The Effectiveness of Organic-Based Admixed Inhibitors in Multi-Exposure Environments

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***Abstract*—Reinforced Cement Concrete (RCC) remains the cornerstone of modern construction due to its structural capabilities. However, the durability of RCC is persistently challenged by reinforcement corrosion, particularly under chloride ingress and carbonation exposure. This research investigates the corrosion inhibition efficiency of two organic compounds—4-amino benzoic acid (ABA) and triethyl phosphate (TEP)—as admixed inhibitors in reinforced concrete. Initially, tests were conducted in simulated pore solutions to evaluate the inhibitors' behavior under laboratory-controlled chloride and CO2 exposures. Subsequently, concrete prisms using Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) were cast and subjected to similar exposure conditions. Electrochemical techniques, including Linear Polarization Resistance (LPR) and Half-Cell Potential (HCP), were employed to assess corrosion performance. Additionally, concrete cubes were tested for free chloride content and carbonation depth. The results showed ABA's superior performance, particularly in PPC concrete, where its chelating properties effectively preserved the steel's passive layer. In contrast, TEP, despite promising results in pore solution, was ineffective in concrete, likely due to its single functional group and dosage limitations (Teryusheva, 2020; Shehnazdeep & Pradhan, 2022). This study confirms the potential of ABA as a robust organic corrosion inhibitor in harsh exposure conditions.**

***Index Terms-* Corrosion, Durability, Organic Inhibitors, Concrete, 4-Amino Benzoic Acid, Triethyl Phosphate, Reinforcement Protection**

I. INTRODUCTION

General

Concrete, composed of cement, aggregates, and water, is extensively utilized in infrastructural developments. Despite its compressive strength, its low tensile strength necessitates reinforcement with steel bars, enhancing structural integrity. However, this combination is vulnerable to corrosion caused by environmental agents such as CO2 and chloride ions, which compromise the steel-concrete interface. The consequent rust formation leads to internal stresses, causing cracks, delamination, and structural degradation (www.corrosionengineering.co.uk).

Corrosion's economic implications are vast; for instance, India incurs an annual loss of approximately USD 40 billion—around 4% of its GDP—due to corrosion across infrastructure and industries (www.inspectioneering.com/news/2016-03-08/5202/nace-study-estimates-global-cost-of-corrosion-at-25-trillion-ann). Hence, enhancing concrete durability by integrating corrosion inhibitors becomes critical.

Corrosion Process

Corrosion in reinforced concrete is primarily electrochemical. Concrete's high pH (11–14), resulting from hydroxide formation, creates a passive protective layer on steel. Disruption of this layer due to carbonation (CO2 reaction reducing pH) or chloride ingress (displacing hydroxides) leads to active corrosion. Anodic reactions dissolve iron, while cathodic reactions form hydroxide ions. The resulting rust occupies a larger volume, generating internal stress (IS 456:2000).

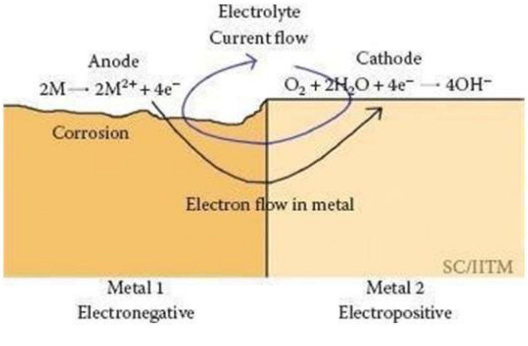

Fig 1. Anodic and cathodic reaction (Source: wantarengineering)

Causes of Corrosion

Carbonation Attack: CO2 reacts with calcium hydroxide in concrete, forming calcium carbonate and reducing pH. This neutralization weakens the passive layer, initiating uniform corrosion (www.civilengineeringforum.me).

Chloride Attack: Chloride ions penetrate concrete, reaching the steel surface and destabilizing the passive film. The localized pitting corrosion thus initiated is highly destructive (www.cdcorrosion.com).

Fig. 2 Carbonation induced corrosion on concrete (Source: corrosion engineering)

Fig. 3 Chloride induced corrosion on concrete (Source: civil engineering forum)

Corrosion Inhibitors

General

Corrosion inhibitors are chemical substances added to concrete to slow or prevent the electrochemical reactions that cause steel corrosion. These are practical, cost-effective solutions compared to physical barriers or coatings (Teryusheva, 2020).

S. N.	Parameter	Adversities
1	Viscosity	Decrease in viscosity of self-compacting concrete (Blankson and Erdem, 2015)
2	Permeability	Reduction in permeability caused by the pore-blocking effect (Söylev et al., 2007b)
3	Workability	Enhancement of concrete workability due to the presence of –OH and –COOH groups (Söylev et al., 2008)
4	Bond	The bond between steel and concrete weakens due to reduced adhesion (Söylev et al., 2007b)

History and Current Scenario

Historically used in industries since the 19th century, inhibitors are now essential in construction, particularly for their eco-friendly, non-toxic alternatives. The corrosion inhibitors market, valued at $8.7 billion in 2021, is growing rapidly, especially in Asia-Pacific due to infrastructure expansion (BCC Research, 2022). Water-based inhibitors dominate due to their convenience and compatibility.

II. LITERATURE REVIEW

General

Despite advancements, corrosion remains a significant challenge. Researchers have explored chemical compounds, especially organic inhibitors, for their influence on electrochemical reactions within concrete (Al-Baghdadi et al., 2023).

Organic Groups Used As Inhibitors

Various compounds such as alkanolamines, fatty acids, and amines have been evaluated for their inhibition potential. Their effectiveness lies in forming protective films or chelating with steel ions (Ormellase et al., 2006).

Literature Study of Corrosion Inhibitors

Morris et al. (2002) tested alkyl-aminoalcohol-based inhibitors in concrete exposed to marine and immersion conditions. Their findings highlighted the impact of inhibitors in reducing Icorr and improving corrosion resistance, particularly in low w/c ratio mixes.

III. EXPERIMENTAL PROGRAM

General

An experimental program was conducted to analyze the performance of ABA and TEP in both pore solutions and concrete environments under chloride and carbonation exposures.

Procedure

- Pore solution tests with CO2 and NaCl.
- Preparation and testing of materials (cement, aggregates, water, steel).
- Casting concrete prisms (300×300×150 mm) with OPC and PPC using embedded TMT rebars.
- Casting 100 mm cubes for chloride and carbonation analysis.
- Exposing specimens to 5% CO2 and chloride solution.

Materials Tested

Tests ensured material conformity with IS standards. Key results include:

•PPC Cement: Specific gravity 2.89; setting time 90/300 min (IS 1489:1991).

•OPC Cement: Specific gravity 3.1; setting time 123/270 min (IS 8112:1989).

•Fine Aggregates: Fineness modulus 3.01; Zone II grading (IS 383:1970).

IV. RESULTS AND DISCUSSION

Results from LPR, HCP, and visual inspection confirmed the inhibitors' effectiveness in both pore solution and concrete (Shehnazdeep & Pradhan, 2022).

Tests on Pore Solution

Solution 1: Control

Solution 2: With ABA

Solution 3: With TEP

Findings:

ABA significantly reduced Icorr and visual rust formation (Rakanta et al., 2013).

TEP showed initial performance but failed to maintain efficacy in concrete specimens (Han et al., 2012).

Visual differences in rusting corroborated electrochemical results. After testing the rebars in the pore solution, visible rust formation was observed on the steel surface. Fig. 4 illustrates the progression of rust on rebars immersed in Solution 1 at different exposure durations: 24 hours, 48 hours, and 120 hours.

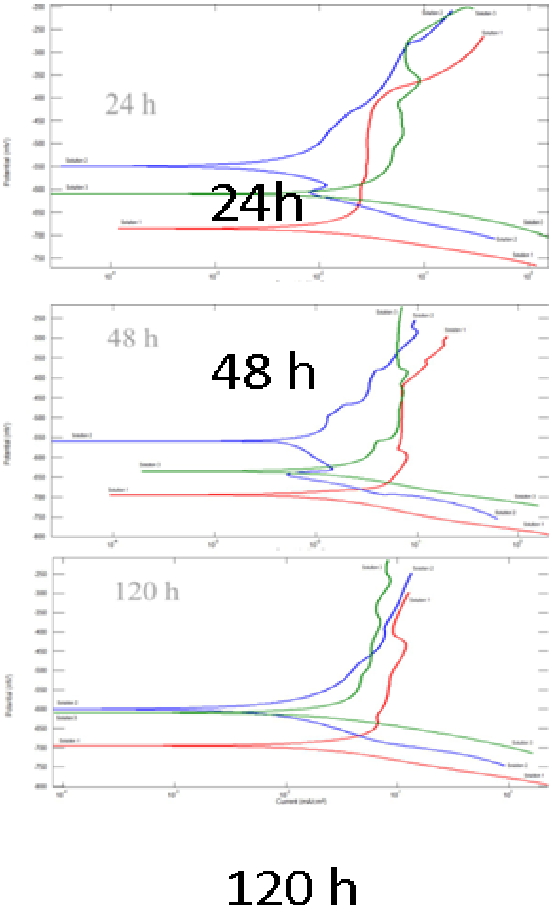

Fig. 4 illustrates the progression of rust on rebars immersed in Solution 1 at different exposure durations: 24 hours, 48 hours, and 120 hours.

Fig. 5 Shows the solution1 specimens

Fig. 6 Shows the solution 2 specimens

Fig. 7 Shows the solution 3 specimens

IV. CONCLUSION

ABA emerged as an effective corrosion inhibitor in PPC concrete due to its multifunctional chelating groups, maintaining passive film integrity. TEP, although showing promise in pore solution, lacked efficacy in concrete, likely due to its single functional group and inadequate bonding with steel (Kaur et al., 2016; Teryusheva, 2020).

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