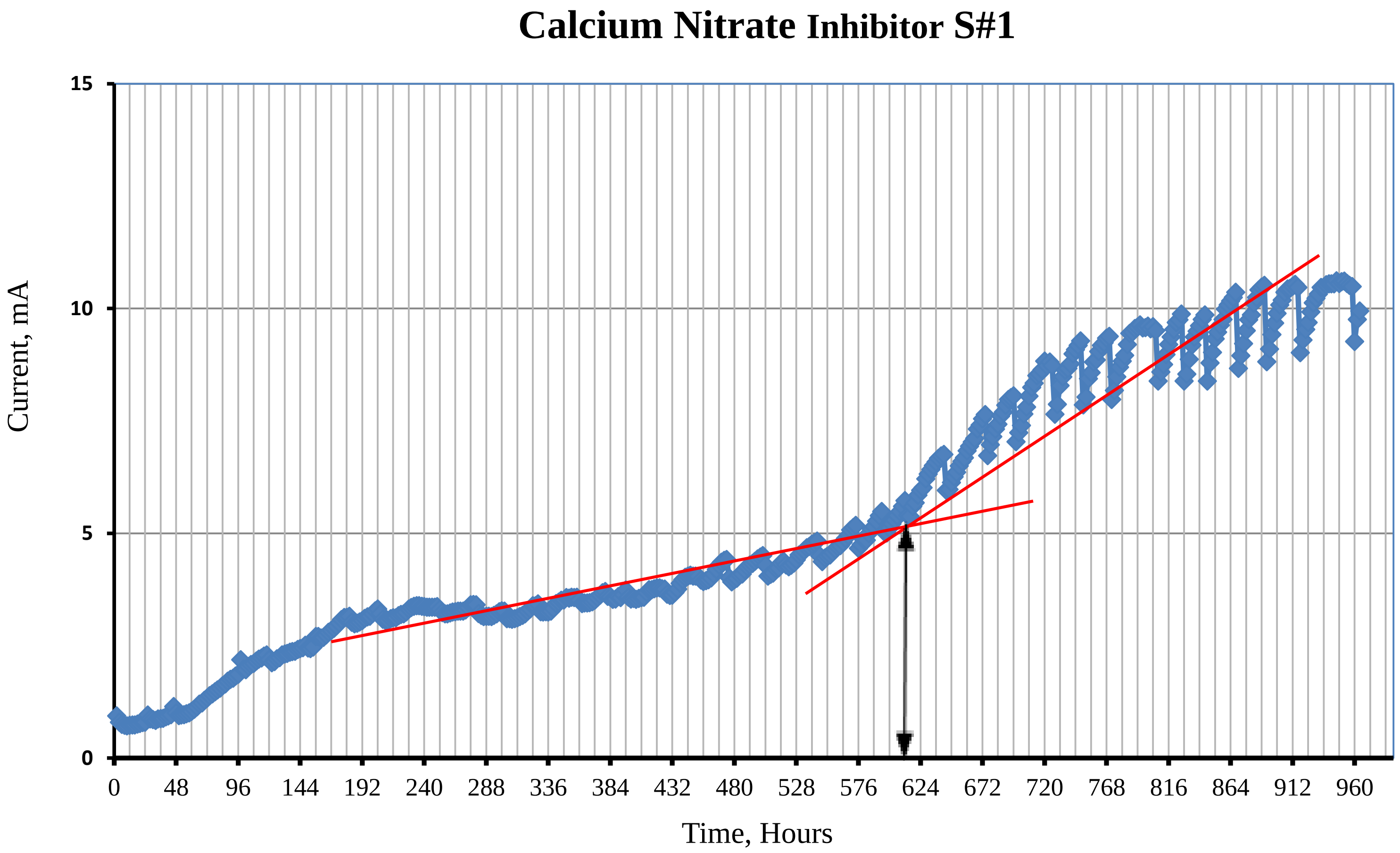


Figure 4.28 Current versus Time Plot for Specimen with Calcium Nitrate Inhibitor (Specimen #1).

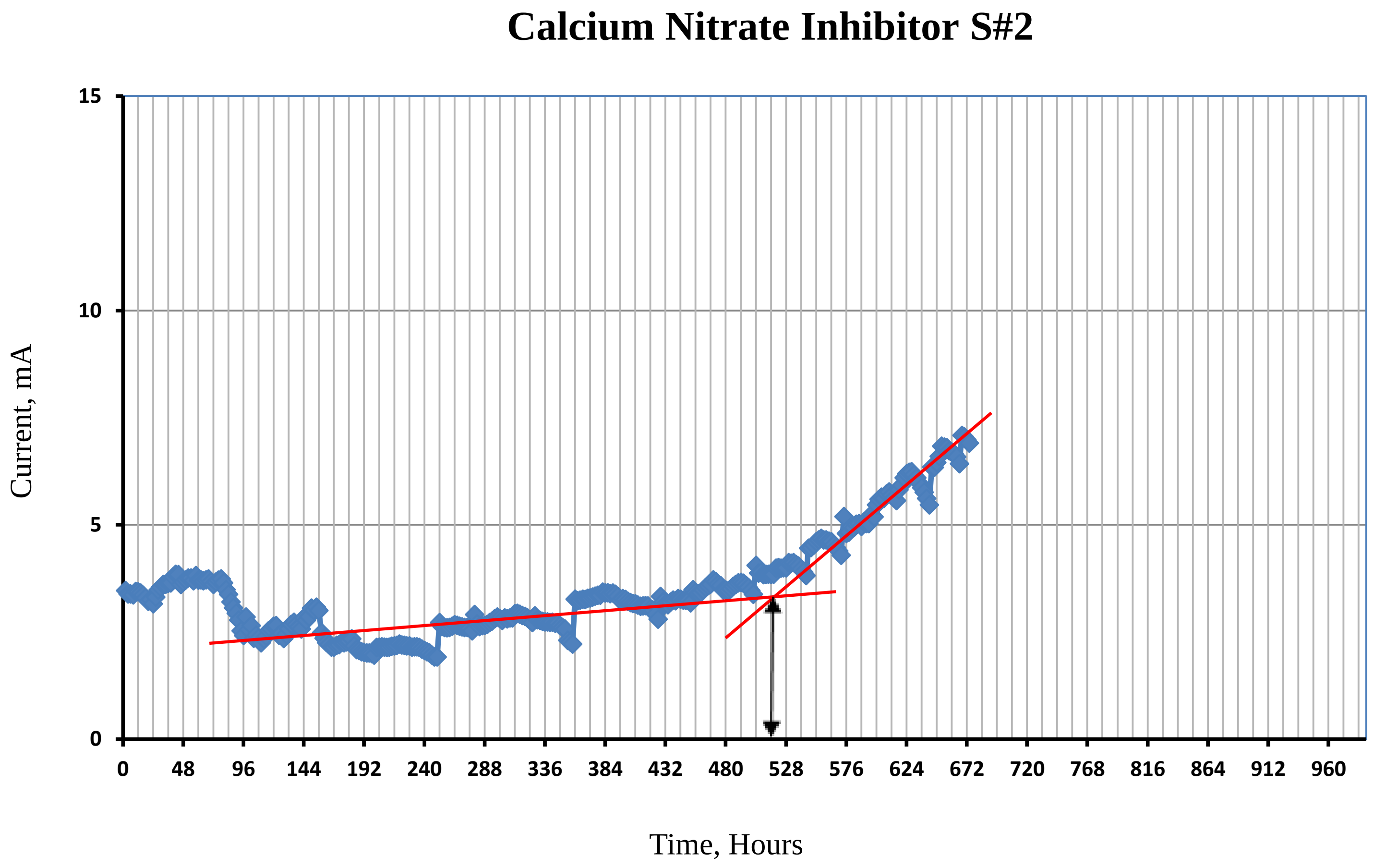


Figure 4.29 Current versus Time Plot for Specimen with Calcium Nitrate Inhibitor (Specimen #2).

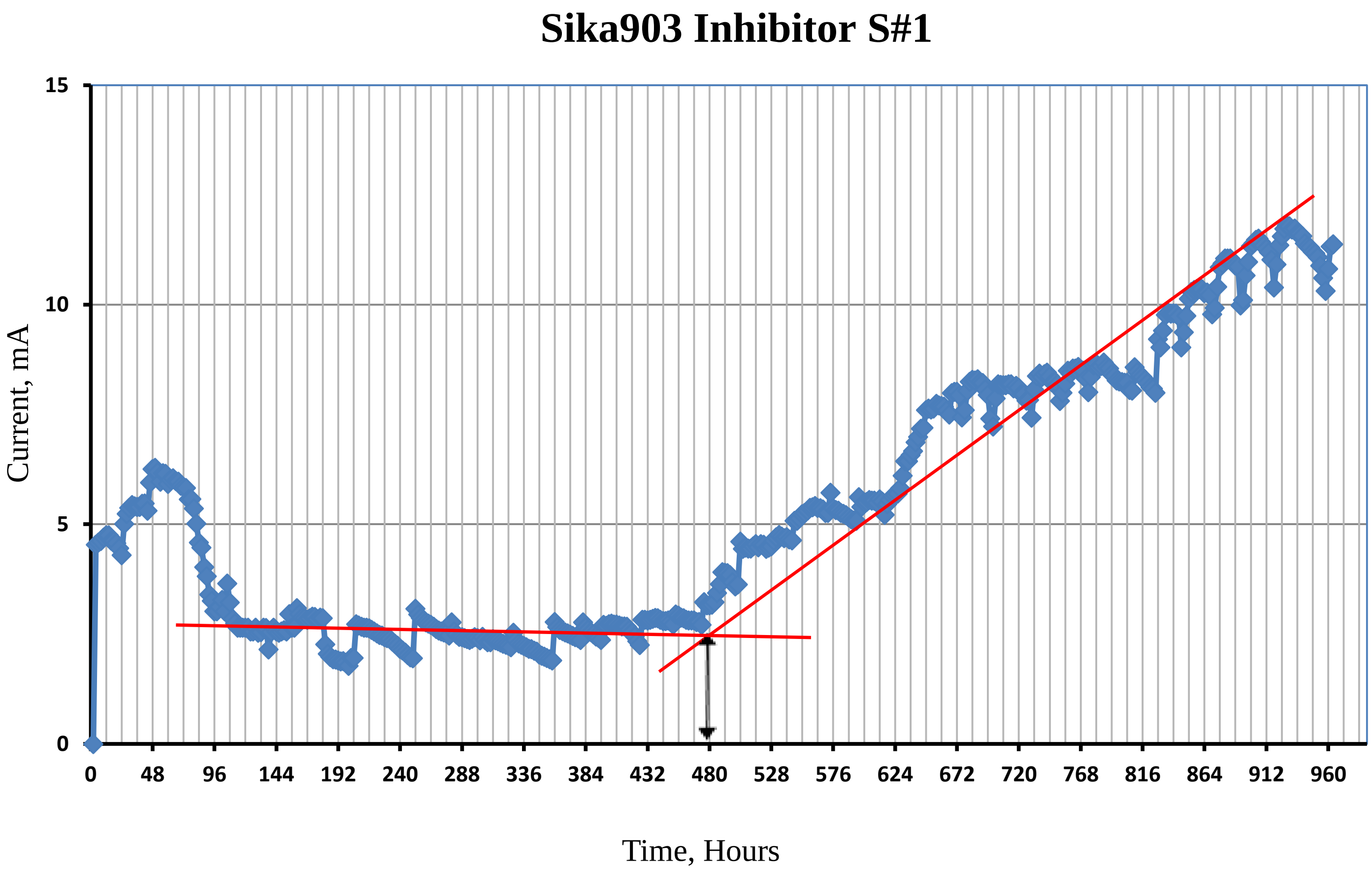


Figure 4.30 Current versus Time Plot for Specimen with Sika903 Inhibitor (Specimen #1).

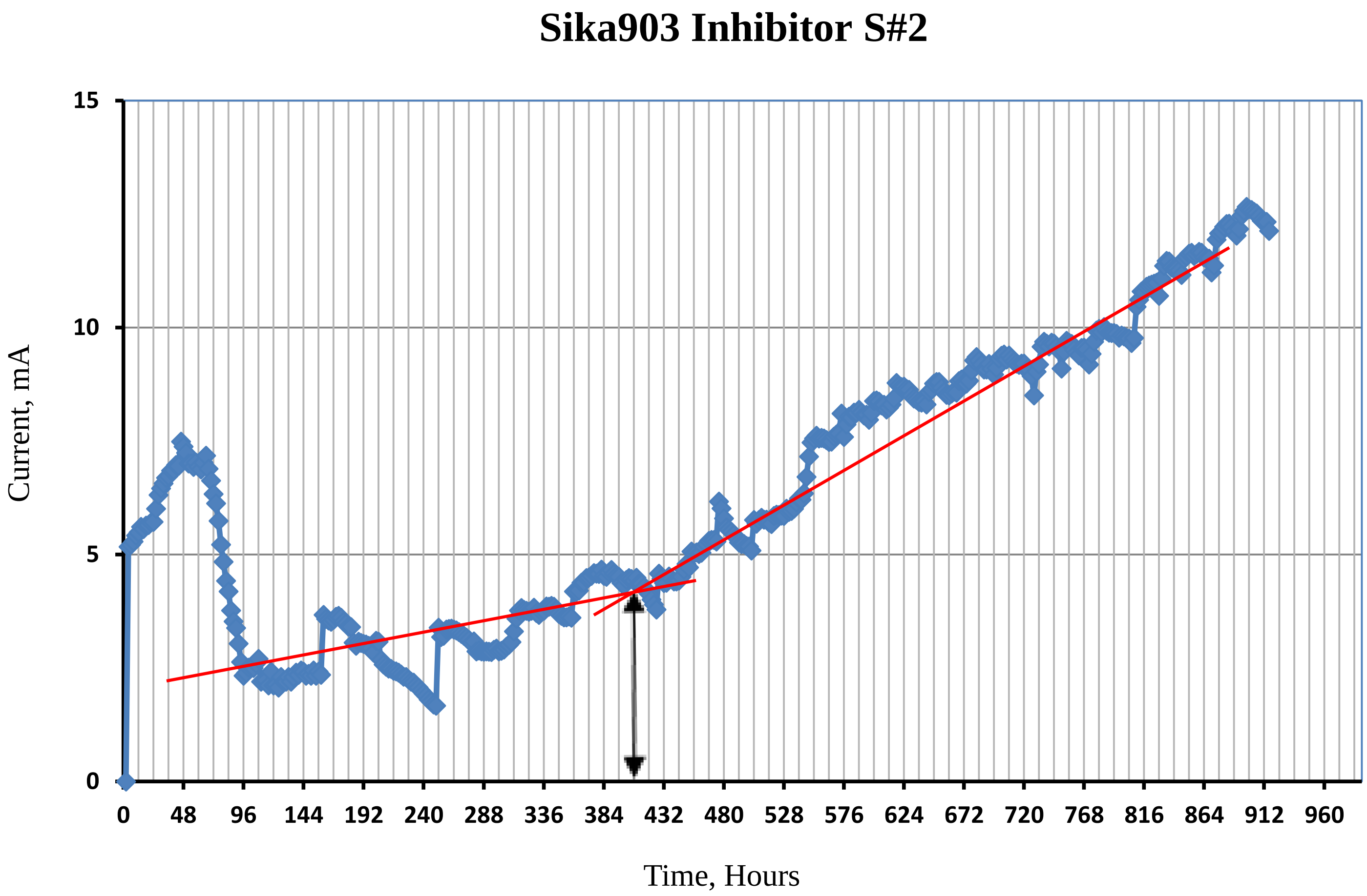


Figure 4.31 Current versus Time Plot for Specimen with Sika903 Inhibitor (Specimen #2).

Table 4.45 Time to Cracking of Concrete Specimens

Inhibitor	**Specimen**	**From Graphs**		**Visual Inspection**	
		Time (Hours)	**Average Time (Hours)**	**Time (Hours)**	**Average Time (Hours)**
Control	1	240*	240*	240	240
	2	240*		240	
Cemetec	1	276	258	288	264
	2	240		240	
Conplast	1	360	396	360	408
	2	432		456	
Sika901	1	528	510	552	528
	2	492		504	
Calcium Nitrate	1	612	564	624	576
	2	516		528	
Sika903	1	480	444	504	468
	2	408		432	

*Data from visual inspection was taken since measurements could not be conducted due to errors with the data logger.

The time to cracking of concrete specimens was determined for each specimen from the time-current plots. It represents the intersection point between tangents for current-time curve [56], as shown in Figures 4.22 through 4.31. Moreover, the time to cracking of concrete was determined by visual inspection every day. Table 4.45 presents a comparison between the results for time to cracking of concrete specimens from graphs and visual inspection. It could be noted that there is no big difference between the results from graphs and visual inspection though the results of the latter were always marginally more than those of the former. Time to cracking of concrete specimens with inhibitors was more than that in the control specimens. This proves the efficiency of all corrosion inhibitors in delaying reinforcement corrosion. The effectiveness of the inhibitors to minimize corrosion of steel in reinforced concrete is ranked from highest to lowest as follows: Calcium Nitrate, Sika901, Sika903, Conplast, Cemetec. However, it should be noted that the time to cracking of concrete specimens with Cemetec inhibitor was marginally more than the control concrete specimens because its inefficiency in such exposure condition. The average time to cracking in the control specimens was 240 hours, while it was 264 hours in the concrete specimens with Cemetec inhibitor.

The time to cracking of concrete is related to the resistivity of concrete [55]. Thus, the increase in the time to cracking of concrete with the addition of inhibitors indicates that the inhibitors increase the resistivity of concrete. The maximum resistivity was noted in the concrete specimens prepared with Calcium Nitrate. The time to cracking of concrete specimens prepared with Cemetec was slightly more than that in the control specimens. This indicates that this inhibitor does not increase the electrical resistivity of concrete. However, the decrease in the corrosion activity noted by I_{corr} measurements may be due to its anodic inhibition.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study was conducted to assess the effectiveness of seven inhibitors in minimizing reinforcement corrosion and to calculate the extension in service-life of structure by using these inhibitors. Sixty reinforced concrete beam specimens were prepared and were exposed to five commonly occurring zones. Twelve reinforced concrete beam specimens were cast and subjected to accelerated corrosion. One hundred and thirty two cylindrical concrete specimens were prepared and were exposed to tidal zone. Based on the results developed in this investigation, the following conclusions could be drawn:

1. Corrosion potentials in the specimens with most of corrosion inhibitors were less negative than those in the control specimens. Therefore, these corrosion inhibitors were effective in delaying the time to initiation of corrosion.
2. Time to cracking of concrete was more in the specimens with corrosion inhibitors than that in the control specimens under accelerated corrosion test.
3. Corrosion inhibitors can be used to delay reinforcement corrosion and to increase the service life of structure. The ranking for the effectiveness of these inhibitors according to economy and the extension in service life of structures in each zone are tabulated below:

a. Atmospheric Zone

Inhibitor	**Rank**	**Extension in Service Life (%)**
Calcium Nitrate	1	609.2
Sika 903	2	225.8
Sika 901	3	131.8
Conplast	4	33.1
Cemetec	5	23.2

b. Tidal Zone

Inhibitor	**Rank**	**Extension in Service Life (%)**
Calcium Nitrate	1	106.1
Conplast	2	48.4
Sika 901	3	46.4
Sika 903	4	35.83
Cemetec	5	27.74

c. Below ground Zone .

Inhibitor	Rank	Extension in Service Life (%)
Calcium Nitrate	1	248.37
Sika 903	2	149.08

d. Capillary Zone

Inhibitor	Rank	Extension in Service Life (%)
Calcium Nitrate	1	1236.78
Sika 901	2	64.11
Sika 903	3	34.41
Conplast	4	16.78

e. Submerged Zone

Inhibitor	Rank	Extension in Service Life (%)
Conplast	1	85.57
Calcium Nitrate	2	61.24
Cemetec	3	38.26

The severity of any zone depends on the presence of chloride ions, oxygen and moisture. The severity of the investigated zones was ranked from lowest to highest as follows: submerged (least sever), atmospheric, below ground, capillary and tidal zone (most sever). The absence of oxygen in the submerged zone makes it the least severe than other zones. The tidal zone was the most sever zone because oxygen and moisture were available.

- For concrete exposed to wet and dry cycles with 5% NaCl seawater.

Inhibitor	**Rank**	**Extension in Service Life (%)**
Calcium Nitrate	1	395.85
Cemetec	2	67.35
Sika903	3	57.6
Conplast	4	50.37
Sika901	5	45.79

- For chloride-contaminated concrete.

  - 0.2% Chloride Content

Inhibitor	**Rank**	**Extension in Service Life (%)**
Calcium Nitrate	1	113.63
Cemetec	2	90.64
Cortec	3	90.28
Sika903	4	62.25
Sika901	5	48.03
Rheocrete	6	14.36
Conplast	7	14.26

- 0.4% Chloride Content

Inhibitor	Rank	Extension in Service Life (%)
Calcium Nitrate	1	124.75
Cemetec	2	95.59
Sika901	3	58.05
Cortec	4	57.28
Rheocrete	5	19.33
Conplast	6	12.15
Sika903	7	1.82

- 0.8% Chloride Content

Inhibitor	Rank	Extension in Service Life (%)
Calcium Nitrate	1	67.85
Sika901	2	63.34
Rheocrete	3	34.5
Cortec	4	33.54
Conplast	5	28.73
Sika903	6	8.54
Cemetec	7	7.38

- 1.5% Chloride Content

Inhibitor	**Rank**	**Extension in Service Life (%)**
Sika901	1	126.73
Calcium Nitrate	2	121.14
Rheocrete	3	90.09
Conplast	4	52.82
Cortec	5	32.14
Cemetec	6	2.36

Calcium Nitrate was generally the most effective inhibitor in all the chloride contamination percentages. Sika901 was also very effective in chloride contamination of 1.5%. The time to cracking of concrete decreased with the increase in the chloride contamination. The effectiveness of Rheocrete and Sika901 does not change too much with the increase of chloride contamination as compared with the effectiveness of other inhibitors.

4. Accelerated corrosion test results for beam concrete specimens showed the efficiency of inhibitors in delaying cracking of concrete and the increase in service-life of structure. The ranking for the effectiveness of these inhibitors and the extension in service life of structures are tabulated below:

Inhibitor	**Rank**	**Extension in Service Life (%)**
Calcium Nitrate	1	140
Sika901	2	120
Sika903	3	95
Conplast	4	70
Cemetec	5	2.5

The addition of inhibitor increased the resistivity of concrete and, thus, decreased the rate of reinforcement corrosion. Cemetec was the least in decreasing the resistivity. Its performance in decreasing reinforcement corrosion could, therefore, be attributed to anodic protection rather than due to a decrease in the resistivity.

5.2 Recommendations

1. Calcium Nitrate was the most effective inhibitor in minimizing reinforcement corrosion and extended the service-life of structure. It is highly recommended to be used in aggressive environments.
2. Recommended inhibitors for the various zones investigated are summarized below:

Zone	**Recommended Inhibitor**		
	1	2	3
Atmospheric	Calcium Nitrate	Sika 903	Sika 901
Tidal	Calcium Nitrate	Conplast	Sika 901
Below ground	Calcium Nitrate	Sika 903	-
Capillary	Calcium Nitrate	Sika 901	Sika 903
Submerged	Conplast	Calcium Nitrate	Cemetec

3. Recommended inhibitors for the concrete contaminated with chloride are summarized below:

Chloride Concentration (%)	**Recommended Inhibitor**		
	1	2	3
0.2	Calcium Nitrate	Cemetec	Cortec
0.4	Calcium Nitrate	Cemetec	Sika901
0.8	Calcium Nitrate	Sika901	Rheocrete
1.5	Sika901	Calcium Nitrate	Rheocrete

References

[1] Maslehuddin, M., Rasheeduzzafar, Page, C. L. Al-Mana, A. I., "Influence of Some Parameters Relevant to Arabian Gulf Environment on Reinforcement Corrosion," *Arabian Journal for Science and Engineering:* Theme Issue on Corrosion and its Prevention, April 1995, Vol. 20, pp. 239-257.

[2] Maslehuddin, M., Saricimen, H., Al-Mana, A. I., and Shamim, M., "Performance of Concrete in A High Chloride-Sulfate Environment," *American Concrete Institute, Special Publication SP-122*, 1990, Vol. 122, pp. 469-494.

[3] Saricimen, H., Al-Tayyib, A. J., Maslehuddin, M., Shamim, M., "Concrete Deterioration in High Chloride-Sulfate Environment and Repair Strategies," *American Concrete Institute, Special Publication,* 1991, Vol. 128, pp. 19-34.

[4] Ramachandran, V.S. (1984). *Concrete Admixtures Handbook: Properties, Science and Technology,* Noyes Publications, Park Ridge, New Jersey.

[5] Zoltanetzky J.R., C. Gordon, and J. Parnes (1990). "New Developments in Corrosion Inhibiting Admixture Systems for Reinforced Concrete". In: Page CL, Treadaway KWJ, Bamforth PB, editors. *Corrosion of Reinforcement in Concrete*. London: Elsevier Applied Science; pp. 825 – 850.

[6] Treadaway, KWJ. and A. D. Russel, (1968). "The inhibition of the Corrosion of Steel in Concrete", *Transportation Research Board,* Highways and Public Works, Vol. 36, No. 19, pp. 40-41.

[7] Craig, R.J. and L.E. Wood (1970). "Effectiveness of Corrosion Inhibitors and Their Influence on the Physical Properties of Portland Cement Mortars". *Highway Research Board*, No. 328, pp. 77-78.

[8] Gouda V.K. and W.Y. Halaka (1970). "Corrosion and Corrosion Inhibition of Reinforced Steel Embedded in Concrete". *British Corrosion Journal*, Vol. 5, No. 5 pp. 204–208.

[9] Gaidis, JM. (2004). "Chemistry of Corrosion Inhibitors", *Cement & Concrete Composites,* Vol. 26, No. 3, pp. 181-190.

[10] Griffin, D.F. (1975). "Corrosion Inhibitors for Reinforced Concrete", *ACI Special Publication SP-49,* American Concrete Institute, Detroit, pp. 95-102.

[11] El-Jazairi, B., N.S. Berke, and W.R. Grace (1990). " The Use of Calcium Nitrate as a Corrosion Inhibiting Admixture to Steel Reinforcement in Concrete", *Corrosion*

of Reinforcement in Concrete, Elsevier Applied Science, London, 1990. pp. 571-585.

[12] Montes, P.T.W. Bremner, and D.H. Lister (2004). "Influence of Calcium Nitrate Inhibitor and Crack Width on Corrosion of Steel in High Performance Concrete Subjected to a Simulated Marine Environment", *Cement & Concrete Composites*, Vol. 26, No. 3, pp. 243-254.

[13] Berke, N.S. and M.C. Hicks (2004). "Predicting Long-term Durability of Steel Reinforced Concrete with Calcium Nitrate Corrosion Inhibitor", *Cement & Concrete Composites*. Vol. 26, No. 3, pp. 191-198.

[14] Justnes, H. and E.C. Hygaard (1994). "The Influence of Technical Grade Calcium Nitrate Additions on the Chloride Binding Capacity of Cement and the Rate of Chloride Induced Reinforcement Corrosion of Steel Embedded in Mortars", *Corrosion and Corrosion Protection of Steel in Concrete*, Swamy, R.N. Ed., Vol. 1, pp. 491-502.

[15] Maeder, U.A. (1989). "A New Class of Corrosion Inhibitors", *Proceedings, 3rd International Conference on Deterioration and Repair of Reinforced Concrete in the Arabian Gulf*, Bahrain, Vol. 1, pp. 119-133.

[16] Nmai, C.K. (2004). "Multi-functional Organic Corrosion Inhibitor". *Cement & Concrete Composites,* Vol. 26, No. 3, pp. 199-208.

[17] Wombacher, F.U., U. Maeder and B. Marazzani (2004). "Aminoalchohol Based Mixed Corrosion Inhibitors", *Cement & Concrete Composites*. Vol. 26, No. 3, pp. 209-216.

[18] Jamil, A., A. Shriri, A.R. Boulif, M.F. Montemor and M.G.S. Ferreira (2005). "Corrosion Behavior of Reinforcing Steel Exposed to an Aminoalcohol Based Corrosion Inhibitor", *Cement & Concrete Composites,* Vol. 27, pp. 671–678.

[19] Scott, A., A. Civjan, J.M. Lafave, T. Joanna, D. Lovett, L. Jose, and D.W. Pfeifer (2005). "Effectiveness of Corrosion Inhibiting Admixture Combinations in Structural Concrete", *Cement & Concrete Composites*, Vol. 27, pp. 688–703.

[20] Qian, S. and D. Cusson (2004). "Electrochemical Evaluation of the Performance of Corrosion-inhibiting Systems in Concrete Bridges", *Cement & Concrete Composites,* Vol. 26, pp. 217–233.

[21] Berke, N.S., F. Gianetti, P.G. Tourney, and Z.G. Matta (1993). "The Use of Calcium Nitrate Corrosion Inhibitor to Improve the Durability of Reinforced Concrete in the Arabian Gulf", *Proceedings, 4th International Conference on*

Deterioration and Repair of Reinforced Concrete in the Arabian Gulf, Bahrain, pp. 873-885.

[22] Matta, R.G. and N.S. Berke. (1994). "The Use of Calcium Nitrate Corrosion Inhibiting Admixture to Extend the Life of Reinforced Concrete in the Arabian Gulf", *Proceedings, 1st International Conference on Reinforced Concrete Materials in Hot Climates*. United Arab Emirates, pp. 24-27.

[23] Al-Amoudi, O.S.B., M. Maslehuddin, A.N. Lashari, and A.A. Almusallam, AA. (2003). "Effectiveness of Corrosion Inhibitors in Contaminated Concrete", *Cement & Concrete Composites.* Vol. 25, i. 4-5, pp. 439-450.

[24] Malik, A.U., F. Andijani, F. Al-Moali and G. Ozair (2004). "Studies on the Performance of Migratory Corrosion Inhibitors in Protection of Rebar Concrete in Gulf Seawater Environment". *Cement & Concrete Composites*. Vol. 26, No. 3, pp. 243-252.

[25] Al-Mehthel, M., Al-Dulaijan, S. U., Al-Idi, S.H., Shameem, M., Ali, M.R. and Maslehuddin, M. (2009). "Performance of Generic and Proprietary Corrosion Inhibitors in Chloride-contaminated Silica Fume Cement Concrete". *Construction and Building Materials*, 23, pp. 1768-1774.

[26] Pereira, E.V., Figueira, R.B., Salta, M.M., and Fonseca, I.T.E., "Long-term Efficiency of Two Organic Corrosion Inhibitors for Reinforced Concrete," *Materials Science Forum*, Vol. 636-637, 2010, pp.1059-1064.

[27] Ormellese, M., Lazzari, L., Goidanich, S., Fumagalli, G., Brenna, A. (2009), "A Study of Organic Substances as Inhibitors for Chloride-induced Corrosion in Concrete," Dipartimento di Chimica, Materiali e Ingegneria Chimica G. Natta, - Politecnico di Milano, Via Mancinelli, 7, Milan, Italy.

[28] Mennucci, M. M., Banczek, E.P., Rodrigues, P.R.P, Costa, I., "Evaluation of Benzotriazole as Corrosion Inhibitor for Carbon Steel in Simulated Pore Solution", *Cement and Concrete Composites*, Vol.31, Issue 6, July 2009, pp. 418-424.

[29] Nguyen, T.A., Shi, X., "A Mechanistic Study of Corrosion Inhibiting Admixtures," *Anti-Corrosion Methods and* Materials, Vol. 56, Issue 1, 2009, pp. 3-12.

[30] Song, H.W., Saraswathy, V., Muralidharan, S., Lee, C.H., Thangavel, K., "Role of Alkaline Nitrites in the Corrosion Performance of Steel in Composite Cements", *Journal of Applied Chemistry*, Vol. 39, Issue 1, January 2009, pp. 15-22.

[31] Benzina Mechmeche, L., Dhouibi, L., Ben Ouezzdou, M., Triki, E., Zucchi, F., "Investigation of the Early Effectiveness of an Amino-alcohol Based Corrosion

Inhibitor Using Simulated Pore Solutions and Mortar Specimens," *Cement and Concrete Composites*, Vol. 30, Issue 3, March 2008, pp. 167-173.

[32] Ann, K. Y. and Buenfeld, N. R., "The Effect of Calcium Nitrite on the Chloride-induced Corrosion of Steel in Concrete," *Magazine of Concrete Research*, Vol. 59, Issue 9, November 2007, pp. 689-697.

[33] ASTM C 876 (1996). *Standard Test Method for Half-cell Potentials of Uncoated Reinforcing Steel in Concrete*, Annual Book of ASTM Standards, Vol. 4.02, American Society for Testing and Materials, Philadelphia.

[34] Stern, M. and A. L. Geary (1957). A theoretical Analysis of the Slope of the Polarization Curves, *Journal of Electrochemical Society*, Vol. 104, pp. 56.

[35] ASTM G 1 (2003). *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*, Annual Book of ASTM Standards, Vol. 4.02, American Society for Testing and Materials, Philadelphia.

[36] Ahmad, Shamsad (2009). "Techniques for Inducing Accelerated Corrosion of Steel in Concrete". *The Arabian Journal for Science and Engineering*, Vol. 34, December No. 2C.

[37] Sika, (2012). "*Sika FerroGrad 901: Corrosion Inhibiting Admixture*," Product Data Sheet, Sika Corp.

[38] Sika, (2012). "*Sika FerroGrad 903: Penetrating, Corrosion Inhibiting, Impregnation Coating for Hardened Concrete*" Product Data Sheet, Sika Corp.

[39] RHEOCRETE, (2012). "*RHEOCRETE CNI: Corrosion Inhibiting Admixture,*" Product Data Sheet, BASF Chemical Company.

[40] Conplast, (2012). "*Conplast-CN: Corrosion Inhibiting Admixture* ," Product Data sheet, FOSROC Corp.

[41] Corec, (2012). "*Cortec MCI-2000: Corrosion Inhibiting Admixture*" Product Data Sheet, FOSROC Corp.

[42] CEMETEC, (2012) "CEMETEC-CCI-S: Corrosion Inhibiting Admixture," Product Data Sheet, CMCI Corp.

[43] ASTM G 109 -2007. *Standard Test Method for Determining Effect of Chemical Admixture on corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments.* Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia.

[44] ASTM C1152 / C1152 M-2012. *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete.* Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia.

[45] Al-Amoudi, O.S.B., M. Maslehuddin (1993). "The Effect of Chloride and Sulfate Ions on Reinforced Corrosion", Cement and Concrete Research. Vol.23, pp. 139-149. Printed in the USA.

[46] Robertson, I.N. and Newtson, C. (2009)." Performance of Corrosion Inhibitors in Concrete Exposed to Marine Environment". *Hawaii Department of Transportation,* pp. 901-906.

[47] Paredes, M.A. Cavallo, A.A, Kessler, R, Virmani, Y.O and Sagüés, A.A (2010). "Corrosion Inhibitors in Concrete Second Interim Report". *Florida Department of Transportation.* University of South Florida, pp. 2959-2968.

[48] Balaguru, P. (2001). "Evaluation of Corrosion Inhibitors". *New Jersey Department of Transportation*, Final Report, Piscataway, NJ 08854-8014, pp.127-136.

[49] Nakamura, E. (2008). "Half-Cell Potential Measurements to Assess Corrosion Risk of Reinforcement Steel". *International RILEM Conference*, Varenna (LC) Como Lake – Italy, pp. 1-9.

[50] Kitjapat."Effect of Steel Corrosion Level on Flexural Behavior of Rienforced Concrete", *Faculty of Engineering, Kasetsart University*, Bangkok, Thailand, fengkpp@ku.ac.th.

[51] NRMCA, (2000). "Concrete in Practice", Technical Information, www.nrmca.org.

[52] Srinivasan, Rengaswamy (1996). "Design of Cathodic Protection of Rebars in Concrete Structures: An Electrochemical Engineering Approach". *India, APL's Milton*, Vol.17, No.4, pp. 362-370.

[53] CAA (2012). "A dmixture Technical Sheet – ATS 9 Corrosion Inhibiting Admixtures". *West Midlands,*www.admixtures.org.uk.

[54] Montgomery, D.C. (2009). Design and Analysis of Experiments . , 7th ed. New York. Wiley.

[55] Hornbostel, Karla. (2003). "Relationship Between Concrete Resistivity and Corrosion Rate – A literature Review", *Cement & Concrete Composites*. Vol.39, pp. 60-72.

[56] Liu, Youping. (1996). Modeling the Time-to-Corrosion Cracking of the Cover Concrete in Chloride Contaminated Reinforced Concrete Structure, PHD Thesis. *Virginia Polytechnic Institute*, Blacksburg, Virginia.

APPENDIXES

APPENDIX A

Potentials for Beams (Atmospheric Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE12**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
25/02/2103	15	-84	-101	-17	-24	-20	-30	-22	-17	-93	-21	-25	-20	-39
13/03/2103	33	-86	-76	-111	-97	-21	-21	-24	-22	-81	-104	-21	-23	-57
30/03/2013	50	-81	-85	-89	-105	-85	-98	-95	-88	-83	-97	-92	-92	-91
15/04/2013	65	-137	-135	-122	-123	-81	-76	-86	-89	-136	-123	-79	-88	-106
30/04/2013	80	-140	-154	-126	-134	-110	-132	-120	-116	-147	-130	-121	-118	-129
14/05/2013	94	-95	-100	-32	-26	-68	-66	-263	-264	-98	-29	-67	-264	-114
01/06/2013	110	-142	-138	-128	-124	-114	-118	-131	-131	-140	-126	-116	-131	-128
15/06/2013	125	-183	-180	-160	-157	-137	-135	-112	-114	-182	-159	-136	-113	-147
30/06/2013	140	-175	-169	-154	-147	-141	-142	-144	-146	-172	-151	-142	-145	-152
25/07/2013	165	-221	-220	-115	-113	-105	-105	-121	-123	-221	-114	-105	-122	-140
12/08/2013	182	-205	-203	-198	-188	-212	-210	-179	-189	-204	-193	-211	-184	-198
22/08/2013	192	-214	-212	-279	-273	-250	-248	-254	-258	-213	-276	-249	-256	-249

Potentials for Beams (Atmospheric Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE12**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
25/02/2103	15	-18	-16	-25	-26	-21	-8	-23	-22	-17	-26	-15	-23	-20
13/03/2103	33	-33	-31	-32	-31	-58	-58	-78	-83	-32	-32	-58	-81	-51
30/03/2013	50	-15	-20	-21	-20	-28	-35	-20	-18	-18	-21	-32	-19	-22
15/04/2013	65	-98	-97	-81	-84	-113	-111	-76	-74	-98	-83	-112	-75	-92
30/04/2013	80	-102	-107	-118	-109	-86	-67	-69	-84	-105	-114	-77	-77	-93
14/05/2013	94	-117	-112	-108	-103	-121	-118	-112	-113	-115	-106	-120	-113	-113
01/06/2013	110	-131	-121	-104	-110	-131	-121	-113	-118	-126	-107	-126	-116	-119
15/06/2013	125	-124	-126	-101	-99	-148	-138	-88	-84	-125	-100	-143	-86	-114
30/06/2013	140	-105	-108	-127	-125	-201	-201	-104	-102	-107	-126	-201	-103	-134
25/07/2013	165	-116	-114	-113	-114	-232	-232	-19	-17	-115	-114	-232	-18	-120
12/08/2013	182	-138	-139	-122	-125	-222	-225	-115	-111	-139	-124	-224	-113	-150
22/08/2013	192	-150	-153	-134	-136	-273	-269	-148	-148	-152	-135	-271	-148	-176

Potentials for Beams (Atmospheric Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE												
		Specimen # 1				Specimen # 2				Average Potentials (mV)				
		WE1		WE2		WE1		WE2		WE11	WE12	WE21	WE22	WE11:WE22
		P#1	P#2	P#1	P#2	P#1	P#2	P#1	P#2					
25/02/2103	15	-36	-33	-44	-39	-21	-17	-22	-19	-35	-42	-19	-21	-29
13/03/2103	33	-48	-48	-87	-83	-83	-86	-89	-86	-48	-85	-85	-88	-76
30/03/2013	50	-38	-35	-52	-50	-32	-30	-30	-21	-37	-51	-31	-26	-36
15/04/2013	65	-109	-84	-103	-102	-104	-100	-95	-88	-97	-103	-102	-92	-98
30/04/2013	80	-83	-82	-96	-90	-120	-125	-115	-110	-83	-93	-123	-113	-103
14/05/2013	94	-113	-96	-122	-123	-132	-130	-122	-120	-105	-123	-131	-121	-120
01/06/2013	110	-88	-88	-117	-117	-114	-144	-99	-96	-88	-117	-129	-98	-108
15/06/2013	125	-98	-96	-179	-178	-137	-137	-102	-101	-97	-179	-137	-102	-129
30/06/2013	140	-107	-108	-200	-201	-130	-132	-184	-179	-108	-201	-131	-182	-155
25/07/2013	165	-84	-78	-25	-20	-178	-176	-139	-136	-81	-23	-177	-138	-105
12/08/2013	182	-217	-217	-257	-257	-168	-167	-209	-211	-217	-257	-168	-210	-213
22/08/2013	192	-227	-226	-293	-291	-184	-183	-223	-223	-227	-292	-184	-223	-231

Potentials for Beams (Atmospheric Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE1**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
25/02/2103	15	-37	-41	-20	-30	-28	-31	-31	-20	-39	-25	-30	-26	-30
13/03/2103	33	-55	-56	-70	-76	-86	-88	-68	-68	-56	-73	-87	-68	-71
30/03/2013	50	-86	-88	-35	-31	-50	-52	-50	-43	-87	-33	-51	-47	-54
15/04/2013	65	-84	-92	-98	-87	-109	-102	-108	-98	-88	-93	-106	-103	-97
30/04/2013	80	-106	-102	-107	-110	-105	-103	-110	-108	-104	-109	-104	-109	-106
14/05/2013	94	-124	-132	-127	-121	-133	-130	-132	-140	-128	-124	-132	-136	-130
01/06/2013	110	-122	-121	-118	-119	-132	-132	-121	-121	-122	-119	-132	-121	-123
15/06/2013	125	-124	-124	-125	-125	-128	-127	-126	-126	-124	-125	-128	-126	-126
30/06/2013	140	-114	-112	-119	-121	-123	-126	-122	-122	-113	-120	-125	-122	-120
25/07/2013	165	-122	-122	-132	-133	-106	-105	-93	-92	-122	-133	-106	-93	-113
12/08/2013	182	-188	-187	-169	-168	-214	-216	-192	-192	-188	-169	-215	-192	-191
22/08/2013	192	-202	-202	-188	-188	-252	-252	-206	-206	-202	-188	-252	-206	-212

Potentials for Beams (Atmospheric Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE1**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
25/02/2103	15	-11	-6	-8	-7	-34	-16	-30	-26	-9	-8	-25	-28	-17
13/03/2103	33	-92	-93	-105	-104	-68	-67	-78	-78	-93	-105	-68	-78	-86
30/03/2013	50	-22	-17	-127	-122	-45	-45	-45	-45	-20	-125	-45	-45	-59
15/04/2013	65	-64	-78	-67	-73	-93	-107	-118	-109	-71	-70	-100	-114	-89
30/04/2013	80	-98	-94	-93	-87	-107	-104	-110	-96	-96	-90	-106	-103	-99
14/05/2013	94	-104	-109	-109	-109	-115	-132	-125	-131	-107	-109	-124	-128	-117
01/06/2013	110	-116	-118	-103	-105	-117	-116	-127	-127	-117	-104	-117	-127	-116
15/06/2013	125	-132	-132	-113	-112	-128	-127	-131	-131	-132	-113	-128	-131	-126
30/06/2013	140	-125	-125	-89	-92	-118	-116	-120	-121	-125	-91	-117	-121	-113
25/07/2013	165	-85	-83	-90	-90	-125	-120	-125	-122	-84	-90	-123	-124	-105
12/08/2013	182	-196	-198	-143	-143	-198	-198	-188	-187	-197	-143	-198	-188	-181
22/08/2013	192	-212	-215	-163	-162	-218	-218	-222	-226	-214	-163	-218	-224	-205

Potentials for Beams (Atmospheric Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE1**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
25/02/2103	15	-20	-15	-16	-18	-32	-32	-12	-10	-18	-17	-32	-11	-19
13/03/2103	33	-115	-112	-117	-119	-81	-78	-15	-15	-114	-118	-80	-15	-82
30/03/2013	50	-92	-70	-92	-80	-80	-93	-80	-82	-81	-86	-87	-81	-84
15/04/2013	65	-101	-96	-124	-136	-68	-74	-86	-80	-99	-130	-71	-83	-96
30/04/2013	80	-112	-94	-105	-96	-94	-112	-108	-107	-103	-101	-103	-108	-104
14/05/2013	94	-150	-133	-226	-218	-30	-33	-27	-25	-142	-222	-32	-26	-105
01/06/2013	110	-122	-124	-109	-113	-109	-110	-100	-98	-123	-111	-110	-99	-111
15/06/2013	125	-131	-132	-124	-124	-112	-112	-108	-108	-132	-124	-112	-108	-119
30/06/2013	140	-118	-118	-118	-115	-109	-109	-91	-90	-118	-117	-109	-91	-109
25/07/2013	165	-130	-124	-166	-166	-111	-110	-138	-134	-127	-166	-111	-136	-135
12/08/2013	182	-218	-219	-205	-205	-204	-204	-143	-147	-219	-205	-204	-145	-193
22/08/2013	192	-250	-250	-227	-226	-224	-224	-159	-155	-250	-227	-224	-157	-214

Potentials for Beams (Tidal Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 11/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE12**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
26/02/2103	15	-218	-210	-246	-240	-209	-203	-282	-266	-214	-243	-206	-274	-234
16/03/2103	35	-245	-240	-262	-259	-293	-266	-288	-268	-243	-261	-280	-278	-265
01/04/2103	50	-303	-296	-293	-293	-318	-296	-334	-313	-300	-293	-307	-324	-306
16/04/2103	65	-446	-425	-411	-422	-403	-375	-441	-414	-436	-417	-389	-428	-417
01/05/2103	80	-457	-441	-457	-457	-450	-425	-522	-480	-449	-457	-438	-501	-461
15/05/2103	95	-426	-422	-407	-413	-450	-415	-523	-490	-424	-410	-433	-507	-443
30/05/2013	110	-478	-476	-460	-459	-473	-458	-527	-517	-477	-460	-466	-522	-481
16/06/2013	126	-524	-520	-498	-500	-511	-517	-537	-527	-522	-499	-514	-532	-517
02/07/2013	140	-514	-510	-481	-555	-572	-511	-521	-513	-512	-518	-542	-517	-522
25/07/2013	163	-566	-571	-581	-543	-544	-550	-552	-557	-569	-562	-547	-555	-558
12/08/2013	180	-544	-559	-569	-559	-550	-533	-541	-567	-552	-564	-542	-554	-553
23/08/2013	192	-560	-556	-582	-596	-533	-541	-551	-580	-558	-589	-537	-566	-562

Potentials for Beams (Tidal Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE12**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
26/02/2103	15	-208	-207	-242	-240	-219	-237	-242	-240	-208	-241	-228	-241	-229
16/03/2103	35	-326	-347	-318	-280	-280	-329	-316	-319	-337	-299	-305	-318	-314
01/04/2103	50	-328	-323	-342	-322	-344	-353	-364	-324	-326	-332	-349	-344	-338
16/04/2103	65	-441	-434	-392	-382	-459	-487	-488	-416	-438	-387	-473	-452	-437
01/05/2103	80	-502	-507	-467	-455	-510	-530	-413	-410	-505	-461	-520	-412	-474
15/05/2103	95	-482	-492	-483	-489	-487	-462	-483	-465	-487	-486	-475	-474	-480
30/05/2013	110	-524	-527	-528	-508	-519	-539	-492	-488	-526	-518	-529	-490	-516
16/06/2013	126	-555	-545	-551	-548	-547	-565	-519	-530	-550	-550	-556	-525	-545
02/07/2013	140	-553	-536	-539	-540	-526	-552	-506	-519	-545	-540	-539	-513	-534
25/07/2013	163	-572	-560	-562	-562	-557	-584	-521	-537	-566	-562	-571	-529	-557
12/08/2013	180	-556	-542	-555	-549	-524	-548	-535	-522	-549	-552	-536	-529	-541
23/08/2013	192	-585	-598	-580	-591	-578	-577	-580	-585	-592	-586	-578	-583	-584

Potentials for Beams (Tidal Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 11/02/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE												
		Specimen # 1				Specimen # 2				Average Potentials (mV)				
		WE1		WE2		WE1		WE2		WE11	WE12	WE21	WE22	WE11:WE22
		P#1	P#2	P#1	P#2	P#1	P#2	P#1	P#2					
26/02/2103	15	-280	-265	-257	-237	-174	-163	-340	-336	-273	-247	-169	-338	-257
16/03/2103	35	-331	-295	-280	-265	-248	-230	-340	-322	-313	-273	-239	-331	-289
01/04/2103	50	-331	-301	-327	-303	-250	-239	-343	-334	-316	-315	-245	-339	-304
16/04/2103	65	-425	-404	-418	-406	-381	-367	-458	-441	-415	-412	-374	-450	-413
01/05/2103	80	-497	-475	-478	-445	-480	-435	-504	-488	-486	-462	-458	-496	-475
15/05/2103	95	-482	-463	-468	-440	-509	-483	-491	-462	-473	-454	-496	-477	-475
30/05/2013	110	-526	-507	-510	-470	-513	-517	-531	-556	-517	-490	-515	-544	-516
16/06/2013	126	-550	-534	-538	-497	-541	-530	-580	-571	-542	-518	-536	-576	-543
02/07/2013	140	-541	-519	-527	-479	-518	-512	-564	-549	-530	-503	-515	-557	-526
25/07/2013	163	-569	-542	-544	-524	-561	-551	-593	-573	-556	-534	-556	-583	-557
12/08/2013	180	-545	-532	-472	-469	-538	-528	-575	-568	-539	-471	-533	-572	-528
23/08/2013	192	-554	-550	-494	-486	-552	-538	-593	-587	-552	-490	-545	-590	-544

Potentials for Beams (Tidal Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE												
		Specimen # 1				Specimen # 2				Average Potentials (mV)				
		WE1		WE2		WE1		WE2		WE11	WE12	WE21	WE22	WE11:WE22
		P#1	P#2	P#1	P#2	P#1	P#2	P#1	P#2					
26/02/2103	15	-250	-217	-353	-320	-272	-273	-213	-218	-234	-337	-273	-216	-265
16/03/2103	35	-333	-287	-316	-300	-318	-317	-335	-306	-310	-308	-318	-321	-314
01/04/2103	50	-520	-280	-334	-318	-330	-320	-344	-307	-400	-326	-325	-326	-344
16/04/2103	65	-369	-338	-430	-425	-431	-441	-443	-425	-354	-428	-436	-434	-413
01/05/2103	80	-492	-436	-482	-450	-465	-470	-455	-440	-464	-466	-468	-448	-461
15/05/2103	95	-442	-404	-473	-446	-434	-423	-449	-434	-423	-460	-429	-442	-438
30/05/2013	110	-489	-476	-524	-495	-485	-497	-537	-511	-483	-510	-491	-524	-502
16/06/2013	126	-553	-517	-574	-547	-544	-537	-573	-534	-535	-561	-541	-554	-547
02/07/2013	140	-534	-506	-567	-533	-534	-528	-564	-524	-520	-550	-531	-544	-536
25/07/2013	163	-568	-529	-584	-553	-577	-557	-587	-547	-549	-569	-567	-567	-563
12/08/2013	180	-548	-514	-575	-545	-564	-547	-573	-522	-531	-560	-556	-548	-549
23/08/2013	192	-566	-550	-601	-574	-576	-560	-591	-548	-558	-588	-568	-570	-571

Potentials for Beams (Tidal Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 11/02/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE												
		Specimen # 1				Specimen # 2				Average Potentials (mV)				
		WE1		WE2		WE1		WE2		WE11	WE12	WE21	WE22	WE11:WE22
		P#1	P#2	P#1	P#2	P#1	P#2	P#1	P#2					
26/02/2103	15	-316	-306	-248	-227	-195	-196	-265	-262	-311	-238	-196	-264	-252
16/03/2103	35	-288	-264	-269	-250	-254	-258	-280	-287	-276	-260	-256	-284	-269
01/04/2103	50	-339	-318	-294	-272	-236	-255	-330	-342	-329	-283	-246	-336	-298
16/04/2103	65	-390	-350	-400	-370	-336	-320	-434	-425	-370	-385	-328	-430	-378
01/05/2103	80	-474	-440	-448	-426	-420	-390	-430	-440	-457	-437	-405	-435	-434
15/05/2103	95	-406	-386	-386	-373	-371	-351	-442	-440	-396	-380	-361	-441	-394
30/05/2013	110	-435	-427	-402	-391	-423	-425	-504	-504	-431	-397	-424	-504	-439
16/06/2013	126	-487	-477	-454	-435	-462	-457	-530	-533	-482	-445	-460	-532	-479
02/07/2013	140	-452	-437	-421	-412	-454	-423	-505	-502	-445	-417	-439	-504	-451
25/07/2013	163	-520	-502	-500	-480	-498	-482	-568	-557	-511	-490	-490	-563	-513
12/08/2013	180	-450	-426	-414	-405	-461	-447	-541	-532	-438	-410	-454	-537	-460
23/08/2013	192	-464	-440	-438	-434	-482	-465	-561	-550	-452	-436	-474	-556	-479

Potentials for Beams (Tidal Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**												
		Specimen # 1				**Specimen # 2**				**Average Potentials (mV)**				
		WE1		**WE2**		**WE1**		**WE2**		**WE11**	**WE12**	**WE21**	**WE22**	**WE11:WE22**
		P#1	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**	**P#1**	**P#2**					
26/02/2103	15	-280	-277	-182	-180	-204	-200	-244	-241	-279	-181	-202	-243	-226
16/03/2103	35	-300	-286	-245	-230	-264	-266	-275	-287	-293	-238	-265	-281	-269
01/04/2103	50	-314	-303	-248	-233	-286	-290	-277	-287	-309	-241	-288	-282	-280
16/04/2103	65	-404	-405	-330	-331	-411	-410	-398	-405	-405	-331	-411	-402	-387
01/05/2103	80	-448	-463	-353	-362	-450	-449	-455	-455	-456	-358	-450	-455	-429
15/05/2103	95	-444	-446	-408	-408	-449	-459	-435	-455	-445	-408	-454	-445	-438
30/05/2013	110	-519	-522	-477	-476	-508	-514	-462	-473	-521	-477	-511	-468	-494
16/06/2013	126	-564	-585	-517	-516	-534	-529	-487	-501	-575	-517	-532	-494	-529
02/07/2013	140	-551	-562	-500	-502	-518	-514	-473	-498	-557	-501	-516	-486	-515
25/07/2013	163	-583	-600	-540	-544	-553	-547	-547	-545	-592	-542	-550	-546	-557
12/08/2013	180	-557	-569	-519	-523	-524	-518	-487	-488	-563	-521	-521	-488	-523
23/08/2013	192	-578	-583	-555	-561	-553	-540	-497	-500	-581	-558	-547	-499	-546

Potentials for Beams (Below Ground Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-219	-265	-208	-234	-242	-221	-232
10/04/2013	40	-253	-369	-242	-242	-311	-242	-277
21/04/2013	52	-362	-424	-368	-358	-393	-363	-378
05/05/2013	66	-469	-469	-402	-466	-469	-434	-452
19/05/2013	80	-570	-570	-502	-577	-570	-540	-555
31/05/2013	92	-579	-579	-570	-663	-579	-617	-598
17/06/2013	109	-594	-592	-612	-609	-593	-611	-602
03/07/2013	125	-607	-608	-637	-631	-608	-634	-621
17/07/2013	139	-618	-618	-641	-628	-618	-635	-626
29/07/2013	151	-640	-641	-659	-665	-641	-662	-651
13/08/2013	165	-612	-613	-655	-635	-613	-645	-629
28/08/2013	180	-621	-620	-658	-644	-621	-651	-636

Potentials for Beams (Below Ground Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		Specimen # 2		Average Potentials (mV)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
21/03/2013	21	-238	-232	-225	-215	-235	-220	-228
10/04/2013	40	-304	-250	-327	-223	-277	-275	-276
21/04/2013	52	-384	-388	-346	-323	-386	-335	-360
05/05/2013	66	-508	-541	-490	-393	-525	-442	-483
19/05/2013	80	-555	-640	-567	-451	-598	-509	-553
31/05/2013	92	-630	-630	-579	-454	-630	-517	-573
17/06/2013	109	-555	-559	-562	-437	-557	-500	-528
03/07/2013	125	-561	-567	-611	-524	-564	-568	-566
17/07/2013	139	-554	-555	-597	-517	-555	-557	-556
29/07/2013	151	-569	-567	-569	-530	-568	-550	-559
13/08/2013	165	-588	-588	-618	-546	-588	-582	-585
28/08/2013	180	-599	-599	-628	-567	-599	-598	-598

Potentials for Beams (Below Ground Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-193	-205	-239	-244	-199	-242	-220
10/04/2013	40	-222	-272	-277	-269	-247	-273	-260
21/04/2013	52	-360	-392	-317	-313	-376	-315	-346
05/05/2013	66	-528	-550	-482	-434	-539	-458	-499
19/05/2013	80	-577	-555	-582	-553	-566	-568	-567
31/05/2013	92	-612	-541	-603	-566	-577	-585	-581
17/06/2013	109	-491	-545	-463	-433	-518	-448	-483
03/07/2013	125	-524	-571	-475	-461	-548	-468	-508
17/07/2013	139	-502	-536	-566	-443	-519	-505	-512
29/07/2013	151	-565	-550	-564	-547	-558	-556	-557
13/08/2013	165	-488	-547	-545	-550	-518	-548	-533
28/08/2013	180	-498	-566	-552	-566	-532	-559	-546

Potentials for Beams (Below Ground Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-265	-259	-190	-193	-262	-192	-227
10/04/2013	40	-265	-239	-207	-267	-252	-237	-245
21/04/2013	52	-356	-361	-335	-394	-359	-365	-362
05/05/2013	66	-297	-512	-492	-436	-405	-464	-434
19/05/2013	80	-427	-630	-504	-479	-529	-492	-510
31/05/2013	92	-441	-614	-581	-461	-528	-521	-524
17/06/2013	109	-432	-587	-547	-430	-510	-489	-499
03/07/2013	125	-585	-597	-587	-520	-591	-554	-572
17/07/2013	139	-640	-647	-505	-510	-644	-508	-576
29/07/2013	151	-605	-648	-508	-557	-627	-533	-580
13/08/2013	165	-670	-687	-494	-521	-679	-508	-593
28/08/2013	180	-636	-675	-595	-617	-656	-606	-631

Potentials for Beams (Below Ground Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-167	-225	-245	-223	-196	-234	-215
10/04/2013	40	-205	-213	-329	-193	-209	-261	-235
21/04/2013	52	-446	-300	-378	-264	-373	-321	-347
05/05/2013	66	-370	-421	-370	-310	-396	-340	-368
19/05/2013	80	-461	-512	-469	-447	-487	-458	-472
31/05/2013	92	-501	-573	-446	-398	-537	-422	-480
17/06/2013	109	-407	-437	-372	-390	-422	-381	-402
03/07/2013	125	-418	-444	-387	-437	-431	-412	-422
17/07/2013	139	-401	-419	-375	-428	-410	-402	-406
29/07/2013	151	-410	-498	-418	-460	-454	-439	-447
13/08/2013	165	-405	-466	-398	-444	-436	-421	-428
28/08/2013	180	-438	-528	-466	-511	-483	-489	-486

Potentials for Beams (Below Ground Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-230	-269	-277	-240	-250	-259	-254
10/04/2013	40	-293	-287	-325	-274	-290	-300	-295
21/04/2013	52	-397	-320	-465	-307	-359	-386	-372
05/05/2013	66	-454	-400	-520	-458	-427	-489	-458
19/05/2013	80	-547	-545	-572	-548	-546	-560	-553
31/05/2013	92	-585	-575	-594	-543	-580	-569	-574
17/06/2013	109	-501	-534	-563	-579	-518	-571	-544
03/07/2013	125	-524	-547	-576	-595	-536	-586	-561
17/07/2013	139	-506	-519	-536	-583	-513	-560	-536
29/07/2013	151	-537	-584	-583	-641	-561	-612	-586
13/08/2013	165	-512	-536	-547	-606	-524	-577	-550
28/08/2013	180	-556	-563	-559	-615	-560	-587	-573

Potentials for Beams (Capillary Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-242	-307	-183	-212	-275	-198	-236
10/04/2013	40	-327	-317	-174	-315	-322	-245	-283
21/04/2013	51	-345	-349	-231	-362	-347	-297	-322
05/05/2013	65	-307	-411	-273	-316	-359	-295	-327
19/05/2013	79	-467	-524	-425	-469	-496	-447	-471
29/05/2013	89	-498	-514	-420	-469	-506	-445	-475
18/06/2013	108	-455	-477	-420	-448	-466	-434	-450
03/07/2013	123	-464	-486	-435	-466	-475	-451	-463
17/07/2013	137	-494	-527	-444	-474	-511	-459	-485
28/07/2013	148	-514	-541	-460	-501	-528	-481	-504
13/08/2013	165	-365	-524	-455	-487	-445	-471	-458
28/08/2013	180	-528	-534	-489	-491	-531	-490	-511

Potentials for Beams (Capillary Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-314	-188	-158	-166	-251	-162	-207
10/04/2013	40	-318	-243	-145	-233	-281	-189	-235
21/04/2013	51	-382	-257	-188	-282	-320	-235	-277
05/05/2013	65	-298	-330	-148	-265	-314	-207	-260
19/05/2013	79	-487	-468	-156	-446	-478	-301	-389
29/05/2013	89	-438	-492	-230	-452	-465	-341	-403
18/06/2013	108	-455	-532	-308	-399	-494	-354	-424
03/07/2013	123	-462	-542	-314	-407	-502	-361	-431
17/07/2013	137	-464	-565	-333	-423	-515	-378	-446
28/07/2013	148	-489	-591	-408	-471	-540	-440	-490
13/08/2013	165	-474	-585	-365	-457	-530	-411	-470
28/08/2013	180	-484	-604	-388	-479	-544	-434	-489

Potentials for Beams (Capillary Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		Specimen # 2		Average Potentials (mV)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
21/03/2013	21	-167	-197	-305	-166	-182	-236	-209
10/04/2013	40	-159	-193	-399	-158	-176	-279	-227
21/04/2013	51	-193	-320	-409	-200	-257	-305	-281
05/05/2013	65	-147	-384	-347	-206	-266	-277	-271
19/05/2013	79	-162	-504	-488	-320	-333	-404	-369
29/05/2013	89	-158	-485	-472	-359	-322	-416	-369
18/06/2013	108	-302	-473	-423	-375	-388	-399	-393
03/07/2013	123	-416	-505	-436	-391	-461	-414	-437
17/07/2013	137	-435	-515	-456	-407	-475	-432	-453
28/07/2013	148	-483	-549	-489	-431	-516	-460	-488
13/08/2013	165	-465	-533	-479	-414	-499	-447	-473
28/08/2013	180	-470	-544	-527	-432	-507	-480	-493

Potentials for Beams (Capillary Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		Specimen # 2		Average Potentials (mV)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
21/03/2013	21	-177	-173	-263	-209	-175	-236	-206
10/04/2013	40	-74	-162	-389	-304	-118	-347	-232
21/04/2013	51	-132	-103	-423	-345	-118	-384	-251
05/05/2013	65	-62	-52	-374	-327	-57	-351	-204
19/05/2013	79	-467	-461	-482	-461	-464	-472	-468
29/05/2013	89	-466	-454	-484	-462	-460	-473	-467
18/06/2013	108	-297	-334	-442	-419	-316	-431	-373
03/07/2013	123	-314	-367	-456	-429	-341	-443	-392
17/07/2013	137	-332	-399	-472	-456	-366	-464	-415
28/07/2013	148	-373	-438	-516	-473	-406	-495	-450
13/08/2013	165	-346	-415	-494	-465	-381	-480	-430
28/08/2013	180	-497	-481	-509	-513	-489	-511	-500

Potentials for Beams (Capillary Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-182	-173	-183	-194	-178	-189	-183
10/04/2013	40	-244	-58	-61	-94	-151	-78	-114
21/04/2013	51	-278	-98	-237	-124	-188	-181	-184
05/05/2013	65	-218	-44	-46	-132	-131	-89	-110
19/05/2013	79	-385	-167	-160	-286	-276	-223	-250
29/05/2013	89	-354	-258	-137	-192	-306	-165	-235
18/06/2013	108	-290	-199	-256	-188	-245	-222	-233
03/07/2013	123	-309	-211	-265	-193	-260	-229	-245
17/07/2013	137	-324	-224	-283	-204	-274	-244	-259
28/07/2013	148	-356	-286	-311	-224	-321	-268	-294
13/08/2013	165	-346	-267	-305	-216	-307	-261	-284
28/08/2013	180	-376	-295	-386	-271	-336	-329	-332

Potentials for Beams (Capillary Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-209	-200	-274	-177	-205	-226	-215
10/04/2013	40	-231	-283	-345	-67	-257	-206	-232
21/04/2013	51	-309	-325	-412	-117	-317	-265	-291
05/05/2013	65	-402	-222	-386	-62	-312	-224	-268
19/05/2013	79	-536	-517	-520	-195	-527	-358	-442
29/05/2013	89	-524	-501	-514	-168	-513	-341	-427
18/06/2013	108	-451	-462	-483	-267	-457	-375	-416
03/07/2013	123	-467	-477	-496	-304	-472	-400	-436
17/07/2013	137	-498	-500	-512	-347	-499	-430	-464
28/07/2013	148	-535	-533	-539	-379	-534	-459	-497
13/08/2013	165	-519	-514	-523	-356	-517	-440	-478
28/08/2013	180	-535	-524	-536	-433	-530	-485	-507

Potentials for Beams (Submerged Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-328	-386	-336	-294	-357	-315	-336
10/04/2013	40	-363	-399	-323	-253	-381	-288	-335
21/04/2013	51	-400	-514	-431	-311	-457	-371	-414
05/05/2013	65	-506	-606	-554	-477	-556	-516	-536
19/05/2013	79	-634	-640	-590	-559	-637	-575	-606
29/05/2013	89	-652	-619	-633	-569	-636	-601	-618
18/06/2013	108	-565	-579	-558	-534	-572	-546	-559
03/07/2013	123	-576	-587	-574	-555	-582	-565	-573
17/07/2013	137	-587	-606	-582	-565	-597	-574	-585
28/07/2013	148	-606	-628	-603	-589	-617	-596	-607
12/08/2013	165	-587	-606	-579	-567	-597	-573	-585
27/08/2013	180	-616	-622	-593	-572	-619	-583	-601

Potentials for Beams (Submerged Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-247	-237	-278	-279	-242	-279	-260
10/04/2013	40	-299	-224	-338	-363	-262	-351	-306
21/04/2013	51	-376	-350	-374	-391	-363	-383	-373
05/05/2013	65	-533	-519	-531	-545	-526	-538	-532
19/05/2013	79	-605	-620	-636	-642	-613	-639	-626
29/05/2013	89	-705	-634	-642	-644	-670	-643	-656
18/06/2013	108	-536	-541	-558	-524	-539	-541	-540
03/07/2013	123	-558	-550	-593	-547	-554	-570	-562
17/07/2013	137	-569	-562	-608	-563	-566	-586	-576
28/07/2013	148	-585	-578	-624	-588	-582	-606	-594
12/08/2013	165	-552	-569	-612	-558	-561	-585	-573
27/08/2013	180	-561	-585	-650	-579	-573	-615	-594

Potentials for Beams (Submerged Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		Specimen # 2		Average Potentials (mV)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
21/03/2013	21	-194	-223	-296	-382	-209	-339	-274
10/04/2013	40	-229	-284	-381	-437	-257	-409	-333
21/04/2013	51	-288	-336	-389	-400	-312	-395	-353
05/05/2013	65	-357	-522	-548	-535	-440	-542	-491
19/05/2013	79	-410	-612	-595	-628	-511	-612	-561
29/05/2013	89	-399	-613	-574	-622	-506	-598	-552
18/06/2013	108	-386	-520	-453	-511	-453	-482	-468
03/07/2013	123	-410	-556	-471	-551	-483	-511	-497
17/07/2013	137	-437	-574	-494	-574	-506	-534	-520
28/07/2013	148	-600	-597	-507	-603	-599	-555	-577
12/08/2013	165	-441	-576	-438	-550	-509	-494	-501
27/08/2013	180	-467	-586	-448	-561	-527	-505	-516

Potentials for Beams (Submerged Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 01/03/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		Specimen # 1		Specimen # 2		Average Potentials (mV)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
21/03/2013	21	-296	-382	-292	-196	-339	-244	-292
10/04/2013	40	-381	-437	-200	-128	-409	-164	-287
21/04/2013	51	-389	-400	-475	-237	-395	-356	-375
05/05/2013	65	-548	-535	-480	-250	-542	-365	-453
19/05/2013	79	-595	-628	-489	-337	-612	-413	-512
29/05/2013	89	-574	-622	-462	-327	-598	-395	-496
18/06/2013	108	-453	-511	-502	-298	-482	-400	-441
03/07/2013	123	-471	-551	-524	-300	-511	-412	-462
17/07/2013	137	-494	-574	-553	-324	-534	-439	-486
28/07/2013	148	-507	-603	-570	-355	-555	-463	-509
12/08/2013	165	-438	-550	-511	-326	-494	-419	-456
27/08/2013	180	-448	-561	-673	-491	-505	-582	-543

Potentials for Beams (Submerged Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-201	-219	-239	-286	-210	-263	-236
10/04/2013	40	-126	-170	-316	-359	-148	-338	-243
21/04/2013	51	-307	-271	-369	-398	-289	-384	-336
05/05/2013	65	-309	-295	-540	-554	-302	-547	-425
19/05/2013	79	-398	-373	-568	-588	-386	-578	-482
29/05/2013	89	-418	-498	-494	-550	-458	-522	-490
18/06/2013	108	-364	-324	-436	-424	-344	-430	-387
03/07/2013	123	-392	-351	-459	-446	-372	-453	-412
17/07/2013	137	-414	-377	-498	-486	-396	-492	-444
28/07/2013	148	-479	-413	-534	-531	-446	-533	-489
12/08/2013	165	-356	-404	-467	-459	-380	-463	-422
27/08/2013	180	-403	-450	-488	-477	-427	-483	-455

Potentials for Beams (Submerged Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 01/03/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		Specimen # 1		**Specimen # 2**		**Average Potentials (mV)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
21/03/2013	21	-380	-205	-251	-243	-293	-247	-270
10/04/2013	40	-428	-319	-218	-207	-374	-213	-293
21/04/2013	51	-686	-434	-358	-320	-560	-339	-450
05/05/2013	65	-492	-439	-449	-553	-466	-501	-483
19/05/2013	79	-520	-462	-489	-569	-491	-529	-510
29/05/2013	89	-547	-476	-509	-581	-512	-545	-528
18/06/2013	108	-644	-395	-550	-553	-520	-552	-536
03/07/2013	123	-718	-495	-610	-569	-607	-590	-598
17/07/2013	137	-660	-473	-578	-581	-567	-580	-573
28/07/2013	148	-572	-510	-558	-604	-541	-581	-561
12/08/2013	165	-520	-494	-512	-597	-507	-555	-531
27/08/2013	180	-540	-515	-526	-586	-528	-556	-542

Potentials for Cylinders (Without Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-165	-122	-179	-150	-264	-209	-182
19/03/2013	43	-251	-164	-247	-176	-296	-231	-228
03/04/2013	57	-359	-333	-329	-211	-372	-258	-310
17/04/2013	71	-381	-362	-406	-356	-415	-228	-358
01/05/2013	85	-338	-346	-410	-335	-434	-348	-369
16/05/2013	100	-439	-471	-526	-433	-510	-431	-468
01/06/2013	115	-561	-571	-534	-416	-536	-498	-519
16/06/2013	130	-467	-455	-493	-377	-504	-465	-460
01/07/2013	145	-471	-461	-502	-387	-516	-474	-469
17/07/2013	161	-486	-472	-514	-399	-524	-463	-476
03/08/2013	177	-565	-563	-504	-489	-511	-460	-515
19/08/2013	193	-587	-525	-583	-574	-566	-555	-565

Potentials for Cylinders (Without Chloride Contamination)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-108	-191	-257	-196	-104	-126	-164
19/03/2013	43	-248	-285	-270	-224	-198	-267	-249
03/04/2013	57	-295	-322	-345	-241	-356	-328	-315
17/04/2013	71	-284	-321	-367	-265	-419	-343	-333
01/05/2013	85	-312	-403	-363	-394	-385	-359	-369
16/05/2013	100	-472	-476	-416	-458	-456	-434	-452
01/06/2013	115	-463	-493	-331	-380	-458	-458	-431
16/06/2013	130	-411	-443	-456	-423	-446	-425	-434
01/07/2013	145	-422	-459	-461	-439	-474	-433	-448
17/07/2013	161	-436	-475	-480	-454	-486	-447	-463
03/08/2013	177	-432	-466	-467	-444	-480	-441	-455
19/08/2013	193	-498	-544	-500	-516	-514	-698	-545

Potentials for Cylinders (Without Chloride Contamination)

Mix 3 : Conplast Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-107	-170	-156	-130	-175	-159	-150
19/03/2013	43	-252	-200	-227	-221	-297	-244	-240
03/04/2013	57	-299	-395	-363	-296	-387	-293	-339
17/04/2013	71	-404	-265	-319	-404	-393	-410	-366
01/05/2013	85	-444	-376	-402	-417	-455	-426	-420
16/05/2013	100	-500	-499	-469	-476	-497	-358	-467
01/06/2013	115	-536	-502	-507	-509	-520	-471	-508
16/06/2013	130	-475	-439	-460	-506	-508	-446	-472
01/07/2013	145	-490	-455	-475	-511	-513	-452	-483
17/07/2013	161	-519	-485	-498	-531	-532	-471	-506
03/08/2013	177	-500	-467	-489	-520	-522	-462	-493
19/08/2013	193	-561	-489	-529	-568	-558	-532	-540

Potentials for Cylinders (Without Chloride Contamination)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-154	-174	-126	-163	-174	-196	-165
19/03/2013	43	-237	-247	-263	-274	-290	-235	-258
03/04/2013	57	-389	-358	-325	-388	-300	-374	-356
17/04/2013	71	-437	-380	-409	-383	-393	-388	-398
01/05/2013	85	-452	-431	-451	-426	-447	-453	-443
16/05/2013	100	-539	-523	-494	-503	-516	-510	-514
01/06/2013	115	-517	-506	-510	-574	-541	-532	-530
16/06/2013	130	-509	-512	-501	-487	-497	-487	-499
01/07/2013	145	-518	-516	-519	-505	-506	-507	-512
17/07/2013	161	-528	-520	-527	-549	-524	-519	-528
03/08/2013	177	-514	-512	-515	-519	-505	-510	-513
19/08/2013	193	-589	-569	-578	-570	-522	-553	-564

Potentials for Cylinders (Without Chloride Contamination)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 06/02/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-136	-162	-135	-147	-168	-163	-152
19/03/2013	43	-292	-285	-203	-253	-251	-272	-259
03/04/2013	57	-322	-334	-317	-361	-378	-369	-347
17/04/2013	71	-356	-276	-223	-244	-316	-361	-296
01/05/2013	85	-373	-361	-375	-375	-349	-406	-373
16/05/2013	100	-389	-399	-439	-402	-407	-472	-418
01/06/2013	115	-397	-465	-395	-361	-395	-448	-410
16/06/2013	130	-344	-400	-314	-308	-375	-437	-363
01/07/2013	145	-350	-411	-327	-319	-385	-447	-373
17/07/2013	161	-363	-429	-342	-334	-409	-460	-390
03/08/2013	177	-343	-419	-282	-325	-393	-445	-368
19/08/2013	193	-437	-447	-286	-444	-432	-453	-417

Potentials for Cylinders (Without Chloride Contamination)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average Potentials (mV)**
26/02/2013	20	-179	-132	-180	-179	-187	-190	-175
19/03/2013	43	-295	-243	-203	-267	-234	-297	-257
03/04/2013	57	-306	-274	-321	-387	-346	-383	-336
17/04/2013	71	-408	-303	-443	-331	-341	-366	-365
01/05/2013	85	-477	-369	-478	-431	-405	-416	-429
16/05/2013	100	-486	-419	-528	-489	-509	-492	-487
01/06/2013	115	-565	-448	-509	-488	-459	-441	-485
16/06/2013	130	-455	-375	-476	-459	-489	-461	-453
01/07/2013	145	-466	-392	-485	-470	-499	-467	-463
17/07/2013	161	-528	-412	-503	-484	-521	-477	-488
03/08/2013	177	-472	-394	-492	-476	-508	-466	-468
19/08/2013	193	-487	-439	-549	-562	-576	-547	-527

Potentials for Cylinders (With Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^-(0.2%)				**Cl^-(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-181	-84	-149	-138	-175	-183	-174	-177
09/05/2013	30	-78	-62	-179	-106	-80	-128	-172	-127
24/05/2013	45	-175	-96	-254	-175	-139	-144	-153	-145
13/06/2013	64	-164	-91	-191	-149	-145	-153	-184	-161
28/06/2013	79	-185	-122	-231	-179	-164	-181	-212	-186
13/07/2013	94	-206	-130	-204	-180	-156	-163	-204	-174
23/07/2013	104	-229	-223	-246	-233	-185	-197	-225	-202
08/08/2013	119	-212	-242	-218	-224	-165	-184	-216	-188
20/08/2013	131	-232	-251	-245	-243	-239	-240	-252	-244
05/09/2013	147	-274	-288	-242	-268	-267	-267	-283	-272

Potentials for Cylinders (With Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^-(0.8%)				**Cl^-(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-249	-205	-202	-219	-234	-236	-297	-256
09/05/2013	30	-244	-207	-203	-218	-276	-297	-287	-287
24/05/2013	45	-186	-252	-224	-221	-356	-412	-398	-389
13/06/2013	64	-206	-230	-237	-224	-347	-359	-361	-356
28/06/2013	79	-225	-237	-250	-237	-346	-378	-326	-350
13/07/2013	94	-221	-224	-245	-230	-334	-357	-313	-335
23/07/2013	104	-251	-251	-269	-257	-352	-392	-348	-364
08/08/2013	119	-236	-236	-254	-242	-342	-372	-326	-347
20/08/2013	131	-331	-332	-336	-333	-409	-425	-406	-413
05/09/2013	147	-327	-336	-323	-329	-407	-409	-394	-403

Potentials for Cylinders (With Chloride Contamination)
Mix 2 : Rheocrete Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl⁻(0.2%)				**Cl⁻(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-138	-123	-176	-146	-108	-132	-197	-146
09/05/2013	30	-91	-69	-110	-90	-110	-112	-159	-127
24/05/2013	45	-106	-150	-130	-129	-264	-129	-151	-181
13/06/2013	64	-162	-186	-174	-174	-209	-184	-179	-191
28/06/2013	79	-205	-207	-214	-209	-255	-247	-244	-249
13/07/2013	94	-179	-204	-189	-191	-241	-235	-231	-236
23/07/2013	104	-219	-229	-181	-210	-303	-276	-284	-288
08/08/2013	119	-189	-211	-199	-200	-263	-257	-251	-257
20/08/2013	131	-218	-216	-206	-213	-273	-271	-284	-276
05/09/2013	147	-242	-219	-207	-223	-261	-278	-285	-275

Potentials for Cylinders (With Chloride Contamination)

Mix 2 : Rheocrete Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE							
		Cl^{-}(0.8%)				Cl^{-}(1.5%)			
		S#1	S#2	S#3	Average (mV)	S # 1	S # 2	S # 3	Average (mV)
24/04/2013	15	-205	-231	-225	-220	-269	-309	-305	-294
09/05/2013	30	-149	-168	-176	-164	-233	-264	-298	-265
24/05/2013	45	-167	-234	-252	-218	-264	-355	-393	-337
13/06/2013	64	-174	-188	-224	-195	-259	-263	-295	-272
28/06/2013	79	-214	-218	-245	-226	-265	-285	-299	-283
13/07/2013	94	-235	-245	-255	-245	-285	-304	-310	-300
23/07/2013	104	-252	-285	-298	-278	-315	-349	-327	-330
08/08/2013	119	-245	-255	-275	-258	-294	-322	-311	-309
20/08/2013	131	-258	-304	-292	-285	-316	-345	-375	-345
05/09/2013	147	-266	-278	-285	-276	-366	-316	-315	-332

Potentials for Cylinders (With Chloride Contamination)
Mix 3 : Conplast Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE							
		Cl^{-}(0.2%)				Cl^{-}(0.4%)			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-206	-146	-152	-168	-163	-195	-198	-185
09/05/2013	30	-136	-100	-124	-120	-75	-105	-106	-95
24/05/2013	45	-118	-73	-103	-98	-123	-184	-112	-140
13/06/2013	64	-179	-155	-162	-165	-157	-174	-148	-160
28/06/2013	79	-188	-167	-194	-183	-154	-166	-158	-159
13/07/2013	94	-197	-183	-202	-194	-169	-174	-169	-171
23/07/2013	104	-211	-207	-223	-214	-188	-243	-184	-205
08/08/2013	119	-205	-194	-211	-203	-175	-188	-181	-181
20/08/2013	131	-249	-217	-214	-227	-222	-200	-251	-224
05/09/2013	147	-271	-217	-248	-245	-241	-243	-329	-271

Potentials for Cylinders (With Chloride Contamination)

Mix 3 : Conplast Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^-(0.8%)				**Cl^-(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-208	-243	-242	-231	-308	-275	-296	-293
09/05/2013	30	-134	-161	-197	-164	-251	-240	-283	-258
24/05/2013	45	-143	-154	-281	-193	-316	-235	-367	-306
13/06/2013	64	-157	-188	-212	-186	-264	-260	-325	-283
28/06/2013	79	-169	-199	-222	-197	-279	-263	-309	-284
13/07/2013	94	-176	-207	-231	-205	-287	-278	-311	-292
23/07/2013	104	-191	-227	-270	-229	-321	-303	-354	-326
08/08/2013	119	-180	-218	-250	-216	-305	-286	-327	-306
20/08/2013	131	-211	-258	-264	-244	-324	-327	-386	-346
05/09/2013	147	-303	-256	-296	-285	-326	-345	-398	-356

Potentials for Cylinders (With Chloride Contamination)
Mix 4 : Cemetec Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE							
		Cl¯(0.2%)				Cl¯(0.4%)			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-87	-80	-110	-92	-103	-192	-109	-135
09/05/2013	30	-67	-72	-36	-58	-115	-96	-77	-96
24/05/2013	45	-74	-107	-85	-89	-127	-139	-117	-128
13/06/2013	64	-88	-148	-122	-119	-144	-187	-198	-176
28/06/2013	79	-94	-152	-142	-129	-152	-155	-165	-157
13/07/2013	94	-99	-169	-158	-142	-168	-167	-184	-173
23/07/2013	104	-106	-245	-183	-178	-211	-190	-217	-206
08/08/2013	119	-102	-181	-170	-151	-182	-175	-194	-184
20/08/2013	131	-184	-194	-184	-187	-210	-208	-208	-209
05/09/2013	147	-192	-264	-186	-214	-212	-236	-238	-229

Potentials for Cylinders (With Chloride Contamination)

Mix 4 : Cemetec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl¯(0.8%)				**Cl¯(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-200	-186	-246	-211	-276	-257	-276	-270
09/05/2013	30	-150	-113	-180	-148	-200	-219	-223	-214
24/05/2013	45	-215	-151	-333	-233	-237	-297	-262	-265
13/06/2013	64	-201	-166	-240	-202	-255	-279	-279	-271
28/06/2013	79	-183	-154	-211	-183	-266	-280	-285	-277
13/07/2013	94	-192	-162	-219	-191	-271	-295	-299	-288
23/07/2013	104	-228	-184	-244	-219	-296	-322	-333	-317
08/08/2013	119	-207	-171	-224	-201	-281	-311	-319	-304
20/08/2013	131	-251	-186	-252	-230	-302	-344	-386	-344
05/09/2013	147	-297	-206	-229	-244	-334	-348	-389	-357

Potentials for Cylinders (With Chloride Contamination)

Mix 5 : Sika901 Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl¯(0.2%)				**Cl¯(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-116	-138	-139	-131	-148	-115	-121	-128
09/05/2013	30	-146	-132	-120	-133	-163	-162	-156	-160
24/05/2013	45	-105	-79	-61	-82	-89	-150	-210	-150
13/06/2013	64	-185	-199	-175	-186	-177	-164	-200	-180
28/06/2013	79	-200	-206	-198	-201	-169	-166	-220	-185
13/07/2013	94	-209	-216	-185	-203	-182	-174	-229	-195
23/07/2013	104	-212	-218	-199	-210	-200	-196	-277	-224
08/08/2013	119	-209	-212	-189	-203	-192	-180	-245	-206
20/08/2013	131	-248	-246	-149	-214	-266	-197	-262	-242
05/09/2013	147	-240	-232	-205	-226	-259	-211	-293	-254

Potentials for Cylinders (With Chloride Contamination)

Mix 5 : Sika901 Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl¯(0.8%)				**Cl¯(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-184	-252	-234	-223	-278	-281	-310	-290
09/05/2013	30	-166	-189	-172	-176	-247	-190	-229	-222
24/05/2013	45	-207	-228	-211	-215	-218	-245	-215	-226
13/06/2013	64	-187	-199	-244	-210	-247	-234	-229	-237
28/06/2013	79	-199	-212	-257	-223	-242	-244	-231	-239
13/07/2013	94	-212	-218	-266	-232	-259	-259	-235	-251
23/07/2013	104	-273	-239	-314	-275	-266	-295	-257	-273
08/08/2013	119	-225	-228	-276	-243	-254	-264	-249	-256
20/08/2013	131	-230	-261	-288	-260	-391	-265	-334	-330
05/09/2013	147	-284	-296	-279	-286	-378	-294	-314	-329

Potentials for Cylinders (With Chloride Contamination)

Mix 6 : Calcium Nitrate Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^-(0.2%)				**Cl^-(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-92	-159	-163	-138	-196	-168	-191	-185
09/05/2013	30	-33	-101	-136	-90	-123	-134	-124	-127
24/05/2013	45	-122	-121	-109	-117	-163	-161	-177	-167
13/06/2013	64	-90	-138	-167	-132	-127	-109	-184	-140
28/06/2013	79	-99	-149	-182	-143	-146	-119	-187	-151
13/07/2013	94	-106	-159	-209	-158	-151	-122	-195	-156
23/07/2013	104	-120	-171	-269	-187	-170	-151	-228	-183
08/08/2013	119	-111	-165	-222	-166	-158	-125	-219	-167
20/08/2013	131	-160	-173	-216	-183	-199	-133	-263	-198
05/09/2013	147	-203	-200	-201	-201	-241	-120	-253	-205

Potentials for Cylinders (With Chloride Contamination)

Mix 6 : Calcium Nitrate Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^{-}(0.8%)				**Cl^{-}(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-219	-179	-182	-193	-258	-209	-245	-237
09/05/2013	30	-207	-156	-224	-196	-219	-216	-239	-225
24/05/2013	45	-114	-215	-283	-204	-327	-254	-280	-287
13/06/2013	64	-240	-234	-201	-225	-254	-256	-289	-266
28/06/2013	79	-245	-209	-209	-221	-255	-262	-299	-272
13/07/2013	94	-264	-219	-217	-233	-267	-273	-312	-284
23/07/2013	104	-281	-243	-224	-249	-288	-306	-337	-310
08/08/2013	119	-275	-231	-245	-250	-277	-287	-325	-296
20/08/2013	131	-262	-269	-265	-265	-307	-312	-359	-326
05/09/2013	147	-252	-290	-282	-275	-267	-314	-364	-315

Potentials for Cylinders (With Chloride Contamination)

Mix 7 : Cortec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl^{-}(0.2%)				**Cl^{-}(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-100	-117	-144	-120	-183	-234	-277	-231
09/05/2013	30	-120	-156	-131	-136	-127	-150	-182	-153
24/05/2013	45	-58	-76	-86	-73	-169	-124	-128	-140
13/06/2013	64	-120	-142	-148	-137	-158	-173	-178	-170
28/06/2013	79	-125	-145	-158	-143	-151	-184	-187	-174
13/07/2013	94	-129	-149	-169	-149	-162	-194	-198	-185
23/07/2013	104	-143	-207	-188	-179	-179	-211	-273	-221
08/08/2013	119	-135	-154	-179	-156	-167	-201	-218	-195
20/08/2013	131	-160	-163	-205	-176	-243	-231	-237	-237
05/09/2013	147	-209	-227	-250	-229	-236	-244	-250	-243

Potentials for Cylinders (With Chloride Contamination)

Mix 7 : Cortec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl¯(0.8%)				**Cl¯(1.5%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S # 1**	**S # 2**	**S # 3**	**Average (mV)**
24/04/2013	15	-266	-300	-249	-272	-344	-342	-324	-337
09/05/2013	30	-214	-207	-182	-201	-296	-300	-294	-297
24/05/2013	45	-218	-218	-212	-216	-276	-302	-301	-293
13/06/2013	64	-222	-209	-202	-211	-266	-289	-314	-290
28/06/2013	79	-238	-218	-218	-225	-294	-327	-322	-314
13/07/2013	94	-244	-224	-231	-233	-304	-338	-334	-325
23/07/2013	104	-266	-254	-265	-262	-337	-364	-364	-355
08/08/2013	119	-251	-234	-240	-242	-319	-345	-348	-337
20/08/2013	131	-314	-285	-251	-283	-410	-426	-412	-416
05/09/2013	147	-339	-266	-269	-291	-391	-426	-251	-356

Potentials for Cylinders (With Chloride Contamination)

Mix 8 : Sika903 Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Free Half-Cell Corrosion Potentials, mV CSE**							
		Cl$^-$(0.2%)				**Cl$^-$(0.4%)**			
		S#1	**S#2**	**S#3**	**Average (mV)**	**S#1**	**S#2**	**S#3**	**Average (mV)**
24/04/2013	15	-100	-180	-136	-139	-239	-204	-242	-228
09/05/2013	30	-118	-169	-129	-139	-135	-91	-129	-118
24/05/2013	45	-65	-99	-91	-85	-137	-33	-130	-100
13/06/2013	64	-88	-111	-130	-110	-117	-99	-118	-111
28/06/2013	79	-109	-124	-166	-133	-140	-104	-170	-138
13/07/2013	94	-113	-143	-174	-143	-151	-114	-181	-149
23/07/2013	104	-130	-173	-221	-175	-181	-139	-223	-181
08/08/2013	119	-149	-157	-198	-168	-164	-120	-194	-159
20/08/2013	131	-187	-216	-208	-204	-219	-187	-217	-208
05/09/2013	147	-192	-217	-240	-216	-222	-164	-242	-209

Potentials for Cylinders (With Chloride Contamination)

Mix 8 : Sika903 Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Free Half-Cell Corrosion Potentials, mV CSE							
		Cl^{-}(0.8%)				Cl^{-}(1.5%)			
		S#1	S#2	S#3	Average (mV)	S#1	S#2	S#3	Average (mV)
24/04/2013	15	-211	-254	-243	-236	-329	-312	-361	-334
09/05/2013	30	-140	-182	-186	-169	-294	-296	-326	-305
24/05/2013	45	-199	-235	-235	-223	-366	-377	-352	-365
13/06/2013	64	-179	-214	-209	-201	-309	-304	-324	-312
28/06/2013	79	-188	-237	-215	-213	-300	-316	-349	-322
13/07/2013	94	-204	-242	-218	-221	-309	-328	-359	-332
23/07/2013	104	-224	-275	-247	-249	-324	-366	-390	-360
08/08/2013	119	-211	-254	-233	-233	-312	-344	-367	-341
20/08/2013	131	-266	-291	-287	-281	-400	-421	-417	-413
05/09/2013	147	-264	-294	-406	-321	-308	-407	-414	-376

APPENDIX B

I_{corr} for Beams (Atmospheric Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} ($\mu A/cm^2$)						
		Specimen # 1		Specimen # 2		Average I_{corr} ($\mu A/cm^2$)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
13/03/2103	33	0.01611	0.010070	0.00707	0.01025	0.013090	0.008661	0.010876
15/04/2013	65	0.02583	0.01452	0.01295	0.01094	0.020175	0.011945	0.016060
14/05/2013	94	0.02635	0.01546	0.03412	0.04464	0.020905	0.039380	0.030143
15/06/2013	125	0.08421	0.01860	0.03624	0.05112	0.051405	0.043680	0.047543
25/07/2013	165	0.10620	0.02168	0.03812	0.06061	0.063940	0.049365	0.056653
22/08/2013	192	0.19740	0.03012	0.09742	0.06540	0.113760	0.081410	0.097585

I_{corr} for Beams (Atmospheric Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
13/03/2103	33	0.00725	0.009677	0.01665	0.00901	0.008463	0.012830	0.010646
15/04/2013	65	0.01036	0.01172	0.01965	0.00949	0.011040	0.014569	0.012804
14/05/2013	94	0.01698	0.01582	0.02280	0.03226	0.016400	0.027530	0.021965
15/06/2013	125	0.01715	0.02012	0.07624	0.04421	0.018635	0.060225	0.039430
25/07/2013	165	0.01747	0.02300	0.15720	0.05748	0.020235	0.107340	0.063788
22/08/2013	192	0.05099	0.06425	0.17750	0.06000	0.057620	0.118750	0.088185

I_{corr} for Beams (Atmospheric Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
13/03/2103	33	0.00725	0.009677	0.01665	0.00901	0.008463	0.012830	0.010646
15/04/2013	65	0.01036	0.01172	0.01965	0.00949	0.011040	0.014569	0.012804
14/05/2013	94	0.01698	0.01582	0.02280	0.03226	0.016400	0.027530	0.021965
15/06/2013	125	0.01715	0.02012	0.07624	0.04421	0.018635	0.060225	0.039430
25/07/2013	165	0.01747	0.02300	0.15720	0.05748	0.020235	0.107340	0.063788
22/08/2013	192	0.05099	0.06425	0.17750	0.06000	0.057620	0.118750	0.088185

I_{corr} for Beams (Atmospheric Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} ($\mu A/cm^2$)						
		Specimen # 1		Specimen # 2		Average I_{corr} ($\mu A/cm^2$)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
13/03/2103	33	0.01287	73.00320	0.01101	0.02176	0.012870	0.016385	0.014628
15/04/2013	65	0.01474	219.75760	0.04354	0.03010	0.014740	0.036820	0.025780
14/05/2013	94	0.01587	259.21540	0.08035	0.03329	0.015870	0.056820	0.036345
15/06/2013	125	0.01897	300.56780	0.12470	0.04528	0.018971	0.084989	0.051980
25/07/2013	165	0.02385	555.46000	0.14400	0.05738	0.023850	0.100690	0.062270
22/08/2013	192	0.05922	756.69870	0.16050	0.09450	0.059220	0.127500	0.093360

I_{corr} for Beams (Atmospheric Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
13/03/2103	33	0.01015	0.00964	0.00835	0.01120	0.009895	0.009777	0.009836
15/04/2013	65	0.01189	0.00984	0.01065	0.03055	0.010863	0.020600	0.015731
14/05/2013	94	0.02297	0.01066	0.01290	0.04407	0.016815	0.028485	0.022650
15/06/2013	125	0.03971	0.01347	0.01688	0.04655	0.026590	0.031715	0.029153
25/07/2013	165	0.05037	0.02847	0.01985	0.04946	0.039420	0.034655	0.037038
22/08/2013	192	0.07580	0.04040	0.02450	0.05704	0.058100	0.040770	0.049435

I_{corr} for Beams (Atmospheric Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
13/03/2103	33	0.01555	0.00694	144.2666	291	0.011245	0.000000	0.011245
15/04/2013	65	0.01880	0.01700	150.9375	496.70700	0.017900	0.000000	0.017900
14/05/2013	94	0.01998	0.01717	175.06600	638.05850	0.018575	0.000000	0.018575
15/06/2013	125	0.02178	0.01823	192.32200	666.53240	0.020005	0.000000	0.020005
25/07/2013	165	0.02453	0.01884	194.36400	725.5040	0.021685	0.000000	0.021685
22/08/2013	192	0.03334	0.01913	194.75700	763.97520	0.026235	0.000000	0.026235

I_{corr} for Beams (Atmospheric Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	Duration (Days)	Corrosion current density I_{corr} (μA/cm²)						
		Specimen # 1		Specimen # 2		Average I_{corr} (μA/cm²)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
13/03/2103	33	0.01029	0.01070	0.01170	0.00912	0.010495	0.010410	0.010452
15/04/2013	65	0.01241	0.01125	0.01772	0.01748	0.011830	0.017600	0.014715
14/05/2013	94	0.01556	0.01285	0.01855	0.02285	0.014205	0.020700	0.017453
15/06/2013	125	0.016981	0.01665	0.01899	0.02303	0.016816	0.021010	0.018913
25/07/2013	165	0.01871	0.02184	0.01998	0.03113	0.020275	0.025553	0.022914
22/08/2013	192	0.02888	0.03023	0.07017	0.04476	0.029555	0.057465	0.043510

I_{corr} for Beams (Tidal Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion current density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
17/03/2103	37	0.04265	0.05470	0.07746	0.07057	0.048675	0.074015	0.061345
16/04/2013	66	0.1118	0.0805	0.0991	0.1377	0.096145	0.118360	0.107253
15/05/2013	95	0.1288	0.13570	0.1535	0.16005	0.132250	0.156775	0.144513
17/06/2103	127	0.1175	0.1981	0.1724	0.2802	0.157825	0.226285	0.192055
19/07/2103	159	0.22148	0.2780	0.19024	0.2950	0.249740	0.242620	0.246180
22/08/2103	192	0.2830	0.3738	0.2923	0.2197	0.328400	0.255970	0.292185

I_{corr} for Beams (Tidal Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
17/03/2103	37	0.14891	0.06935	0.11518	0.05559	0.109130	0.085385	0.097258
16/04/2013	66	0.1827	0.0884	0.1556	0.0678	0.135515	0.111695	0.123605
15/05/2013	95	0.2078	0.12761	0.1662	0.09284	0.167705	0.129515	0.148610
17/06/2103	127	0.2547	0.1315	0.1989	0.1846	0.193125	0.191740	0.192433
19/07/2103	159	0.31313	0.1352	0.24031	0.2153	0.224180	0.227820	0.226000
22/08/2103	192	0.3302	0.1495	0.2535	0.3399	0.239870	0.296685	0.268278

I_{corr} for Beams (Tidal Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
17/03/2103	37	0.10699	0.06740	0.03554	0.13467	0.087195	0.085103	0.086149
16/04/2013	66	0.1538	0.1318	0.0627	0.1795	0.142835	0.121125	0.131980
15/05/2013	95	0.1927	0.14075	0.0867	0.25343	0.166700	0.170060	0.168380
17/06/2103	127	0.1930	0.1411	0.0951	0.3154	0.167066	0.205281	0.186173
19/07/2103	159	0.19384	0.1421	0.11546	0.3614	0.167945	0.238415	0.203180
22/08/2103	192	0.22297	0.15269	0.12063	0.48805	0.187830	0.304340	0.246085

I_{corr} for Beams (Tidal Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm^2)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm^2)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
17/03/2103	37	0.06859	0.11164	0.09212	0.10920	0.090115	0.100660	0.095388
16/04/2013	66	0.0884	0.1420	0.0962	0.1069	0.115175	0.101550	0.108363
15/05/2013	95	0.1601	0.31941	0.1183	0.12205	0.239735	0.120160	0.179948
17/06/2103	127	0.1895	0.3215	0.1325	0.1231	0.255525	0.127830	0.191678
19/07/2103	159	0.25410	0.3288	0.15947	0.1241	0.291435	0.141795	0.216615
22/08/2103	192	0.28585	0.31648	0.17838	0.16668	0.301165	0.172530	0.236848

I_{corr} for beams (Tidal Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} (μA/cm²)						
		Specimen # 1		Specimen # 2		Average I_{corr} (μA/cm²)		
		WE1	WE2	WE1	WE2	WE11:WE12	WE21:WE22	WE11:WE22
17/03/2103	37	0.04628	0.03668	43.50702	0.06259	0.041480	0.062590	0.052035
16/04/2013	66	0.0464	0.0482	47.5889	0.0813	0.047260	0.081270	0.064265
15/05/2013	95	0.0769	0.07760	51.7472	0.15593	0.077255	0.155930	0.116593
17/06/2103	127	0.0785	0.0812	58.5322	0.1652	0.079832	0.165150	0.122491
19/07/2103	159	0.08044	0.0845	66.68023	0.1755	0.082460	0.175510	0.128985
22/08/2103	192	0.08587	0.19955	88.80398	0.18915	0.142710	0.189150	0.165930

I_{corr} for beams (Tidal Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
17/03/2103	37	0.08015	0.03107	0.03749	0.06645	0.055610	0.051970	0.053790
16/04/2013	66	0.1094	0.0339	0.1040	0.1127	0.071675	0.108345	0.090010
15/05/2013	95	0.1937	0.05976	0.1101	0.12774	0.126710	0.118920	0.122815
17/06/2103	127	0.2546	0.0785	0.1655	0.1741	0.166575	0.169792	0.168183
19/07/2103	159	0.26278	0.09699	0.19059	0.20382	0.179885	0.197205	0.188545
22/08/2103	192	0.3563	0.1149	0.1922	0.2215	0.235595	0.206855	0.221225

I_{corr} for beams (Below Ground Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.0520	0.1037	0.0821	0.0604	0.077845	0.071225	0.074535
05/05/2013	66	0.1631	0.17260	0.10217	0.0622	0.167855	0.082195	0.125025
31/05/2013	92	0.1981	0.1741	0.1124	0.07278	0.186115	0.092575	0.139345
03/07/2013	125	0.20149	0.18214	0.1183	0.0882	0.191815	0.103245	0.147530
29/07/2013	151	0.21082	0.1942	0.12435	0.11120	0.202515	0.117775	0.160145
28/08/2013	180	0.2207	0.1944	0.1367	0.1245	0.207590	0.130610	0.169100

I_{corr} for Beams (Below Ground Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.0125	0.0640	0.0600	0.0040	0.038270	0.032032	0.035151
05/05/2013	66	0.0196	0.07337	0.06852	0.0124	0.046470	0.040450	0.043460
31/05/2013	92	0.1018	0.0895	0.0694	0.01421	0.095665	0.041825	0.068745
03/07/2013	125	0.15460	0.16974	0.0845	0.0445	0.162170	0.064505	0.113338
29/07/2013	151	0.16721	0.2025	0.11945	0.08551	0.184878	0.102480	0.143679
28/08/2013	180	0.1884	0.2028	0.1287	0.1018	0.195607	0.115240	0.155423

I_{corr} for Beams (Below Ground Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.01961	0.04169	0.02825	0.01157	0.019610	0.019910	0.019760
05/05/2013	66	0.02404	0.12261	0.02849	0.01695	0.024040	0.022720	0.023380
31/05/2013	92	0.0272	0.24784	0.03212	0.02213	0.027200	0.027125	0.027163
03/07/2013	125	0.02743	36.7433	0.07414	0.05478	0.027430	0.064460	0.045945
29/07/2013	151	0.06565	45.554	0.09383	0.06494	0.065650	0.079385	0.072518
28/08/2013	180	0.10703	67.75903	0.12513	0.09614	0.107030	0.110635	0.108833

Icorr for Beams (Below Ground Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average Icorr (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.0088	0.0659	0.0296	0.0273	0.037315	0.028420	0.032868
05/05/2013	66	0.0100	0.0688	0.0314	0.0341	0.039385	0.032780	0.036083
31/05/2013	92	0.0164	0.0772	0.0340	0.0381	0.046795	0.036025	0.041410
03/07/2013	125	0.0242	0.1112	0.0411	0.0456	0.067680	0.043360	0.055520
29/07/2013	151	0.0344	0.1626	0.0496	0.0779	0.098479	0.063750	0.081115
28/08/2013	180	0.0471	0.2722	0.0557	0.1600	0.159680	0.107850	0.133765

I_{corr} for Beams (Below Ground Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.0138	0.0213	0.0169	0.0026	0.017570	0.009747	0.013659
05/05/2013	66	0.0148	0.0278	0.0176	0.0031	0.021305	0.010346	0.015825
31/05/2013	92	0.0204	0.0318	0.0189	0.0092	0.026105	0.014075	0.020090
03/07/2013	125	0.0294	0.0365	0.0211	0.0252	0.032940	0.023171	0.028055
29/07/2013	151	0.0397	0.0390	0.0243	0.0338	0.039340	0.029045	0.034193
28/08/2013	180	0.0422	0.0433	0.0271	0.0340	0.042765	0.030580	0.036673

I_{corr} for Beams (Below Ground Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2103	40	0.0342	0.0121	0.0443	0.0830	0.023125	0.063655	0.043390
05/05/2013	66	0.0402	0.0147	0.0509	0.0914	0.027440	0.071165	0.049303
31/05/2013	92	0.0420	0.0298	0.0519	0.0930	0.035905	0.072460	0.054182
03/07/2013	125	0.0513	0.0399	0.0519	0.1112	0.045595	0.081575	0.063585
29/07/2013	151	0.0544	0.0537	0.0527	0.1280	0.054065	0.090325	0.072195
28/08/2013	180	0.0633	0.0575	0.0528	0.1316	0.060375	0.092180	0.076278

I_{corr} for Beams (Capillary Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0377	0.10417	0.00353	0.03748	0.070955	0.020506	0.045731
05/05/2013	65	0.05019	0.1192	0.0162	0.0423	0.084715	0.029230	0.056973
29/05/2013	89	0.0903	0.1287	0.0308	0.0735	0.109490	0.052130	0.080810
03/07/2013	123	0.1325	0.1425	0.0611	0.0857	0.137510	0.073430	0.105470
28/07/2013	148	0.1947	0.1749	0.0836	0.1495	0.184800	0.116540	0.150670
27/08/2013	180	0.2371	0.2797	0.0904	0.1868	0.258380	0.138590	0.198485

I_{corr} for Beams (Capillary Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0295	0.00152	0.00115	0.00851	0.015515	0.004833	0.010174
05/05/2013	65	0.03981	0.0604	0.0014	0.0241	0.050080	0.012750	0.031415
29/05/2013	89	0.0716	0.1479	0.0023	0.0675	0.109755	0.034933	0.072344
03/07/2013	123	0.0988	0.2254	0.0090	0.0800	0.162085	0.044490	0.103287
28/07/2013	148	0.1398	0.3464	0.0201	0.1078	0.243120	0.063925	0.153523
27/08/2013	180	0.1441	0.3834	0.0295	0.1310	0.263755	0.080260	0.172008

I_{corr} for Beams (Capillary Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0012	0.00141	0.09281	0.00127	0.001316	0.047041	0.024178
05/05/2013	65	0.00132	0.0968	0.1075	0.0076	0.049045	0.057559	0.053302
29/05/2013	89	0.0013	0.1057	0.1367	0.0201	0.053485	0.078425	0.065955
03/07/2013	123	0.0345	0.1355	0.1547	0.0755	0.085001	0.115086	0.100043
28/07/2013	148	0.0642	0.1796	0.1958	0.0975	0.121865	0.146675	0.134270
27/08/2013	180	0.0734	0.1882	0.2482	0.1028	0.130775	0.175480	0.153128

I_{corr} for Beams (Capillary Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0013	0.00122	0.08095	0.01598	0.001271	0.048465	0.024868
05/05/2013	65	0.00143	0.0012	0.0898	0.0307	0.001299	0.060250	0.030775
29/05/2013	89	0.0285	0.0448	0.1031	0.0312	0.036660	0.067130	0.051895
03/07/2013	123	0.0647	0.0472	0.1254	0.0422	0.055976	0.083780	0.069878
28/07/2013	148	0.0885	0.0495	0.1376	0.0520	0.069040	0.094790	0.081915
27/08/2013	180	0.1367	0.0799	0.1460	0.1197	0.108285	0.132817	0.120551

I_{corr} for Beams (Capillary Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion current density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0021	0.00152	0.00129	0.00162	0.001798	0.001457	0.001628
05/05/2013	65	0.00999	0.0014	0.0015	0.0024	0.005692	0.001960	0.003826
29/05/2013	89	0.0194	0.0034	0.0013	0.0025	0.011426	0.001902	0.006664
03/07/2013	123	0.0211	0.0041	0.0046	0.0027	0.012638	0.003604	0.008121
28/07/2013	148	0.0244	0.0051	0.0061	0.0028	0.014770	0.004472	0.009621
27/08/2013	180	0.0284	0.0054	0.0181	0.0035	0.016870	0.010758	0.013814

I_{corr} for Beams (Capillary Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0329	0.00854	0.04241	0.00121	0.020718	0.021809	0.021263
05/05/2013	65	0.08852	0.0088	0.0866	0.0012	0.048658	0.043930	0.046294
29/05/2013	89	0.0928	0.0901	0.1239	0.0013	0.091415	0.062596	0.077006
03/07/2013	123	0.0957	0.1254	0.1452	0.0087	0.110575	0.076957	0.093766
28/07/2013	148	0.1153	0.1429	0.1755	0.0144	0.129070	0.094925	0.111998
27/08/2013	180	0.1456	0.1453	0.2160	0.0472	0.145415	0.131590	0.138503

I_{corr} for Beams (Submerged Zone)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0713	0.08886	0.06110	0.01936	0.080070	0.040230	0.060150
05/05/2013	65	0.0737	0.1103	0.06141	0.0203	0.091955	0.040865	0.066410
29/05/2013	89	0.0777	0.14495	0.08318	0.0243	0.111305	0.053762	0.082534
03/07/2013	123	0.08151	0.14515	0.08374	0.02493	0.113331	0.054336	0.083833
28/07/2013	148	0.08510	0.14681	0.0853	0.02574	0.115955	0.055540	0.085748
28/08/2013	180	0.09057	0.2343	0.0886	0.02637	0.162440	0.057480	0.109960

I_{corr} for Beams (Submerged Zone)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0077	0.01312	0.02264	0.02264	0.010391	0.022640	0.016516
05/05/2013	65	0.0157	0.0177	0.02462	0.0246	0.016700	0.024620	0.020660
29/05/2013	89	0.0307	0.01833	0.03737	0.0374	0.024510	0.037370	0.030940
03/07/2013	123	0.03477	0.02039	0.05541	0.03914	0.027580	0.047278	0.037429
28/07/2013	148	0.04541	0.02332	0.0581	0.04316	0.034366	0.050650	0.042508
28/08/2013	180	0.05607	0.0250	0.0613	0.05276	0.040535	0.057025	0.048780

I_{corr} for Beams (Submerged Zone)

Mix 3 : Conplast Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0601	0.06070	0.00823	0.03895	0.060415	0.023590	0.042003
05/05/2013	65	0.0602	0.0673	0.01022	0.0431	0.063755	0.026680	0.045218
29/05/2013	89	0.0713	0.06888	0.01289	0.0446	0.070075	0.028720	0.049398
03/07/2013	123	0.07271	0.07166	0.02114	0.04742	0.072185	0.034278	0.053231
28/07/2013	148	0.07371	0.08745	0.0285	0.04915	0.080581	0.038847	0.059714
28/08/2013	180	0.07379	0.1027	0.0365	0.05160	0.088250	0.044035	0.066143

I_{corr} for Beams (Submerged Zone)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion current density I_{corr} ($\mu A/cm^2$)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} ($\mu A/cm^2$)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0155	0.02798	0.01760	0.00146	0.021720	0.009532	0.015626
05/05/2013	65	0.0189	0.0438	0.02049	0.0019	0.031340	0.011209	0.021274
29/05/2013	89	0.0430	0.05713	0.02761	0.0024	0.050050	0.015007	0.032529
03/07/2013	123	0.06451	0.06846	0.02847	0.00284	0.066485	0.015657	0.041071
28/07/2013	148	0.07201	0.08745	0.0311	0.00378	0.079731	0.017415	0.048573
28/08/2013	180	0.09474	0.1735	0.0348	0.00594	0.134110	0.020369	0.077239

I_{corr} for Beams (Submerged Zone)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion current density I_{corr} (µA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (µA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0022	0.00208	0.01686	0.02500	0.002153	0.020930	0.011542
05/05/2013	65	0.0072	0.0056	0.02145	0.0295	0.006433	0.025460	0.015947
29/05/2013	89	0.0131	0.00587	0.03635	0.0419	0.009478	0.039145	0.024311
03/07/2013	123	0.01365	0.01208	0.04159	0.05702	0.012867	0.049305	0.031086
28/07/2013	148	0.01421	0.01251	0.0472	0.06376	0.013361	0.055491	0.034426
28/08/2013	180	0.02150	0.0131	0.0520	0.06996	0.017295	0.060990	0.039143

I_{corr} for Beams (Submerged Zone)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 10/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		Specimen # 1		**Specimen # 2**		**Average I_{corr} (μA/cm²)**		
		WE1	**WE2**	**WE1**	**WE2**	**WE11:WE12**	**WE21:WE22**	**WE11:WE22**
10/04/2013	40	0.0284	0.00911	0.02867	0.02677	0.018745	0.027720	0.023233
05/05/2013	65	0.0476	0.0192	0.03574	0.0440	0.033400	0.039880	0.036640
29/05/2013	89	0.0807	0.02413	0.03862	0.0459	0.052430	0.042255	0.047343
03/07/2013	123	0.11629	0.02634	0.04894	0.04877	0.071315	0.048857	0.060086
28/07/2013	148	0.12541	0.04234	0.0840	0.05092	0.083876	0.067460	0.075668
28/08/2013	180	0.13487	0.0502	0.1142	0.05400	0.092535	0.084095	0.088315

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average I_{corr} (µA/cm²)**
19/03/2013	**43**	0.001284	0.004810	0.001630	0.000404	0.012540	0.000704	0.003562
17/04/2013	**71**	0.003324	0.011680	0.025900	0.005451	0.022340	0.001834	0.011755
16/05/2013	**100**	0.013360	0.023730	0.037000	0.007451	0.080540	0.013510	0.029265
16/06/2013	**130**	0.043560	0.038740	0.040520	0.015230	0.097720	0.056180	0.048658
16/07/2013	**160**	0.060840	0.045600	0.046060	0.019333	0.167900	0.093440	0.072196
19/08/2013	**193**	0.170210	0.105560	0.067130	0.020790	0.083560	0.276100	0.120558

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 2 : Cemetec Inhibitor

Date of Exposure: 06/02/2013

Date	Duration (Days)	Corrosion current density I_{corr} (µA/cm²)						
		S # 1	S # 2	S # 3	S # 4	S # 5	S # 6	Average I_{corr} (µA/cm²)
19/03/2013	**43**	0.000751	0.000610	0.003811	0.001670	0.001354	0.000413	0.001435
17/04/2013	**71**	0.010770	0.007228	0.011110	0.003801	0.032900	0.011200	0.012835
16/05/2013	**100**	0.027190	0.016850	0.065330	0.012440	0.050400	0.019180	0.031898
16/06/2013	**130**	0.028640	0.019850	0.074510	0.029740	0.066310	0.022240	0.040215
16/07/2013	**160**	0.028820	0.027660	0.088060	0.047430	0.071040	0.024070	0.047847
19/08/2013	**193**	0.031830	0.034910	0.179900	0.063220	0.086440	0.030500	0.071133

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 3 : Conplast Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average I_{corr} (µA/cm²)**
19/03/2013	**43**	0.001177	0.001309	0.005873	0.004891	0.003288	0.008811	0.004225
17/04/2013	**71**	0.017850	0.003717	0.010300	0.021350	0.035450	0.023150	0.018636
16/05/2013	**100**	0.034560	0.028970	0.018920	0.040340	0.067580	0.027700	0.036345
16/06/2013	**130**	0.044210	0.033970	0.030110	0.035540	0.074256	0.030050	0.041356
16/07/2013	**160**	0.054540	0.044350	0.032470	0.051160	0.089340	0.043290	0.052525
19/08/2013	**193**	0.084030	0.063740	0.035770	0.183680	0.097850	0.047560	0.085438

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 4 : Sika901 Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average I_{corr} (µA/cm²)**
19/03/2013	**43**	0.006221	0.001035	0.006221	0.003079	0.015490	0.008693	0.006790
17/04/2013	**71**	0.036210	0.025520	0.038360	0.033140	0.038740	0.016970	0.031490
16/05/2013	**100**	0.039210	0.036530	0.038380	0.057520	0.056950	0.027400	0.042665
16/06/2013	**130**	0.048700	0.038470	0.051140	0.063330	0.069050	0.045100	0.052632
16/07/2013	**160**	0.067120	0.040020	0.061970	0.070370	0.084020	0.052970	0.062745
19/08/2013	**193**	0.096529	0.053017	0.091870	0.090190	0.103280	0.112460	0.091224

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 5 : Calcium Nitrate Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average I_{corr} (µA/cm²)**
19/03/2013	**43**	0.004477	0.001235	0.001234	0.001156	0.002535	0.003589	0.002371
17/04/2013	**71**	0.007530	0.003281	0.005210	0.004287	0.006455	0.016880	0.007274
16/05/2013	**100**	0.008968	0.003373	0.006201	0.004927	0.011650	0.021010	0.009355
16/06/2013	**130**	0.011040	0.006487	0.006222	0.015300	0.007498	0.033300	0.013308
16/07/2013	**160**	0.014260	0.009360	0.006258	0.022660	0.008787	0.044040	0.017561
19/08/2013	**193**	0.016290	0.015030	0.013340	0.033815	0.021810	0.055910	0.026033

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 6 : Sika903 Inhibitor

Date of Exposure: 06/02/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**						
		S # 1	**S # 2**	**S # 3**	**S # 4**	**S # 5**	**S # 6**	**Average I_{corr} (μA/cm²)**
19/03/2013	**43**	0.014260	0.001408	0.009790	0.006850	0.005303	0.001694	0.006551
17/04/2013	**71**	0.041130	0.005336	0.053260	0.007942	0.006876	0.017150	0.021949
16/05/2013	**100**	0.070460	0.005855	0.055900	0.013210	0.021200	0.028720	0.032558
16/06/2013	**130**	0.098840	0.016660	0.071200	0.014480	0.022400	0.031190	0.042462
16/07/2013	**160**	0.128400	0.024430	0.089570	0.019480	0.022700	0.035860	0.053407
19/08/2013	**193**	0.111974	0.045800	0.110940	0.065310	0.066770	0.098410	0.083201

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm^2)**							
		Cl^{-}(0.2%)				**Cl^{-}(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average (μA/cm^2)**	**S # 1**	**S # 2**	**S # 3**	**Average (μA/cm^2)**
24/04/2013	**15**	0.01341	0.01297	0.03432	0.0202333	0.03394	0.01029	0.02612	0.02345
24/05/2013	**45**	0.04318	0.06775	0.03918	0.0500367	0.06957	0.04753	0.05886	0.0586533
28/06/2013	**79**	0.05365	0.0694	0.0463	0.05645	0.07458	0.06991	0.08742	0.0773033
23/07/2013	**104**	0.08792	0.09123	0.08031	0.0864867	0.08663	0.08991	0.1337	0.1034133
20/08/2013	**131**	0.0959	0.19522	0.1184	0.1365067	0.131	0.1414	0.1541	0.1421667

I_{corr} for Cylinders (Without Chloride Contamination)

Mix 1 : No Inhibitor (Control)

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm^2)**							
		Cl^-(0.8%)				**Cl^-(1.5%)**			
		S # 1	**S # 2**	**S # 3**	**Average (µA/cm^2)**	**S # 1**	**S # 2**	**S # 3**	**Average (µA/cm^2)**
24/04/2013	**15**	0.01298	0.0369	0.01621	0.02203	0.0798	0.164	0.1032	0.115677
24/05/2013	**45**	0.02077	0.0931	0.05237	0.055413	0.0897	0.2283	0.2091	0.1757
28/06/2013	**79**	0.05663	0.1176	0.06114	0.078457	0.1224	0.2547	0.2613	0.2128
23/07/2013	**104**	0.08318	0.152	0.09056	0.10858	0.1599	0.3097	0.3014	0.257
20/08/2013	**131**	0.12655	0.1856	0.1425	0.15155	0.1704	0.3338	0.348	0.28408

I_{corr} for Cylinders (With Chloride Contamination)

Mix 2 : Rheocrete Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**							
		Cl¯(0.2%)				**Cl¯(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average (μA/cm²)**	**S # 1**	**S # 2**	**S # 3**	**Average (μA/cm²)**
24/04/2013	**15**	0.0036	0.00916	0.00828	0.0070153	0.00913	0.00818	0.00602	0.007776
24/05/2013	**45**	0.0464	0.02014	0.02687	0.0311367	0.03672	0.04864	0.00878	0.0313807
28/06/2013	**79**	0.0723	0.0312	0.0454	0.0496333	0.0594	0.0711	0.02511	0.05187
23/07/2013	**104**	0.1397	0.0525	0.0645	0.0855667	0.07094	0.1181	0.07128	0.0867733
20/08/2013	**131**	0.145	0.0664	0.07994	0.0971133	0.09173	0.1228	0.0851	0.0998767

I_{corr} for Cylinders (With Chloride Contamination)

Mix 2 : Rheocrete Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**							
		Cl^{-}(0.8%)				**Cl^{-}(1.5%)**			
		S # 1	**S # 2**	**S # 3**	**Average (µA/cm²)**	**S # 1**	**S # 2**	**S # 3**	**Average (µA/cm²)**
24/04/2013	**15**	0.01413	0.01378	0.02039	0.0161	0.0119	0.0353	0.0558	0.034323
24/05/2013	**45**	0.03675	0.01844	0.04281	0.032667	0.0488	0.0591	0.069	0.05897
28/06/2013	**79**	0.0542	0.04564	0.06574	0.055193	0.0641	0.0667	0.0845	0.071783
23/07/2013	**104**	0.09389	0.08243	0.09123	0.089183	0.0725	0.0852	0.1121	0.089947
20/08/2013	**131**	0.1193	0.0954	0.0977	0.104133	0.1377	0.1022	0.1822	0.1407

I_{corr} for Cylinders (With Chloride Contamination)

Mix 3 : Conplast Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**							
		Cl¯(0.2%)				**Cl¯(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average (µA/cm²)**	**S # 1**	**S # 2**	**S # 3**	**Average (µA/cm²)**
24/04/2013	**15**	0.01068	0.0085	0.00659	0.0085897	0.00877	0.00412	0.00842	0.007103
24/05/2013	**45**	0.0252	0.01443	0.00787	0.0158322	0.01112	0.01422	0.0392	0.0215133
28/06/2013	**79**	0.02655	0.04144	0.03551	0.0345	0.02169	0.0444	0.0635	0.0431967
23/07/2013	**104**	0.03365	0.06456	0.0924	0.0635367	0.07415	0.08403	0.0873	0.0818267
20/08/2013	**131**	0.1215	0.0975	0.0947	0.1045667	0.0982	0.1183	0.1016	0.1060333

I_{corr} for Cylinders (With Chloride Contamination)

Mix 3 : Conplast Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm²)**							
		Cl^{-}(0.8%)				**Cl^{-}(1.5%)**			
		S # 1	**S # 2**	**S # 3**	**Average (μA/cm²)**	**S # 1**	**S # 2**	**S # 3**	**Average (μA/cm²)**
24/04/2013	**15**	0.01237	0.02217	0.00981	0.014783	0.0347	0.0128	0.1099	0.052477
24/05/2013	**45**	0.02972	0.02956	0.04007	0.033117	0.0923	0.0149	0.1438	0.083667
28/06/2013	**79**	0.04645	0.03784	0.0494	0.044563	0.1112	0.0202	0.1541	0.095153
23/07/2013	**104**	0.09961	0.09055	0.08461	0.09159	0.1479	0.0514	0.1712	0.1235
20/08/2013	**131**	0.1262	0.09892	0.09952	0.108213	0.2163	0.1077	0.2225	0.182167

I_{corr} for Cylinders (With Chloride Contamination)

Mix 4 : Cemetec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (μA/cm^2)**							
		Cl^{-}(0.2%)				**Cl^{-}(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average (μA/cm^2)**	**S # 1**	**S # 2**	**S # 3**	**Average (μA/cm^2)**
24/04/2013	**15**	0.00623	0.00916	0.00926	0.0082157	0.00958	0.00779	0.00741	0.008258
24/05/2013	**45**	0.00953	0.01407	0.01446	0.012685	0.01139	0.00934	0.01774	0.0128233
28/06/2013	**79**	0.00966	0.0504	0.01557	0.0252103	0.01499	0.048	0.02255	0.0285133
23/07/2013	**104**	0.01444	0.07115	0.03737	0.0409867	0.02126	0.06541	0.04365	0.04344
20/08/2013	**131**	0.05228	0.08221	0.06061	0.0650333	0.04768	0.07308	0.07873	0.0664967

I_{corr} for Cylinders (With Chloride Contamination)

Mix 4 : Cemetec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} (µA/cm²)**							
		Cl¯(0.8%)				**Cl¯(1.5%)**			
		S # 1	**S # 2**	**S # 3**	**Average (µA/cm²)**	**S # 1**	**S # 2**	**S # 3**	**Average (µA/cm²)**
24/04/2013	**15**	0.00674	0.03767	0.01539	0.019933	0.0239	0.017	0.0194	0.020073
24/05/2013	**45**	0.01078	0.04675	0.07488	0.044137	0.0589	0.03	0.0504	0.046407
28/06/2013	**79**	0.02304	0.08751	0.09924	0.06993	0.0652	0.0795	0.0708	0.07183
23/07/2013	**104**	0.03741	0.1003	0.131	0.08957	0.0875	0.1567	0.1241	0.12276
20/08/2013	**131**	0.05312	0.2076	0.1695	0.143407	0.1808	0.2853	0.1899	0.218667

I_{corr} for Cylinders(With Chloride Contamination)

Mix 5 : Sika901 Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**							
		Cl^-(0.2%)				**Cl^-(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**	**S # 1**	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**
24/04/2013	**15**	0.01097	0.01296	0.00669	0.010206	0.01136	0.00879	0.01004	0.010063
24/05/2013	**45**	0.01212	0.0227	0.02945	0.0214233	0.02571	0.0334	0.02275	0.0272867
28/06/2013	**79**	0.02472	0.05409	0.0449	0.0412367	0.04441	0.04455	0.03465	0.0412033
23/07/2013	**104**	0.03894	0.07546	0.08874	0.0677133	0.0904	0.05547	0.06059	0.06882
20/08/2013	**131**	0.04926	0.089	0.0936	0.0772867	0.143	0.06877	0.09504	0.10227

I_{corr} for Cylinders (With Chloride Contamination)

Mix 5 : Sika901 Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} (µA/cm²)							
		Cl^-(0.8%)				Cl^-(1.5%)			
		S # 1	S # 2	S # 3	Average (µA/cm²)	S # 1	S # 2	S # 3	Average (µA/cm²)
24/04/2013	**15**	0.01409	0.02512	0.03238	0.023863	0.0478	0.0153	0.0514	0.03818
24/05/2013	**45**	0.01703	0.03534	0.0417	0.031355	0.1026	0.0629	0.0688	0.078083
28/06/2013	**79**	0.03858	0.05712	0.04783	0.047843	0.1092	0.0702	0.0689	0.08278
23/07/2013	**104**	0.05441	0.08133	0.08551	0.07375	0.1114	0.0877	0.088	0.095683
20/08/2013	**131**	0.08417	0.09756	0.1132	0.09831	0.136	0.135	0.1164	0.129133

I_{corr} for Cylinders (With Chloride Contamination)

Mix 6 : Calcium Nitrate Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} (µA/cm²)							
		Cl¯(0.2%)				Cl¯(0.4%)			
		S # 1	S # 2	S # 3	Average (µA/cm²)	S # 1	S # 2	S # 3	Average (µA/cm²)
24/04/2013	**15**	0.00454	0.00939	0.00921	0.007713	0.00978	0.01655	0.0103	0.0122087
24/05/2013	**45**	0.0301	0.01188	0.0116	0.0178603	0.01466	0.02508	0.0179	0.0192133
28/06/2013	**79**	0.03787	0.01987	0.01992	0.0258867	0.03574	0.03114	0.02467	0.0305167
23/07/2013	**104**	0.06331	0.03161	0.02663	0.0405167	0.04414	0.04884	0.04475	0.04591
20/08/2013	**131**	0.0736	0.05111	0.05342	0.0593767	0.0715	0.0505	0.0651	0.0623667

I_{corr} for Cylinders (With Chloride Contamination)

Mix 6 : Calcium Nitrate Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**							
		Cl^-(0.8%)				**Cl^-(1.5%)**			
		S # 1	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**	**S # 1**	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**
24/04/2013	**15**	0.01523	0.00962	0.04306	0.022636	0.0616	0.0322	0.0107	0.034823
24/05/2013	**45**	0.03332	0.02332	0.06617	0.040937	0.0822	0.0665	0.0353	0.061313
28/06/2013	**79**	0.05592	0.04632	0.0841	0.062113	0.0944	0.0783	0.0463	0.073
23/07/2013	**104**	0.0903	0.05913	0.09104	0.080157	0.1185	0.0833	0.0931	0.098297
20/08/2013	**131**	0.11239	0.07592	0.09539	0.094567	0.1241	0.1173	0.1177	0.119717

I_{corr} for Cylinders (With Chloride Contamination)

Mix 7 : Cortec Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**							
		Cl^-(0.2%)				**Cl^-(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**	**S # 1**	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**
24/04/2013	**15**	0.01423	0.01485	0.01634	0.0151403	0.01487	0.01415	0.0206	0.01654
24/05/2013	**45**	0.02221	0.01794	0.02121	0.0204533	0.04544	0.0157	0.02064	0.02726
28/06/2013	**79**	0.02841	0.0595	0.0295	0.0391367	0.04853	0.04777	0.04307	0.0464567
23/07/2013	**104**	0.04422	0.06652	0.03664	0.0491267	0.05121	0.06744	0.0688	0.0624837
20/08/2013	**131**	0.04925	0.08163	0.08256	0.0711467	0.06314	0.1109	0.094	0.0893467

I_{corr} for Cylinders (With Chloride Contamination)

Mix 7 : Cortec Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} (µA/cm²)							
		Cl¯(0.8%)				Cl¯(1.5%)			
		S # 1	S # 2	S # 3	Average (µA/cm²)	S # 1	S # 2	S # 3	Average (µA/cm²)
24/04/2013	**15**	0.03425	0.01437	0.0375	0.028707	0.0823	0.0586	0.083	0.074643
24/05/2013	**45**	0.05483	0.04783	0.04372	0.048793	0.0832	0.0995	0.1043	0.09565
28/06/2013	**79**	0.08371	0.05387	0.04996	0.062513	0.0902	0.1381	0.1238	0.117373
23/07/2013	**104**	0.0958	0.07443	0.05651	0.07558	0.1102	0.1659	0.1796	0.1519
20/08/2013	**131**	0.2281	0.0932	0.0753	0.1322	0.1488	0.1738	0.3291	0.217233

I_{corr} for Cylinders (With Chloride Contamination)

Mix 8 : Sika903 Inhibitor

Date of Exposure: 09/04/2013

Date	**Duration (Days)**	**Corrosion Current Density I_{corr} ($\mu A/cm^2$)**							
		Cl¯(0.2%)				**Cl¯(0.4%)**			
		S # 1	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**	**S # 1**	**S # 2**	**S # 3**	**Average ($\mu A/cm^2$)**
24/04/2013	**15**	0.00677	0.01009	0.0188	0.0118873	0.00859	0.02151	0.00986	0.0133207
24/05/2013	**45**	0.00758	0.02803	0.05655	0.0307213	0.01028	0.06716	0.01975	0.0323967
28/06/2013	**79**	0.01889	0.05464	0.07275	0.048759	0.02147	0.07221	0.0744	0.0560267
23/07/2013	**104**	0.0324	0.07645	0.07837	0.0624067	0.05577	0.08359	0.09566	0.07834
20/08/2013	**131**	0.05664	0.08163	0.0942	0.07749	0.168	0.117	0.1115	0.1321667

I_{corr} for Cylinders (With Chloride Contamination)

Mix 8 : Sika903 Inhibitor

Date of Exposure: 09/04/2013

Date	Duration (Days)	Corrosion Current Density I_{corr} (µA/cm²)							
		Cl¯(0.8%)				Cl¯(1.5%)			
		S # 1	S # 2	S # 3	Average (µA/cm²)	S # 1	S # 2	S # 3	Average (µA/cm²)
24/04/2013	**15**	**0.01737**	**0.01999**	**0.03025**	**0.022537**	**0.1232**	**0.0488**	**0.066**	**0.07932**
24/05/2013	**45**	**0.0214**	**0.06224**	**0.07341**	**0.05235**	**0.1288**	**0.0663**	**0.1146**	**0.103223**
28/06/2013	**79**	**0.05329**	**0.0869**	**0.1056**	**0.08193**	**0.1425**	**0.0887**	**0.1818**	**0.13768**
23/07/2013	**104**	**0.09253**	**0.102**	**0.1222**	**0.105577**	**0.2215**	**0.1356**	**0.2334**	**0.196837**
20/08/2013	**131**	**0.1431**	**0.12**	**0.152**	**0.138367**	**0.2878**	**0.1595**	**0.3318**	**0.2597**

VITA

Name : Ahmed Abdullah Alawi Al-Naghi

Nationality : Yemeni.

Date of Birth : 9th October 1979

Education :

- Graduated from high school in 1998 with grade of 86%, scientific section, Thamar, Yemen.
- Graduated from Thamar University with B.Sc. degree in the civil engineering, structural section in 2005 with grade of 91.16%.
- Received a scholarship from the Ministry of Higher Education and Thamar University to study MS degree at KFUPM in 2010.
- Finished MS program at KFUPM with GPA (3.72/4).

Work and Experience:

In 2006, appointed as a graduate assistant at Thamar University, college of engineering and I am still working there as a faculty member.

During the period from 2006 right 2010, I worked as a supervisor and engineer designer for a lot of reinforced concrete projects in both the national and private sectors in Yemen.