Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

CHLORIDE INDUCED REBAR CORROSION RESISTANCE OF AZADIRACHTA INDICA AND CALOTROPIS GIGANTEA LEAF EXTRACT

SREENIVASA M B
Assistant Professor, Centre for Post Graduate Studies, VTU, Mysuru, Karnataka.
Email: mbsreenivasa@gmail.com

Dr. M NAGESH
Professor and Head, Department of Civil Engineering, Government Engineering College, Mosalehosahalli, Hassan, Karnataka.

Dr. RAGHU BABU UPPARA
Associate Professor, Department of Civil Engineering, Srinivasa Ramanujan Institute of Technlology, Anantapura, Andhra Pradesh.

Abstract

In this study, the corrosion of rebars was examined in simulated concrete pore (SCP) solution containing 2% sodium chloride (NaCl) with different concentrations of natural green corrosion inhibitors, include Azadirachta Indica (AI) and Calotropis Gigantea (CG), ranging from 0% to 3%. Open circuit potential values, and Linear Polarization resistance (LPR), measurements used in the study to evaluate the inhibitors effectiveness in preventing corrosion. Furthermore, a comparison was made between the efficiency of the organic inhibitors and the chemical inhibitor benzotriazole (BTA). According to the findings, the green inhibitors made from leaf extracts showed passive behavior in SCP solution, particularly when compared to samples that had no inhibitors at all. The green inhibitors showed less passive behavior and comparatively higher negative potential values than the chemical inhibitors. In SCP solution containing 2% NaCl, LPR experiments showed that the inhibitors AI and CG achieved corrosion inhibition efficiencies of 38.85% and 16.21% respectively, at a 2% dosage. By comparison, the SCP solution containing BTA at an identical concentration demonstrated a 38.52% efficiency of inhibition. In a similar line, the outcomes of the accelerated corrosion test shown that the organic inhibitors, at a dose of 2%, had higher corrosion resistance than the control, demonstrating their efficacy in preventing corrosion. The specimens treated with benzotriazole exhibited superior corrosion inhibition, as evidenced by their higher time to induce the corrosion crack and lower anodic current, especially at 2% of dosage.

Keywords: Rebar Corrosion; Leaf Extract Inhibitor; Green Corrosion Inhibitor; Concrete; Lpr; Electrochemical Technique.

1. INTRODUCTION

According to G. K. Glass and N. R. Buenfeld [1] research, major economic losses and safety concerns, corrosion has a significant impact on the global construction sector. Global data shows that the annual cost of corrosion is between 3 and 4 % of the world's gross domestic product (GDP). A country's economy is also affected by corrosion-related infrastructure failure. In addition to having a negative economic impact on the construction sector, corrosion presents a major safety hazard. Corrosion damages structural integrity, increasing the risk of collapse of buildings, bridges, pipelines, and other critical infrastructure. To ensure public safety, this puts lives at risk and requires costly corrective action.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

C. Li et al. [2] found that researching corrosion mitigation methods is crucial in the construction industry. By developing effective strategies to prevent or reduce corrosionin construction industry can save maintenance and repair costs, increase the lifespan of structures, boost overall operational efficiency, and protect people from serious hazards by creating efficient techniques to avoid or reduce corrosion.

Studies have shown how corrosion harms different kinds of materials and structures and have shed light on the underlying mechanisms and processes of degradation. J. O. Okeniyiet al. [3] found that improvements in corrosion research and technology have led to the development of innovative corrosion mitigation techniques. Studies have shown that improvements in corrosion research and technology have led to the development of innovative corrosion mitigation techniques include mineral admixtures, protective coatings, corrosion inhibitors, cathodic protection systems, and materials resistant to corrosion. The construction industry may enhance the sustainability of construction projects, lower maintenance costs, boost structural durability, and lessen the impact of corrosion on infrastructure by investigating and adopting mitigating strategies. The industry's financial sustainability and safety will be significantly influenced by a proactive approach to corrosion control in the coming years. Y. Tang, Y. et al. [4] found that corrosion inhibitors are one of the most important corrosion mitigation strategies discussed above for safeguarding the embedded reinforcing steel in concrete. Their efficacy, affordability, and ease of use made them highly prized in the concrete sector. The corrosion potential of the reinforced steel is greatly decreased using corrosion inhibitors, increasing the longevity and durability of these buildings. Previous literature has reported on the efficiency of inorganic corrosion inhibitors in solutions. Calcium nitrate and nitrite inhibitors are widely used as corrosion inhibitors in concrete applications worldwide, despite their toxicity and tendency to cause skin and eye irritation. These days, researchers are interested in organic corrosion inhibitors and published reviews of the most widely used organic corrosion inhibitors along with their mechanism. When applied to concrete, organic corrosion inhibitors are likely to postpone the corrosion initiation because they are soluble in water and absorption property. It is feasible to use both synthetic and natural organic corrosion inhibitors. The synthesis and inhibitory effectiveness of green corrosion inhibitors derived from several natural chemicals are reported.

S. A. Abdulsadaet al. [5] found that natural extracts as promising green corrosion inhibitors, a shift towards sustainable corrosion protection over synthetic alternatives. The application of Oxydtron super plasticizer in conjunction with orange peel extract as a corrosion inhibitor increased the resistance to corrosion and chloride ingress into the concrete. I. Pradipta et al. [6] found that green tea extract effectively inhibits corrosion in reinforced steel rebar. Similarly, K. Kavitha et al. [7] found that Rose Damascena leafextracts increase charge transfer resistance and provide protection against chloride ions.

Azadirachta Indica extracts from leaves, roots, and seeds have been found to be effective corrosion inhibitors, with seed extract showing the highest effectiveness[8]–[13]. The study by Arab et al.[13] Found that Azadirachta Indica plant extract and iodide ions effectively inhibit aluminum corrosion in a 0.5 M HCl solution. The extract's synergistic effect suggests potential as a corrosion control method. Valdez-Salas et al.[10] Investigated the corrosion inhibiting properties of Azadirachta indica leaf extract on carbon steel in reinforced concrete structures, finding it to be a promising "green" solution. According to Peter and Sharma[14]research, by lowering mild steel anodic and cathodic reactions and promoting spontaneous and exothermic adsorption, AI extract has been demonstrated to be a promising corrosion inhibitor in extremely acidic conditions. A study examined the effectiveness of Azadirachta indica seed extract as a corrosion inhibitor for mild copper, revealing strong inhibitory properties up to 95% at 1% concentration, with phytochemical components adsorbed on copper surfaces[8]. A study by Okafor et al.[15] Also reported the adsorption of phytochemical components on metal surface, forming insoluble complexes to inhibit mild steel corrosion in H_2SO_4 solutions. The study on the corrosion inhibition of Vernonia amygdalina (Bitter Leaf) and Azadirachta indica under different acid and atmospheric exposure indicated that Azadirachta indica demonstrated superior inhibitive efficiency (85%) in hydrochloric acid solution and sulfuric acid solution, with an 83% inhibitory efficiency in the atmospheric environment after 35 days.

Azadirachta indica leaf extract and Calotropis gigantea were the inhibitors used in this research. A chemical inhibitor called benzotriazole was used to compare the performance of these organic inhibitors. In SCP solution, organic and inorganic inhibitor concentrations are assessed using electrochemical methods to provide optimum inhibitory capacity and in concrete, they are assessed using accelerated corrosion method. The main objective of the present study was to investigate the effect of organic inhibitor on the corrosion of Thermo Mechanical Treated (TMT) rebar under chloride exposure. This work addresses the evaluation of corrosion resistance of the inhibitors in a simulated concrete pore solution over an exposure period of 150 days and in concrete. This line of investigation paves the way for the development and utilization of sustainable corrosion inhibitors in concrete, contributing to the improvement of infrastructure durability and sustainability.

2. EXPERIMANTAL PROGRAM

2.1 Preparation of Rebar Test Specimen

A reinforcing steel bar with a diameter of 10 mm was cut to a length of 100 mm to prepare the test specimens. Steel specimens were polished with sandpapers. One end is connected to a copper wire, and then the surface is sealed to protect the wire connection. The specimens were again polished with sandpapers and cleaned with anhydrous alcohol and acetone to degrease the samples. The steel specimens were protected with epoxy resin, leaving 20 mm of length at another end. This bare portion of the steel specimen is only exposed to a chloride environment during the test. The schematic diagram of steel specimen, which will be used as working electrode and corrosion test setup was shown in Figure 1. [16]

2.2 Preparation of SCP Solutions

A complex mixture of Ca $(OH)_2$, NaOH, KOH and $CaSO_4 2H_2O$ makes up a typical Portland cement concrete pore solution. In this study, a mixture of 0.1 M sodium

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

hydroxide, 0.2 M potassium hydroxide, saturated calcium hydroxide and deionized water was used to simulate concrete pore solution with a pH of 13. The mixture was stirred vigorously for five minutes before being left undisturbed for a day. A 2% NaCl by volume of water was added to the solution to simulate chloride invasion. [17]

2.3 Preparation of Leaf Extract Inhibitors

Fresh leaves of Calotropis gigantea and Azadirachta indica were gathered and cleaned with distilled water to prepare leaf extracts. The leaves are then heated to 40°C for drying. After being pulverised, the leaves are sieved using a 600-micron sieve. The fine powder must next be soaked in ethanol for seven days. The powder was dried at 80°C as the last phase of the procedure and utilised as an inhibitor.[18]

2.4 Electrochemical Measurements

This work used a three-electrode system with a saturated calomel electrode as the reference, a platinum electrode as the counter, and a rebar as the working electrode. Before exposing test specimens to chloride solutions, all specimens were subjected to pre-passivation for one week in SCP solution. To investigate the efficacy of organic inhibitors, leaf extracts prepared as above were added to SCP solution along with 2% NaCl (v/v) at doses of 1%, 2% and 3%. Another experimental work was carried out on rebars subjected to SCP solutions containing chemical inhibitors BTA and SMD with dosages of 1%, 2% and 3% and NaCl 2% (v/v).

Then, electrochemical tests, including open circuit potential, linear polarization resistance, and Tafel Extrapolation tests, were performed using potentiostat for every alternate day at room temperature. LPR test potential scanning range ± 10 mV vs OCP measured at a scanning rate of 0.1 mV/s. The corrosion current density (I_{corr}) values were calculated based on the Stern-Geary equation given below:

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

Where R_p is the polarization resistance measured from the slope of the LPR plot; B is the Stern-Geary constant, which can be calculated using the equation below, after obtaining the anodic (β_a) and cathodic (β_c) slopes from the Tafel plot. The Stern-Geary constant is usually taken to be 26 mV for active corrosion state and 52 mV for passive corrosion state. The Tafel extrapolation test was performed with a scanning range of ± 120 mV at a scanning speed of 1 mV/s. [19]

$$B = \frac{\beta_a \beta_c}{2.303\,(\beta_a + \beta_c)}$$

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

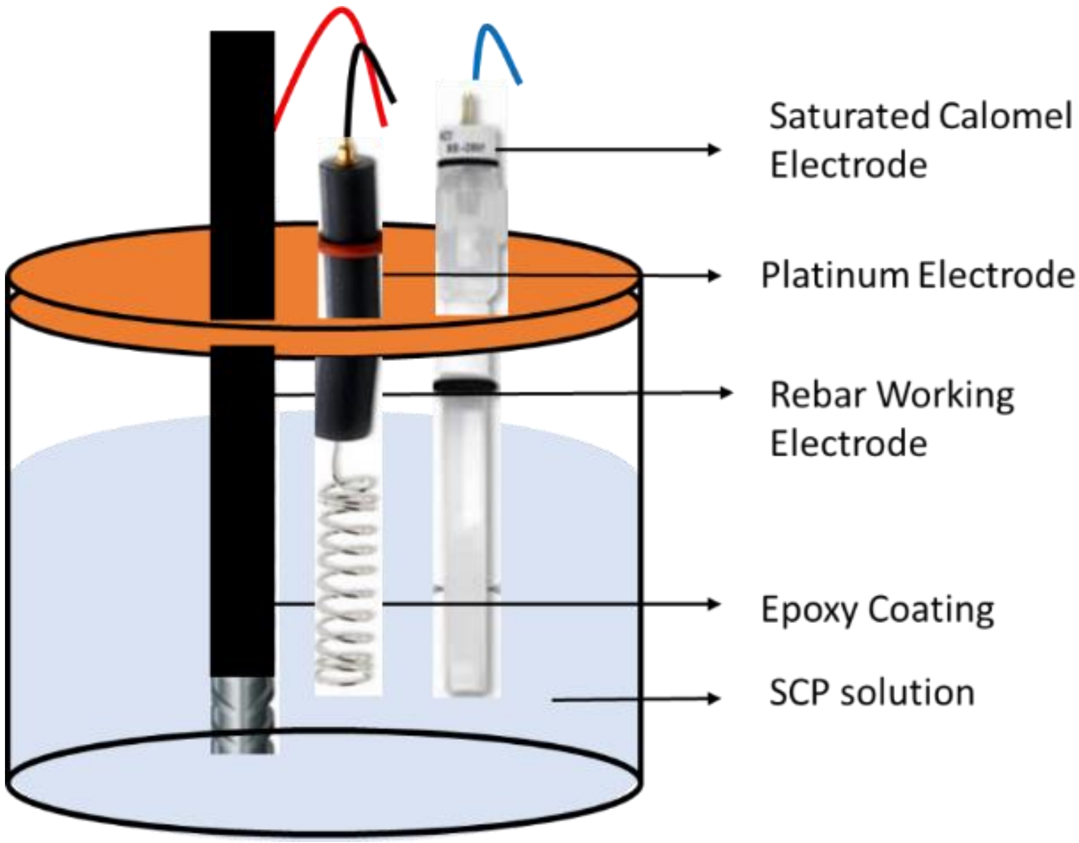

Figure 1: Electrochemical Test Setup for Corrosion Monitoring

2.5 Accelerated Corrosion Test

In order to evaluate the corrosion resistance against chloride induced corrosion, the accelerated corrosion technique is used. In this setup an external stainless-steel rod served as the cathode, while a 2.5% NaCl solution served as the electrolyte. Rebar is embedded in concrete to act as anode. Figure 2 presents a diagram of the test setup. Between the stainless-steel rod and the rebar, an external DC source providing a voltage of 12 V is supplied until the specimen cracks. The time taken for the concrete to crack for the first time was measured and the accompanying anodic current was recorded every two hours. This accelerated test was only used on specimens made of concrete that had 2% of various inhibitors added to it. Cylindrical specimens were subjected to accelerated corrosion testing after being maintained under laboratory conditions for four months after completion of the water curing process. [20]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

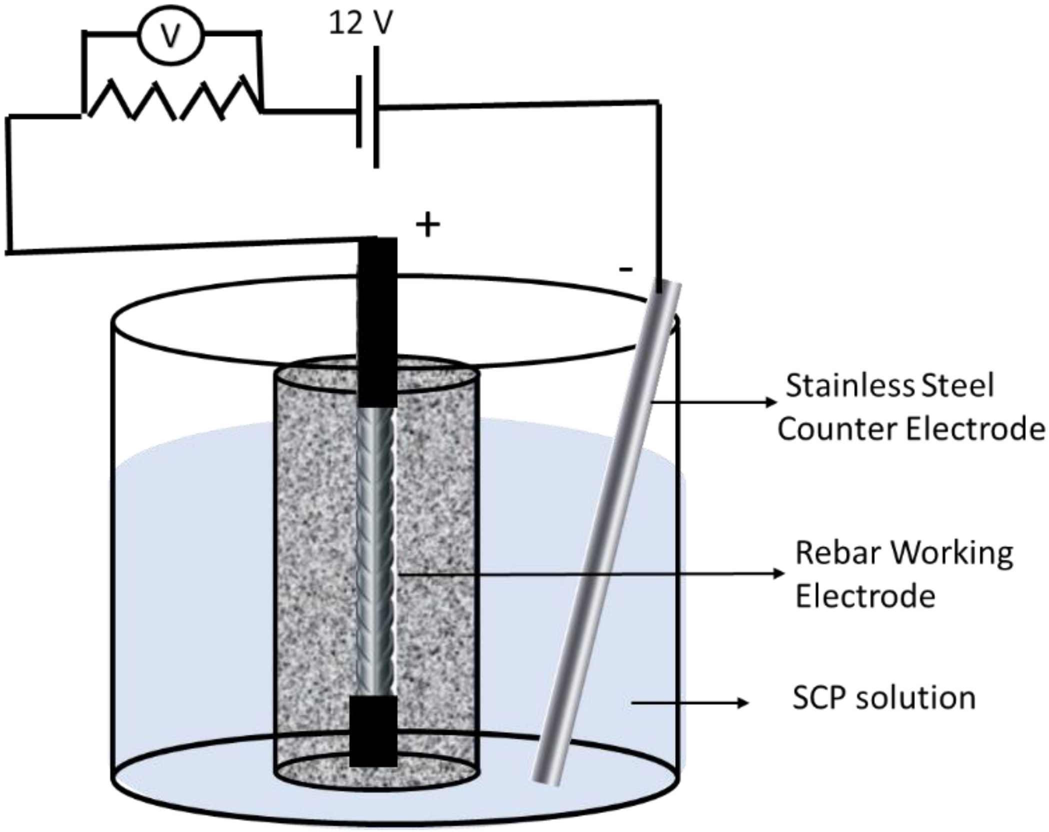

Figure 2: Accelerated Corrosion Test Setup

3. RESULTS AND DISCUSSIONS

3.1 Corrosion Potential values

Open circuit potential (OCP) of rebar in SCP solution containing 2% NaCl with various % ages of both organic and in organic inhibitors with respect to SCE over an exposure period of 180daysis as shown in figure 3a and 3b.Figure 3a and 3bshowthepotential-time behavior of rebar in SCP solution containing 2% NaCl with 0%, 1%, 2%, and 3% of AI and CG respectively. Corrosion risk of rebars subjected to different inhibitors has been interpreted using the OPC values as per the ASTM C876 recommendations as shown in Table 1. In Fig.3a and 3b, the line ASTM threshold represents the 90% corrosion probability. The potential values more negative than this line represents the high risk of corrosion of rebar. In other words, it can also be considered as corrosion that has been initiated on rebar with reaching the potential values to the threshold potential line. The time to initiate the corrosion of rebar subjected to SCP solution with different %ages of inhibitor was tabulated in Table 2.

While observing AI inhibition, the corrosion initiation time was increased from 9 to 28 days, with the dosage level increasing from 0% to 2%. On the other hand, CG inhibitor increased the corrosion initiation time from 9 to 17 days and BTA inhibitor from 9 to 32 days, increasing the dosage from 0% to 3%. That is, with increase in the dose of inhibitors, the

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

corrosion initiation time also increased, but it was limited to 2% in AI and continued further in case of CG and BTA. Comparing the organic inhibitors performance, AI inhibitor delayed the corrosion initiation time of rebars compared to those subjected to CG inhibitor. In addition, at 3% of AI inhibitor, samples had a potential of about -500 mV, while samples subjected to CG inhibitor were over -600 Mv at the same dose and time.

When comparing the effectiveness of organic inhibitors to chemical inhibitors, AI and BTA exhibited very identical trends and arrived at the corrosion initiation time nearly simultaneously up to a 2% dose. While BTA performed effectively, AI performance decreased at a dose of 3% inhibitor.

Table 1: Interpretation of Potentials Vs SCE for Corrosion Risk as per ASTM C876 [19]

Open Circuit Potential (E_{corr}) mV Vs SCE	Corrosion risk
E_{corr}> -125 mV	Low (10%) risk of corrosion
-126mV ≤ E_{corr} ≤ -275 mV	Intermediate (50%) risk of corrosion
E_{corr} ≤ -275 mV	High (>90%)risk of corrosion
E_{corr} ≤ -425 mV	Severe corrosion

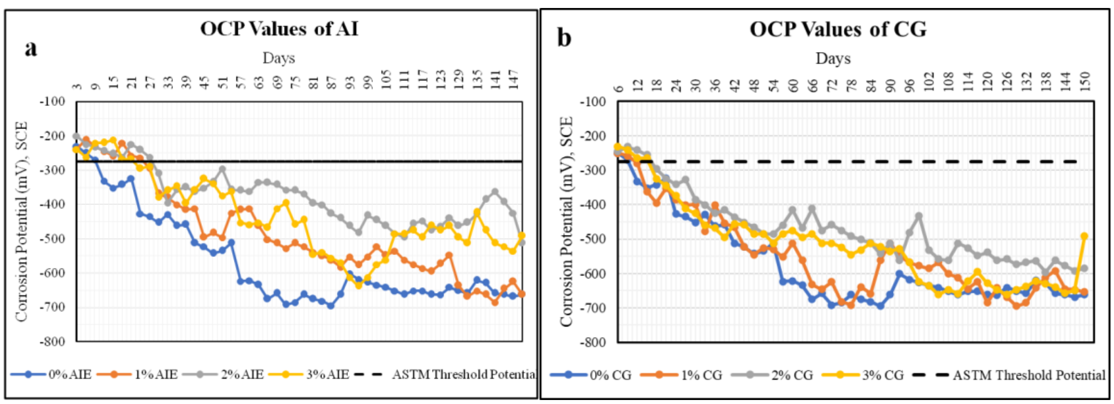

Figure 3: Open Circuit Potential Values of a) AI b) CG Inhibitors

Table 2: Number of Days to Initiate the Corrosion of Rebar Subjected to Different Inhibitors

%age of Inhibitor	AI	CG	BTA
0%	9	9	9
1%	25	11	27
2%	28	15	29
3%	22	17	32

3.2 Corrosion Current Density

Corrosion current density values were monitored over a period of 150 days to evaluate the corrosion inhibition performance of inorganic inhibitor benzotriazole and organic inhibitors AI and CG on rebar subjected to chloride environment. 4a, b and c show the corrosion current density values of the specimens subjected to AI, CG and BTA respectively. The I_{corr} value trends show that, regardless of the inhibitor type, corrosion increases with exposure period up to 180 days at all inhibitor concentrations. According

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

to I_{corr} values, the conditions of rebar exposed to a chloride environment and inhibitors of various dosages, are interpreted using the Table 3 as passive, low to moderate corrosion, moderate to severe corrosion, and very high corrosion. Observing the trends, it is very clear that the specimens without inhibitors turned to severe corrosion earlier than the specimens with inhibitors in almost all types of inhibitors. This means that organic inhibitors also work to prevent corrosion of rebar in chloride environments. Looking deeper into the dose effect on corrosion, 3% inhibitors performed poorly compared to 1 and 2% doses in both AI and CG. The I_{corr} values of the samples subjected to 3% dosage had higher corrosion current density values compared to the others in almost two organic inhibitors. In contrast, samples exposed to the chemical inhibitor BTA showed a gradual decrease in corrosion current density values with increasing dosage from 1 to 3%.Prior to AI and BTA, the corrosion current density values of CG reached high corrosion condition. This indicates that the specimens subjected to AI inhibitor outperformed CG in terms of their ability to withstand corrosion induced by chloride. For a longer duration, the chemical inhibitor BTA outperformed the AI inhibitor in keeping the corrosion current density values below 1 µA/cm^2.

Table 3: Criteria for Assessing the Condition of Rebar using Icorr [19]

Condition of rebar	I_{corr} (µA/cm^2)
Passive	< 0.1
Low to moderate corrosion	0.1 – 0.5
Moderate to high corrosion	0.5 – 1.0
Very high	> 1.0

The efficiency of inhibitor was calculated from i_{corr} values using the below equation[21]–[23].

$$\text{Inhibitor efficiency } \% = \frac{I_{corr} - I_{Corr(Inh)}}{I_{corr}} \text{ X } 100$$

Where I_{corr} and $I_{corr(inh)}$ are the corrosion current density of rebar subjected to SCP solutions with and without inhibitor. Overall efficiency of the inhibitors used in the current study was tabulated as shown in Table 4. With a dosage increase of 1 to 2%, the overall efficiency of the AI inhibitor went from 29.35 to 38.85%.The efficiency of AI was not increased by further dosage increment. CG also showed an increase in efficiency from 12.7 to 16.21 % when the dosage was increased from 1 to 2%, and a further decrease at a dosage of 3%.On the other hand, the efficiency of BTA gradually increased from 30.86 to 41.46% with dose increase from 1 to 3%. It is noteworthy that 2% dosage of organic inhibitors AI and CG showed better performance by delaying corrosion initiation, maintaining moderate to severe corrosion band for longer duration and improved corrosion efficiency.

When comparing the inhibitors efficiency, AI, CG, and BTA shown 29.35%, 12.7%, and 30.86% at 1% of dosage and 38.85%, 16.21 %, and 38.52 %, respectively, at 2% of dosage. Similarly, the inhibitory efficiencies of AI, CG, and BTA were 28.73 %, 9.15 %, and 41.46%, respectively, at a dosage of 3%. It is evident that the inhibitors corrosion inhibition efficiency decreases in the following order: BTA>AI>CG. When comparing the

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

two organic inhibitors, AI improved corrosion inhibition efficiency by a factor of 2-3 relative to CG efficiency. Comparing AI with chemical inhibitor BTA upto 2% there is no significant difference in efficiency, but at 3% dosage BTA almost 1.5 times that of AI.

Table 4: Efficiency of Organic and Inorganic Inhibitors

Inhibitor	AI	CG	BTA
1%	29.35	12.7	30.86
2%	38.85	16.21	38.52
3%	28.73	9.15	41.46

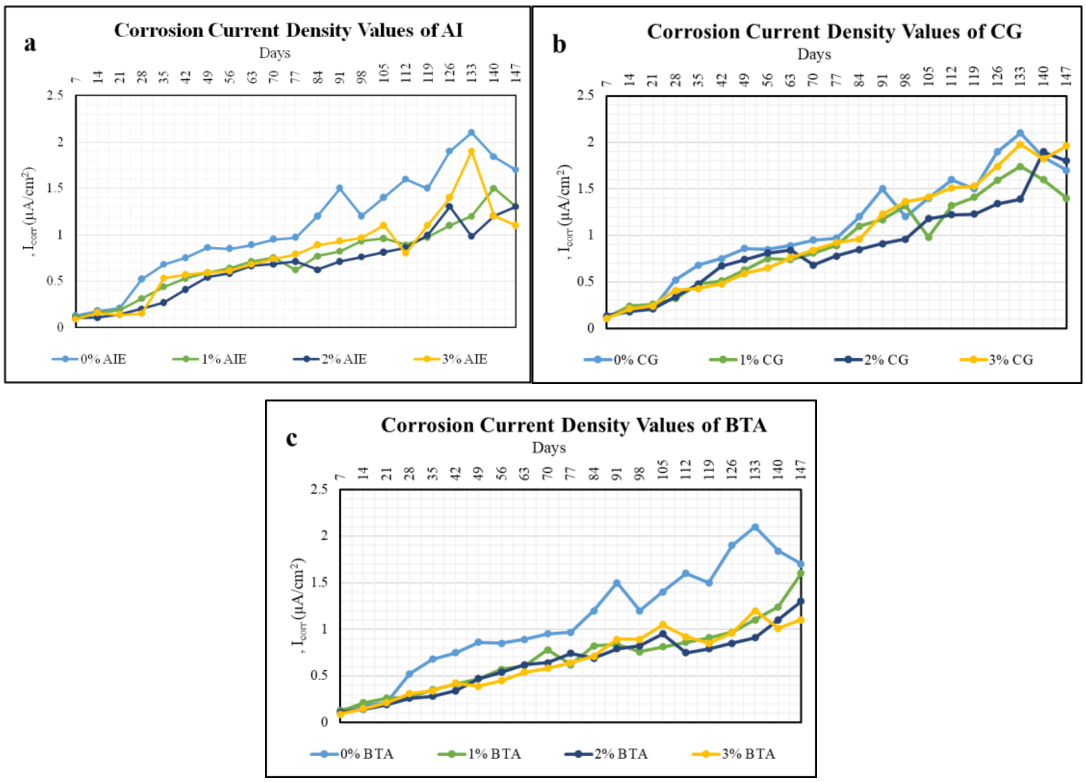

Figure 4: Variation in Corrosion Current Density Values during Exposure to a) AI b) CG c) BTA

3.3 Accelerated Corrosion Test

Table 5 reports the results of the accelerated corrosion test for specimens of reinforced concrete that were both with and without an inhibitor. It was found that after 94–99 hours, the rebar embedded in the concrete specimen with AI caused a crack, but after 85–91 hours, the specimens without any inhibitor caused a crack. The first crack appeared in the reinforced concrete specimens with CG after 87–89 hours, whereas the first crack appeared in the specimens with BTA after 96–101 hours. In contrast to those composed of CG and AI, it demonstrated that the chemical inhibitor BTA postponed the corrosion crack. AI outperformed CG in terms of delaying the corrosion crack and having lower anodic current values, according to observations of the organic inhibitors.

ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

As for organic inhibitors, samples exposed to CG inhibitors performed poorly compared to AI. This was confirmed from the test results which showed that the CG samples had reduced corrosion initiation time and showed lower corrosion potential. In addition concrete samples mixed with CG induced early corrosion cracking and showed higher anodic current than samples mixed with AI. Both the high tannin content and the numerous complex triterpene glycosides that are present in AI are responsible for its exceptional corrosion inhibition property. Although CG did not perform as well as AI, it also reduced corrosion caused by chloride. However, the performance of AI is almost close to that of the chemical inhibitor BTA at the same dosage by reducing the corrosion initiation time and induction time of corrosion cracking in concrete.

Table 5: Results of Accelerated Corrosion Test

System	Time to crack in hrs	Maximum current (mA)
Without Inhibitor	85-91	35-36
AI	94-99	29-31
CG	87-89	34-35
BTA	96-101	28-31

4. CONCLUSION

This study was designed to evaluate the effect of organic inhibitors, specifically CG and AI, by using electrochemical methods on SCP solution and accelerated corrosion testing on concrete samples. After testing the samples for 150 days to determine the optimum dosage and performance of inhibitors, the following results were reached:

1. The chloride-induced corrosion was inhibited by the organic inhibitors AI and CG; however, AI inhibitor outperformed CG in terms of lowering the corrosion initiation time and increasing the corrosion inhibition efficiency.
2. Additionally, it has been observed that the optimum dosage for organic inhibitors is 2%, while inorganic inhibitors performed better at dosage levels higher than 2 %.
3. From accelerated corrosion test on reinforced concrete specimens, the AI inhibitor performance was confirmed by delaying the corrosion crack and showing lesser anodic current value.
4. AI inhibitor performance was compared with chemical inhibitor BTA, both inhibitors showed similar trend at about 2 % dosage. The performance of the AIinhibitor was reduced and the BTA performance steadily increased after a dosage of 2%.

References

1) G. K. Glass and N. R. Buenfeld, “Chloride-induced corrosion of steel,” *Prog. Struct. Eng. Mater.*, vol.

2, no. 4, pp. 448–458, 2000.

2) C. Li, L. Jiang, and S. Li, "Effect of limestone powder addition on threshold chloride concentration for steel corrosion in reinforced concrete," *Cem. Concr. Res.*, vol. 131, no. February, p. 106018, May 2020, doi: 10.1016/j.cemconres.2020.106018.

3) J. O. Okeniyi, C. A. Loto, and A. P. I. Popoola, "Effects of Phyllanthus muellerianus leaf-extract on steel-reinforcement corrosion in 3.5% NaCl-immersed concrete," *Metals (Basel).*, vol. 6, no. 11, Nov. 2016, doi: 10.3390/met6110255.

4) Y. Tang, Y. Zuo, J. Wang, X. Zhao, B. Niu, and B. Lin, "The metastable pitting potential and its relation to the pitting potential for four materials in chloride solutions," *Corros. Sci.*, vol. 80, pp. 111–119, Mar. 2014, doi: 10.1016/j.corsci.2013.11.015.

5) S. A. Abdulsada and T. I. Török, "Studying chloride ions and corrosion properties of reinforced concrete with a green inhibitor and plasticizers," *Struct. Concr.*, vol. 21, no. 5, pp. 1894–1904, Oct. 2020, doi: 10.1002/suco.201900580.

6) I. Pradipta, D. Kong, and J. B. L. Tan, "Natural organic antioxidants from green tea inhibit corrosion of steel reinforcing bars embedded in mortar," *Constr. Build. Mater.*, vol. 227, p. 117058, Dec. 2019, doi: 10.1016/j.conbuildmat.2019.117058.

7) K. Kavitha, H. B. Sherine, and S. Rajendran, "Rosa damascena (Damask Rose) as corrosion inhibitor for mild steel in simulated oil well water medium," *Int. J. Corros. Scale Inhib.*, vol. 11, no. 2, pp. 851–861, 2022, doi: 10.17675/2305-6894-2022-11-2-26.

8) T. V Sangeetha and M. Fredimoses, "Inhibition of mild copper metal corrosion in HNO3 Medium by acid extract of Azadirachta Indica seed," *E-Journal Chem.*, vol. 8, no. SUPPL. 1, pp. S1–S6, 2011, doi: 10.1155/2011/135952.

9) L. Valek and S. Martinez, "Copper corrosion inhibition by Azadirachta indica leaves extract in 0.5 M sulphuric acid," *Mater. Lett.*, vol. 61, no. 1, pp. 148–151, Jan. 2007, doi: 10.1016/j.matlet.2006.04.024.

10) B. Valdez-Salas *et al.*, "Azadirachta indica leaf extract as green corrosion inhibitor for reinforced concrete structures: Corrosion effectiveness against commercial corrosion inhibitors and concrete integrity," *Materials (Basel).*, vol. 14, no. 12, p. 3326, Jun. 2021, doi: 10.3390/ma14123326.

11) K. K. Patel and R. T. Vashi, "Azadirachta indica extract as corrosion inhibitor for copper in nitric acid medium," *Res. J. Chem. Sci.*, vol. 5, no. 11, pp. 59–66, 2015, [Online]. Available: www.isca.me

12) B. S. Swaroop, S. N. Victoria, and R. Manivannan, "Azadirachta indica leaves extract as inhibitor for microbial corrosion of copper by Arthrobacter sulfureus in neutral pH conditions-A remedy to blue green water problem," *J. Taiwan Inst. Chem. Eng.*, vol. 64, pp. 269–278, Jul. 2016, doi: 10.1016/j.jtice.2016.04.007.

13) S. T. Arab, A. M. Al-Turkustani, and R. H. Al-Dhahiri, "Synergistic effect of Azadirachta Indica extract and iodide ions on the corrosion inhibition of aluminium in acid media," *J. Korean Chem. Soc.*, vol. 52, no. 3, pp. 281–294, 2008, doi: 10.5012/jkcs.2008.52.3.281.

14) A. Peter and S. K. Sharma, "Use of Azadirachta indica (AI) as green corrosion inhibitor against mild steel in acidic medium: Anti-corrosive efficacy and adsorptive behaviour," *Int. J. Corros. Scale Inhib.*, vol. 6, no. 2, pp. 112–131, 2017, doi: 10.17675/2305-6894-2017-6-2-2.

15) P. C. Okafor, E. E. Ebenso, and U. J. Ekpe, "Azadirachta indica extracts as corrosion inhibitor for mild steel in acid medium," *Int. J. Electrochem. Sci.*, vol. 5, no. 7, pp. 978–993, 2010, doi: 10.1016/s1452-3981(23)15337-5.

16) Fei-long Fei, Jie Hu, "Corrosion performance of steel reinforcement in simulated concrete pore solutions in the presence of imidazoline quaternary ammonium salt corrosion inhibitor" *Construction and Building Materials, Vol. 70, pp. 43-53, 2014*

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 12-2023
DOI: 10.5281/zenodo.10352135

17) Rajan Anitha, Subramanian Chitra, "Implications of eco edition inhibitor to mitigate corrosion in reinforced steel embedded in concrete" *Construction and Building Materials, vol. 213, pp. 246-256, 2019*

18) Kavitha Rose, Byoung-Suhk, "Surface protection of steel in acid medium by Tabernaemontana divaricate extract: Physicochemical evidence for adsorption of inhibitor" *Journal of molecular liquids, vol. 214, pp. 111-116, 2016*

19) Ha-Won Song and Velu Saraswathy, "Corrosion Monitoring of Reinforced Concrete Structures – A Review" *Int. J. Electrochem. Sci., vol. 2, pp. 1-28, 2007.*

20) U. Raghu Babu and B. Kondraivendhan, "Corrosion performance evaluation of rebar in metakolin blended concrete" *Emerging trends in civil engineering, pp. 335-344, 2020*

21) N. Arioglu, Z. Canan Girgin, and E. Arioglu, "Evaluation of Ratio between Splitting Tensile Strength and Compressive Strength for Concretes up to 120 MPa and its Application in Strength Criterion," *ACI Mater. J.*, vol. 103, no. 1, pp. 18–24, 2006, doi: 10.14359/15123.

22) U. Raghu Babu and B. Kondraivendhan, "Impact of sulphate on chloride-induced corrosion of steel in concrete," *Indian Concr. J.*, vol. 93, no. 7, pp. 8–17, 2019, [Online]. Available: http://www.scopus.com/inward/record.url?eid=2-s2.0-85077509050&partnerID=MN8TOARS

23) A. A. ElShami, S. Bonnet, M. H. Makhlouf, A. Khelidj, and N. Leklou, "Novel green plants extract as corrosion inhibiting coating for steel embedded in concrete," *Pigment Resin Technol.*, vol. 49, no. 6, pp. 501–514, Oct. 2020, doi: 10.1108/PRT-09-2019-0078.