
ENHANCING SERVICE LIFE OF REINFORCED CONCRETE THROUGH BIPOLAR TRAVERSING TYPE CORROSION INHIBITING (TTCI) ADDITIVES- A REVIEW

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Article Received: 08 March 2026

Article Revised: 28 March 2026

Published on: 18 April 2026

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DOI: <https://doi-doi.org/101555/ijrpa.2751>

ABSTRACT

Corrosion of reinforcing steel is a major factor affecting the durability and service life of reinforced concrete structures, particularly in aggressive environmental conditions such as marine exposure and industrial zones. This review paper focuses on the role of Bipolar Traversing Type Corrosion Inhibiting (TTCI) additives as an innovative approach to mitigating reinforcement corrosion. TTCI additives function by forming a protective bipolar film on the steel surface, which restricts both anodic and cathodes reactions responsible for corrosion processes. The study compiles and analyzes existing literature on the mechanism, effectiveness, and performance of TTCI additives in concrete systems. Key aspects such as improved durability, resistance to chloride ion penetration, enhanced service life, and compatibility with supplementary cementations materials are discussed. Additionally, the environmental and economic benefits of using TTCI additives are highlighted, emphasizing their contribution to sustainable construction practices. The review concludes that TTCI additives present a promising solution for extending the lifespan of reinforced concrete structures, although further experimental validation and long-term field studies are recommended.

KEYWORDS: Reinforced Concrete, Corrosion Inhibition, TTCI Additives, Durability Enhancement, Service Life Extension, Steel Reinforcement Corrosion

INTRODUCTION

Reinforced concrete (RC) is one of the most widely used construction materials in modern infrastructure due to its strength, versatility, and cost-effectiveness. It is extensively employed in bridges, buildings, highways, marine structures, and industrial facilities. However, despite its widespread application, the durability of reinforced concrete structures is often compromised by the corrosion of embedded steel reinforcement. Corrosion is recognized as one of the leading causes of premature deterioration in RC structures, significantly reducing their service life and increasing maintenance and repair costs.

The primary cause of reinforcement corrosion is the breakdown of the protective passive layer surrounding steel in concrete. Under normal conditions, the high alkalinity of concrete (pH ~12.5–13.5) forms a thin oxide layer on the steel surface, which prevents corrosion. However, environmental factors such as chloride ion ingress (from seawater or de-icing salts), carbonation (reaction of carbon dioxide with calcium hydroxide), moisture, and oxygen can disrupt this passive layer. Once passivation occurs, electrochemical reactions initiate, leading to the formation of rust. The corrosion products occupy a larger volume than the original steel, causing internal stresses, cracking, spalling, and eventual structural failure. In aggressive environments such as coastal regions, industrial zones, and areas exposed to chemical attack, the rate of corrosion accelerates considerably. This necessitates the development of effective strategies to enhance the durability and extend the service life of reinforced concrete structures. Conventional methods for corrosion protection include increasing concrete cover, using low-permeability concrete, applying surface coatings, cathode protection, and using corrosion-resistant reinforcements such as epoxy-coated or stainless steel bars. While these methods are effective to varying degrees, they often involve high costs, complex application procedures, or long-term maintenance challenges.

In recent years, the use of corrosion inhibitors has emerged as a promising and economical approach for mitigating steel corrosion in concrete. Corrosion inhibitors are chemical compounds that, when added in small quantities to concrete, significantly reduce the rate of corrosion of embedded steel without adversely affecting the mechanical properties of concrete. These inhibitors function by modifying the electrochemical reactions occurring at the steel surface, either by forming a protective film, reducing the permeability of concrete, or interfering with anodic and/or cathode reactions.

Among the various types of corrosion inhibitors, Bipolar Traversing Type Corrosion Inhibiting (TTCI) additives represent an advanced and innovative class of admixtures. TTCI additives are designed to provide dual protection by acting on both anodic and cathode sites of the corrosion cell. Unlike traditional inhibitors that target a single reaction mechanism, TTCI additives traverse through the concrete matrix and establish a protective environment around the reinforcement, thereby enhancing the overall corrosion resistance. These additives typically consist of organic and inorganic compounds that penetrate the concrete, adsorb onto the steel surface, and form a stable, protective barrier that resists chloride attack and moisture ingress.

The concept of bipolar inhibition is particularly advantageous in complex exposure conditions where both anodic metal dissolution and cathode oxygen reduction reactions occur simultaneously. By suppressing both processes, TTCI additives ensure a more comprehensive and sustained corrosion protection mechanism. Furthermore, their ability to migrate through the concrete matrix allows them to reach deeper reinforcement layers, making them effective even in existing structures where direct access to steel is limited. In addition to corrosion resistance, TTCI additives contribute to improving the durability properties of concrete, such as reduced permeability, enhanced resistance to chloride penetration, and improved microstructural integrity. This not only extends the service life of structures but also aligns with sustainable construction practices by reducing the need for frequent repairs and minimizing material consumption. This review aims to provide a comprehensive overview of Bipolar Traversing Type Corrosion Inhibiting (TTCI) additives in reinforced concrete. It focuses on their mechanism of action, types, effectiveness, and influence on mechanical and durability properties of concrete. The study also examines existing research findings, highlights the advantages and limitations of TTCI additives, and identifies future research directions for their effective implementation in modern construction practices. Through this review, an effort is made to establish TTCI additives as a viable solution for enhancing the longevity and performance of reinforced concrete structures in aggressive environments.

Literature review

Yuvaraj Subramaniyan et al (2024) was study on assessing the effectiveness of corrosion inhibitors incorporated into M30 grade concrete, prepared according to Indian Standards, to enhance the durability of reinforced concrete structures. Different mix proportions containing various inhibitor combinations were cast and subjected to a comprehensive set of durability

and electrochemical tests, including pH measurement to evaluate alkalinity, weight loss measurement to quantify corrosion damage, Open Circuit Potential (OCP) to assess corrosion tendency, impressed voltage tests to accelerate corrosion conditions, Rapid Chloride Penetration Test (RCPT) to determine permeability, and chloride diffusion coefficient analysis to study ion transport behavior. In addition, mechanical performance was evaluated through compressive strength and flexural strength tests to ensure that the inclusion of inhibitors does not compromise structural integrity. The results revealed that amine-based inhibitors significantly improve concrete performance by creating a pore-blocking effect, which reduces the ingress of harmful chloride ions—one of the primary causes of reinforcement corrosion. Electrochemical studies, including polarization and impedance measurements after electrochemical injection, demonstrated a marked decrease in corrosion rates of embedded steel even under aggressive chloride exposure. Furthermore, Infrared (IR) spectroscopy confirmed the presence of inhibitor molecules forming a protective layer on the steel surface, thereby enhancing corrosion resistance. Overall, the study concludes that the use of such inhibitors not only improves durability by mitigating corrosion but also maintains the mechanical strength of concrete, making it a viable solution for extending the service life of reinforced concrete structures in harsh environments.

Tangudu Manoj et al (2024) Reinforced concrete (RC) structures are widely used in construction because they combine the high compressive strength of concrete with the tensile strength of embedded steel reinforcement, ensuring durability and structural efficiency; however, one of the most critical challenges affecting their long-term performance is the corrosion of steel reinforcement, which occurs due to the ingress of moisture, oxygen, and aggressive agents such as chlorides or carbon dioxide, leading to the formation of rust that expands in volume, induces internal tensile stresses, and ultimately causes cracking, spalling, and delamination of the surrounding concrete, thereby weakening the bond between steel and concrete and compromising the load-carrying capacity of the structure, which can result in costly maintenance, safety hazards, or even structural failure; therefore, studying corrosion mechanisms is essential as it helps in understanding electrochemical processes involved and supports the development of effective mitigation strategies such as using corrosion-resistant materials, applying protective coatings, or adopting cathode protection systems; in this investigation, the extent of damage in RC flexural members was evaluated at two corrosion levels—no corrosion and 10% corrosion—using non-destructive testing (NDT) techniques, which allow for assessment of internal deterioration without damaging the specimens by

measuring parameters like crack development, surface condition, and internal integrity; additionally, the study compared the performance of different corrosion protection methods including epoxy coating, cementations grout, geopolymer coating, red oxide coating, and polythene wrapping, and the results clearly indicated that geopolymer-based protection was the most effective among all, primarily due to its ability to create a highly alkaline and dense protective layer around the reinforcement that enhances passivation of steel, reduces permeability, and significantly slows down the corrosion process, thereby improving the durability and service life of reinforced concrete structures more efficiently than conventional protective measures.

Abdulrahman A. S et al (2012) corrosion inhibitors are incorporated into concrete to enhance its durability, structural integrity, and service life by protecting embedded steel reinforcement from deterioration, particularly due to chloride ingress and moisture. Traditionally, these inhibitors are classified into organic (such as amine-based compounds) and inorganic types (such as nitrite-based compounds), alongside other corrosion protection techniques like cathodic protection, protective coatings, penetrating sealers, and chloride extraction methods. While amine and nitrite inhibitors have been widely used in high-performance concrete, they present limitations including environmental toxicity, high cost, and lack of local availability in many developing regions, as well as limited effectiveness in completely preventing chloride-induced corrosion. To address these drawbacks, recent research has focused on eco-friendly alternatives, such as green plant-based inhibitors. In this study, a novel hydrophobic inhibitor derived from (bamboo extract) was evaluated and compared with conventional inhibitors like calcium nitrite and ethanolamine over a 180-day exposure period. The performance was assessed using compressive strength tests and advanced electrochemical techniques, including Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR), which provide insights into corrosion behavior and resistance. The results demonstrated that the bamboo-based inhibitor not only improved compressive strength but also exhibited the lowest corrosion rate among all tested inhibitors, likely due to its hydrophobic nature that reduces moisture and chloride penetration into concrete. Additionally, being environmentally benign and sustainable, extract shows strong potential as a superior alternative to traditional nitrite and amine-based corrosion inhibitors for enhancing the long-term durability of reinforced concrete structures.

Jerzy zemajtis et al(1999) experimental study evaluated the effectiveness of corrosion inhibitor admixtures (CIA) from three manufacturers and galvanized steel (GS) in reinforced concrete specimens exposed to conditions simulating bridge environments (horizontal, vertical, tidal, and immersed zones) using repeated ponding with 6% sodium chloride solution. The results showed that chloride levels at the reinforcement depth were high enough to initiate corrosion in all cases, and neither CIA nor control mixes significantly reduced chloride ingress or diffusion. Corrosion potential measurements revealed that specimens with Arimatec 2000 behaved worst, indicating about a 90% probability of active corrosion, while those with Rheocrete 222 showed uncertain corrosion risk similar to control specimens, and DCI-S performed best, indicating a high probability of no corrosion. Corrosion rate data further confirmed that control and Aromatic 2000 specimens had the highest corrosion rates, suggesting damage within 2–10 years, whereas Rheocrete 222 showed moderate improvement with expected damage in 10–15 years, and DCI-S consistently showed the lowest corrosion rates, also extending the expected damage period to 10–15 years, demonstrating its relatively superior performance among the tested inhibitors.

METHODOLOGY

This study adopts a systematic review and experimental-oriented methodology to evaluate the effectiveness of Bipolar Traversing Type Corrosion Inhibiting (TTCI) additives in enhancing the service life of reinforced concrete.

The methodology integrates:

- Literature review
- Material characterization
- Mix design and specimen preparation
- Durability and corrosion assessment tests
- Data analysis and interpretation

This study adopts a structured experimental and literature-based methodology to evaluate the effectiveness of Bipolar Traversing Type Corrosion Inhibiting (TTCI) additives in reinforced concrete. A systematic literature review is conducted using peer-reviewed journals, IS codes such as IS 456:2000 and IS 516, and recent research (last 10–15 years) focusing on corrosion mechanisms, types of inhibitors, and durability enhancement. Concrete is prepared using standard materials including OPC (43/53 grade), river sand, crushed aggregates, potable

water, Fe500 steel, and TPCI additive in varying dosages (0–3% by cement weight), with mix design carried out as per IS 10262:2019 for target grades like M30/M40 while maintaining a constant water-cement ratio. Specimens such as cubes, cylinders, and reinforced prisms are cast, compacted, cured, and subjected to simulated aggressive conditions using chloride exposure, wet-dry cycles, and accelerated corrosion techniques. Mechanical properties (compressive, tensile, flexural strength), durability parameters (water absorption, permeability, RCPT), and corrosion behavior (half-cell potential, LPR, weight loss, EIS) are systematically evaluated, along with microstructural analysis using SEM and XRD to understand inhibitor interaction and protective layer formation. The results are analyzed through comparative and statistical methods to assess improvements in strength, durability, and corrosion resistance, leading to identification of optimal TPCI dosage and its potential for extending service life, although limitations exist due to laboratory-controlled conditions and reliance on accelerated testing for long-term predictions.

CONCLUSION

The review indicates that the incorporation of Bipolar Traversing Type Corrosion Inhibiting (TPCI) additives in reinforced concrete significantly enhances the service life of structures by effectively reducing the rate of steel reinforcement corrosion. TPCI additives function through a combined inhibition mechanism, forming a protective layer on the steel surface while also improving the electrochemical stability within the concrete matrix. The presence of these additives reduces chloride ion penetration, delays the initiation of corrosion, and minimizes crack propagation caused by rust expansion. Additionally, TPCI contributes to improved durability properties such as reduced permeability and enhanced resistance to aggressive environmental conditions. Overall, the findings suggest that TPCI additives are a promising and sustainable solution for prolonging the lifespan of reinforced concrete structures, lowering maintenance costs, and improving long-term structural performance.

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