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AN OVERVIEW OF MCI TECHNOLOGY FOR DURABILITY ENHANCEMENT IN EMBEDDED REINFORCING METALS- RECENT ADVANCEMENTS, ISSUES AND PROSPECTS

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Abstract: This paper provides an overview of the Migratory Corrosion Inhibitor (MCI) technology, which aims to protect steel by building a self-replenishing monomolecular layer. The overview includes a discussion of various types of MCIs, such as amino-alcohol and amine salts-based inhibitors, that have been selected to minimize the corrosion rate.

The paper also describes advanced experiments that have been conducted to find effective solutions for corrosion protection. Additionally, the development of four new chemical compositions are also suggested namely MCI1- (C7H6O+ E-MEA), MCI 2- (M-MEA+ MEA), MCI 3- ($C_4H_{11}NO$+ E-MEA), MCI4 (DMAE+ TETA) (4).

The overview of MCI technology is intended to provide researchers with a deeper understanding of the uses and improvements of MCIs. The role of inhibitors in enhancing durability in concrete, and the problems and prospects associated with their use, are also discussed.

Overall, this systematic literature review is a valuable resource for researchers interested in exploring the potential of MCI technology in various fields of research and practice.

Keywords: *MCI Technology, Corrosion inhibitors, Reinforced Concrete, Durability Enhancement*

1. Introduction

1.1 Background of the study

Corrosion of reinforcing metals in concrete can affect the quality and lifetime of the reinforcing metals. Several techniques have been developed for preventing corrosion, durability enhancement and improving the lifetime of concrete structures and reinforcing metals (Achal et al., 2012) [1] (Otunyo & Kennedy, 2018) [2]. These techniques include coating of the reinforcement (Elshami et al., 2017) [3], alternative reinforcement, concrete surface (Goyal et al., 2018) [4], cathodic protection (Byrne et al., 2016) [5], electrochemical processes (Daniyal & Akhtar, 2020) [6], and different corrosion inhibitors (Raja et al., 2015) [7] (Venkatesh et al., 2018) [8]. Among different techniques, the application of Migratory Corrosion Inhibitors (MCI) (Auqui et al., 2017) [9] is considered as a significant and effective technology for preventing

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corrosion of reinforced metals because of its simple operation, cost effectiveness, and robust corrosion resistance efficiency (Leonovich et al., 2022) [10] (Karthick et al., 2016) [11] (Priya & Rao, 2017) [12] (Jiang et al., 2017) [13]. In general, inhibitors are added into the concrete in smaller volumes, due to which, their performance is delayed and slowed down. Also, the efficiency of the inhibitors is badly affected due to the delay, which reduces the quality of the reinforced quantity. Majority of the concrete inhibitors stabilize the surface of the reinforced metal by composing a protective film and few selected inhibitors also respond with concrete to form a complicated and thereby reduce the reinforced metals permeability. Further corrosion inhibitors are most commonly added as admixtures presented in concrete in the construction industry and are also used for repairing concrete structures such as fixing patches, sprayed on the surface of reinforced metals by applying saturation treatment (Pritzl et al., 2015) [14] (Angst et al., 2016) [15]. Corrosion inhibitors play a significant role in reducing the rate of corrosion in reinforced metals. Several researchers have focused on the study of different types of corrosion inhibitors for corrosion prevention. Due to the advantages, this review paper emphasizes the application of MCI for preventing corrosion and improving the durability of reinforced metals.

1.1 Overview of MCI

Most commonly MCI is utilized on the outer surface of the reinforced metals and the corrosion inhibitors must infiltrate deep into the metal to provide enough support with an aim to prevent the corrosion of the metals. The migratory corrosion inhibitors mainly concentrate on the process of applying inhibitors to the surface of reinforced metals and do not focus on the effect of electrochemical reaction between the metal and the inhibitor (Fateh et al., 2020) [16]. In such cases of migratory corrosion inhibitors, organic-inhibitor compounds such as amine, alkanol amines and carboxylic are profoundly used to prevent corrosion and their chemical reaction with reinforced metals is monitored to control the process of corrosion prevention. Organic inhibitors restrain the response of both anodic and cathodic inhibitors by forming a single layer film at the interface of the reinforced metal surface and concrete (Yuvaraj et al., 2022) [17]. It can be inferred from existing literary works that the alkanol amine-based inhibitors can reduce the rate of corrosion significantly in carbonation induced corrosion. However, this is also applicable to the chloride-induced corrosion of reinforcement. (Lee et al., 2018) [18]. Besides, the results of the experimental analysis demonstrated that penetrating corrosion inhibitors have the potential to minimize the rate of corrosion below 0.1 $\mu A/ cm^2$ when applied on the surface of new or existing reinforced metal structures. Organic inhibitors can be aggregated by the process of chemisorption or physisorption. Chemisorption demonstrates the chemical interaction between organic inhibitors and the active regions of corrosion on the metal surface, where the charges from the polar group of the inhibitors and reinforced metals and its corresponding oxides that are formed in the concrete are shared. Further, these organic inhibitors form a thin coating film that blocks the surface of the reinforced metals from susceptible reactions due to toxic chemicals such as arsenic, cadmium, lead, and chromium compounds. On the other hand, physisorption forms a mechanical roadblock which is created by the organic inhibitors (Zhang et al., 2019) [19]. In the presence of an inorganic inhibitor, sodium monofluorophosphate is fundamentally used as a component to minimize the rate of corrosion and to control the high initial consumption. It is applied on the surface of the reinforced metals in an aqueous solution form (La Iglesia et al., 2012) [20] (Pradhan, 2022) [21].

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MCIs that are employed on the surface of the reinforced metals are appropriate for reconstructing or mending the chloride-contaminated concrete. In concrete structures and reinforced metals, the ions of chloride and inhibitors work based on three processes namely, natural diffusion, electrical migration, and transport due to the natural flow of pore solution which is caused due to the capillary suction or pressure gradient. Most prominently, migratory corrosion inhibitors are formed by commercial organic compounds such as amino alcohols which can swiftly penetrate through the concrete pores and protect the metal bars from corrosion by forming a hydrophobic layer through physical or chemical adsorption. The most important attribute of migratory corrosion inhibitors is that it reacts with the concrete particles and metal compounds to form an insoluble compound to block the concrete pores in order to avoid corrosion. This category of migratory corrosion inhibitors is suitable for rehabilitating reinforced concrete structures and it offers several advantages such as easy operations, high safety with better cost effectiveness. Because of their undue advantages, migratory corrosion inhibitors are predominantly used to prevent corrosion in chloride contaminated concrete surfaces before applying overlays or patches (Song et al., 2017) [22].

Some of the prominent advantages of migratory corrosion inhibitors (MCI) are as follows:

- MCI significantly improves the service lifetime of the existing and new structures by reducing the rate of corrosion and maintaining low rate initiation.
- Utilizing the MCI technology improves the long-term reliability of concrete structures and it is considered one of the main concerns while evaluating reinforced metals and structures.
- MCI helps in strengthening the structural integrity, rehabilitating the structures that are susceptible to failure due to corrosion, and mitigating environmental concerns.

These advantages motivate this review to study different aspects of migratory corrosion inhibitors MCI technology. The main contribution of this review paper can be summarized as follows:

- This review mainly emphasizes the utilization of inhibitors in concrete using MCI technology.
- The corrosion inhibitors are explained in an effective manner that helps in preventing corrosion occurring in the concrete-structures.
- The profound explanation of corrosion inhibitors used for a protective film in the embedded steel bars are illustrated.
- Explanation on the inhibitors that are used for concrete which are categorized into three types of inhibitors that include anodic, cathodic, and mixed inhibitors.
- The current research provides perception regarding the existing durability enhancement research, especially on reinforcing metals.
- The performance of the MCI technology has been explained based on the concrete quality with the advancements, issues, and prospects.
- The extensive investigation of the MCI technology has been explained with the help of real concrete structures.

This systematic literature review will help the researchers to understand the migratory corrosion

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inhibitors (MCI) technology uses and advancements along with the issues and prospects.

2. Systematic Literature Review (SLR)

The SLR of various literary studies is an important aspect of the study since it assists this work in acquiring a detailed knowledge about the existing techniques and processes developed in different research works with a detailed analysis on the challenges and implications. In this section, the study discusses existing works done on MCI technology for strengthening the properties and durability of embedded reinforced metals. Several research works have discussed the application of different MCI techniques for strengthening the reliability, integrity and durability of concrete structures and reinforced metals to enhance its structural strength. The systematic literature review presented in this study reviews related work to outline some of the prominent research gaps related to the application of MCI technology for durability enhancement in reinforced metals.

2.1 Process used in the SLR

The SLR process consists of different phases Focusing on selecting papers for systematic literature review, Searching and selecting process of relevant content from articles, deciding on including and excluding criteria for articles for better quality review study.

The related keywords and search strings are sourced in the initial step by using different search engines such as Elsevier, Springer, Research Gate, Journals and Conference papers related to civil engineering. These search engines provided valuable and prominent content for the conduction of this review.

Table 1 shows the used online databases for selecting articles

Table 1. Online databases for selecting articles

Sl No	Database / Search Engine	URL
1	Elsevier	https://www.elsevier.com/en-in/solutions/scopus
2	Research Gate	https://www.researchgate.net/search
3	Springer	https://link.springer.com/
4	Academia (for journals and conference papers)	https://www.academia.edu/
5	Google Scholar	https://scholar.google.com/

Table 1 discusses online databases used in the processes of finalizing the sourced articles. The latest references (not older than 2012) are selected on the basis of objective and implementation details analyzed in the articles.

Since the review mainly concentrates on the implementation of MCI technology for durability enhancement in embedded reinforced metals, the finalized keywords are selected based on the MCI adoption for concrete structures, metals, MCI for corrosion prevention, role of corrosion inhibitors and durability enhancement.

Furthermore, the papers that are shortlisted for the analysis on basis of finalized keywords by

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taking care of filtered out duplicate papers to access more relevant papers without misguidance. The large volume of articles was accessed and it is practically not feasible to analyze all articles. Hence relevant filtration criteria are applied wherein the articles are filtered accordingly as discussed in table 3.

Table 3. Filtration stages and assessment criteria

Filtration Stage	Assessment criteria
1st filtration	Source papers based on keywords
2nd filtration	Few papers based on the keyword and search strings present in the title are included in the review
3rd filtration	Papers published are not older than 2012 and are from the reputed journals
4th filtration	Filtered papers based on the relevant abstract
5th filtration	Papers are filtered based on the content and objectives of the study like the application of MCI for concrete or reinforced metals

As discussed in table 3, based on the keywords a total number of 61 papers were accessed in the 1st stage. If one or more keywords are present in the title and paper, the article was shortlisted for the review, else it was excluded. In the 2nd stage, if the keywords and search strings are present in the title then they were included for the review and 57 papers were considered after this stage. Based on the 3rd filtering criteria, 53 papers were considered and at the end of 4th stage 42 papers were finalized which are related to the application of MCI technology for enhancing the durability of concrete and embedded reinforced metals. The objective of the SLR is to review more words related to the topic and at the end of fifth stage of filtration, all the finalized papers were considered for the SLR.

The Prisma model for the SLR is given below :

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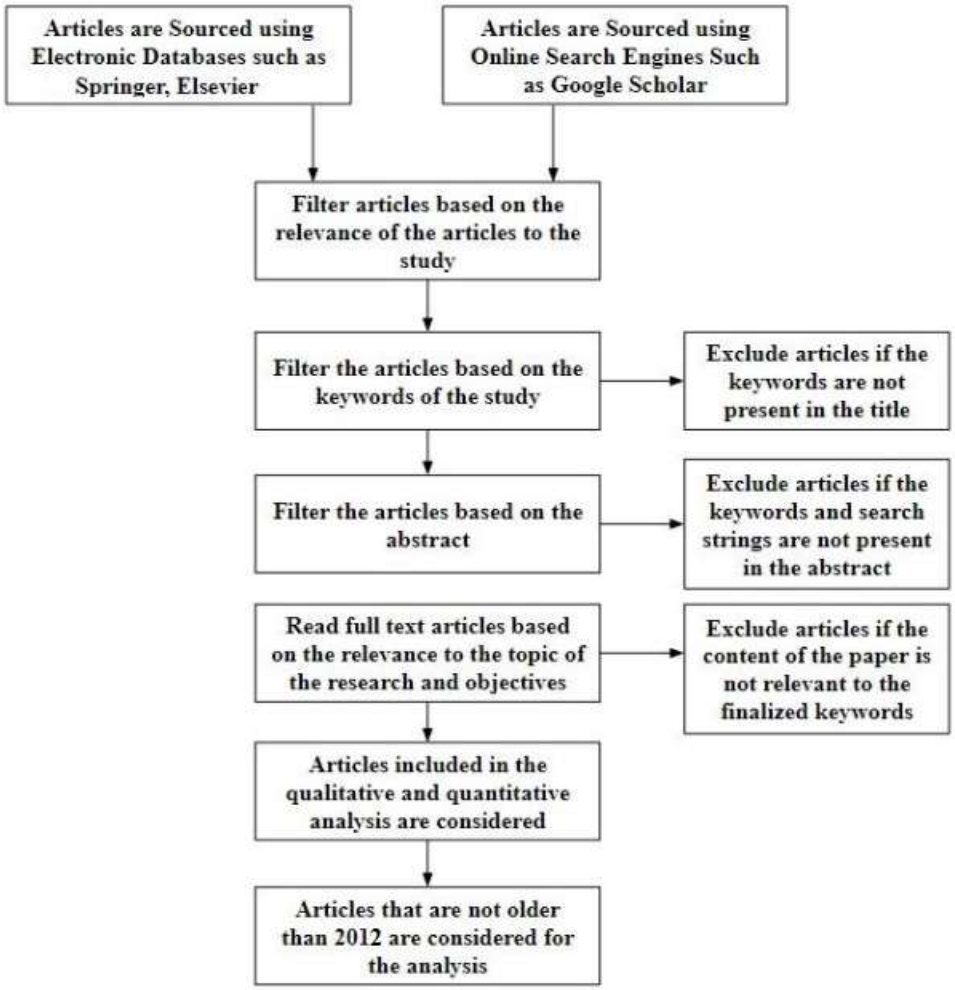

Figure 1. Prisma Model

Figure 1 shows the gradational strategy adopted for formulating relevant content for the systematic literature review for the proposed study by taking into account the assessment criteria discussed in table 4 and they are applied to reviewing the existing works.

To understand the concept of migratory corrosion inhibitors for reinforced metals and concrete by various researchers, the reviewed articles that do not satisfy these criteria shown in the Prisma model in figure 1 and table 3 of the filtration process of articles are not considered for the analysis. The quality of the selected journal articles for study was sorted out on the baseline of high impact factor of journals for a better review.

3. Overview of the research works

Corrosion inhibitors are considered as chemical substance that helps to minimize corrosion rates in the nonexistence of concentration variations of other corrosion agents. Therefore, various researchers utilize various inhibitors such as ferrous salts, stannous salts, phosphates, benzoates, nitrites, and chromates. These mentioned inhibitors are easy to handle and available at a lower cost when compared to the other corrosion protection measures (Ikumapayi et al., 2020) [23]. In-accordance with certain action, these inhibitors are considered in any inhibitor classification, such as mixed, cathodic, or anodic inhibitors (Nam et al., 2018) [24].

 ISSN:1005-748X

3.1 Corrosion inhibitors (CI) classification

Corrosion inhibitors are considered one of the significant processes in corrosion, and the corrosion rate will be minimized by reinforcing the passivity film. The classification of corrosion inhibitors (Sajid et al., 2021) [25] is categorized into three divisions such as natural, organic, inorganic, and green inhibitors. In accordance with certain applications, they are classified as migrated and admixed inhibitors and based on the protection mechanism, they are categorized into cathodic, anodic, and both (cathodic & anodic). In modern structures, corrosion inhibitors are utilized as an admixture, and when it comes to existing construction, they can be utilized as migrating inhibitors.

3.1.1 Organic Inhibitors

In recent days, organic CI are considered as popular inhibitors that are utilized in the construction industry because of the low cost and security competence (Kadhim et al., 2021) [26]. Further, organic inhibitors are used in migrating and admixed inhibitors, on the other hand, alkanol amines and amines are widely considered as natural inhibitors due to the high dissolvability capability and minimum effect on the concrete properties in the fresh or hardened state. Then, Alkanol-amine-based inhibitors have the capability to reduce carbonation and chloride-induced corrosion and the organic inhibitors have the capability to handle the corrosion-rate (that is < 0.1 μA/cm2). Certainly, these inhibitors can be processed by chemisorption or otherwise known as physisorption. Organic CI are broadly utilized in various construction industries due to their potency at broad utilization of temperatures, protected materials compatibility, and water solubility in low toxicity and costs. Further organic CI absorb occurred on the surface in order to develop a protective-film where the water displacement occurs to protect the surface against deteriorating. Basically, the organic corrosion inhibitors include phosphorus, sulfur, oxygen, and nitrogen with electron pairs and structural- moieties with electrons that cooperate with the process of adsorption in metal favouring (Brycki et al., 2018) [45].

3.1.2 Inorganic Inhibitors

Inorganic inhibitors are considered famous in order to diminish the reinforced concrete corrosion rate. Therefore, calcium nitrite plays a significant role and is explored as a most used inhibitor in inorganic classification with the utilization of 4% Ca (NO_2) that mitigates the reinforced concrete corrosion that has no cause of any side effects, especially on concrete strength. At the same time, exposure to a longer structure span in a chloride environment (Xiong et al., 2021) [27]. Certainly, calcium-nitrite improves the transition of ferrous-hydroxides/oxides (unstable) into ferric-hydroxides/oxides (stable) that serve as an oxidizing agent (burly) applied on the reinforcement surface bar. During the utilization of calcium-nitrite-based inhibitors, the main problem is regarding the essential quantity evaluation due to a lesser amount of inhibitors than essential will exhibit a negative impact on concrete as well as steel. Various European countries, such as Switzerland and Germany, have prohibited calcium nitrite because of its toxic and carcinogenic reactions. Due to this cause, substitute inhibitors are considered in the process. Further, sodium mono fluorophosphate (Na_2PO_3F) has the ability to delay the initialization of corrosion and alleviate the corrosion rate presented in carbonated concrete. Moreover, inorganic corrosion includes two processes such as cathodic and anodic, and these cannot reduce the inhibitor action

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mechanism that may affect the entire corrosion process. Further, an inorganic inhibitor processed for the anodic has the possibility to minimize the cathodic polarization to a specific extent due to the maximization of the corrosion rate. Hence it is significant to analyze the individual process that depends on the electrochemical kinetics techniques maximization. Exploiting inhibiting properties increases the possibility of investigating chemical properties of compounds formulated from the fission-product-isotope 9 (Cartledge, 1966) [46].

3.1.3 Natural Inhibitors (NI)

During the process of corrosion, NI are considered a high benefit and efficient to the environment when compared to the other inhibitors. The plant sources used in the real-time environment, such as flavonoids, alkaloids, terpenes, and polyphenolics, are considered natural inhibitors. And these features have the capability to fulfill the needs of natural inhibitors. Further, sugar portions presented in the concentrates on vegetables were utilized as a NI, especially in the reinforced concrete. The properties of physio chemical and mechanical features of reinforced concrete can be improved with the concrete admixture (Magrabe -bannan's- stem- juice) (Shen et al., 2020) [28]. Further, plant sources are utilized with certain requirements, including polyphenolics, terpenes, avonoids, and alkaloids that consist of electron-offering hetero groups such as O, N, S, and electrons that are conjugated. Tannin, which is sugar fractions from vegetable extraction that tested positively and is known as a natural inhibitor, especially for reinforced steel executed in concrete. Therefore, it is studied that magrabe-banana's stem-juice presented in concrete-admixtures used to enhance reinforced-steel concrete physiochemical and mechanical properties with the saturation mixture Ca(OH)2 with NaCl medium concentration. The standardization of natural corrosion inhibitors has been evaluated with the inhibitor stability, pressure, temperature, and electrolyte in concrete (Raja, 2015) [7].

3.1.4 Anodic Inhibitors (AI)

AI used to develop the passivity-layer that is insoluble on the steel bar surface helps to prevent the process of corrosion. Hence, passivating inhibitors include nitrites presented as a certain category of AI in case they are exhibited in sufficient concentration. The passivating inhibitors are categorized into non-oxidizing anions and oxidizing ions. The non-oxidizing ions need oxygen for the steel passivity (Subash et al., 2022) [29]. Further, reinforced concrete relies typically on the calcium nitrate [Ca (NO3O2)] and calcium nitrite [Ca (NO2O2) utilization that comes under the category of anodic inhibitor, and they initiated with the inhibiting properties. Benzoates, orthophosphates, chromates, nitrates, and molybdates are utilized as AI.

3.1.5 Cathodic Inhibitors (CI)

Cathodic inhibitors (CI) such as polyphosphates, zinc oxide, silicates, phosphates, and carbonates are used to resist corrosion by delaying the rate of the cathodic reaction. Basically, these kinds of inhibitors possess metal ions that have the capability to produce a cathodic response because of the alkalinity presented in metal, thus generating insoluble components on the cathodic site with the selected precipitation. However, these are independent of the composition of the metal and only rely on the water chemistry applicable to every metal. At the same time, cathodic inhibitors are less effective when compared to anodic inhibitors (Jyothi et al., 2019) [30].

 ISSN:1005-748X

3.1.6 Admixed Inhibitors

Corrosion inhibits concrete-admixtures enables reinforcement protection to prevent corrosion. Organic-inhibitors are considered famous for utilizing the admixture at 132 degrees Celsius. Therefore, alkanol mines and amines are regarded as salts, and they are used as concrete organic inhibitors. Thus, the inhibitors are combined in the concrete presented in the plastic state. Normally, the inhibitors are used in order to prevent corrosion with the reinforcement bar by defining a defensive obstruction thin layer film presented on the rebar surface via an adsorption component (Shi et al., 2022) [31]. Further, admixed corrosion inhibitors influence the cement hydration process rate to improve the mechanical properties. The utilization of potassium nitrites generates a compressive strength reduction and increases the cause of the alkali-aggregate reaction.

3.1.7 Migrating Corrosion Inhibitors (MCI)

Normally, the MCI can be used in the hardened concrete outside surface, and the inhibitors are used to filter the cover of concrete in order to obtain the steel support to ensure corrosion rate eradication. The MCI concentrates on application and focuses minimally on the interaction of inhibitor and steel. During the utilization of MCIs, the components of organic inhibitors such as carboxylic, alkanol amines, and amine are considered popular (Bavarian et al., 2018) [32]. Normally, organic inhibitors suppress the responses of anodic and cathodic by monolayer film shaping presented at the interface of concrete steel. At the same time, inorganic inhibitors such as sodium mono fluorophosphate are used to preserve the consumption initialization or minimize the erosion rate. Certainly, MCI technology preserves reinforced metal from corrosion, especially in concrete. Most of the corroding rebar presented in deteriorating concrete is considered the leading cause of repairs, deaths, injuries, and financial losses; however, these techniques can be applied and used as a corrosion solution. The utilization of MCI technology extends the life span of the existing and new structures by proactively delaying it by holding rates at a minimum level even after initiation. Further, MCI products support alleviating structural issues, rehabilitating vulnerable states, and structural integrity. The MCI technology processed in accordance with the amine includes amine carboxylates and alcohols and is categorized as mixed inhibitors that impact cathodic and anodic areas of corrosion. MCI is used in various structures, such as a tropical treatment or a concrete admixture. Therefore, it shifts as a liquid via the concrete matrix through capillary action and wanders in a vapor phase across the structure of the concrete pore. During the contact of MCI with embedded metals, it acquired an ionic attraction to structure a protective molecular layer, and this prevents the metal from corrosion.

3.1.8 Green Corrosion

The utilization of appropriate corrosion inhibitors has a higher chance of affecting the concerns of the global environment. However, specific facts have already been examined based on the provided environmental guidelines developed in this stage. The PARCOM - Paris Commission guidelines have been applied to the standard tests that include three areas, such as evaluation of toxicity based on the LC50 - Lethal Concentration-50 that defines the toxin concentration with a test population of 50%. Next, every formulation component is estimated, especially in biodegradation, by evaluating the component persistence. Finally, the product accumulation level

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is measured (Asaad et al., 2021) [33].

3.2 Effect of inhibitors in concrete

The problems with durability enhancement, especially in marine concrete structures, have become a popular aspect in marine construction, including submarine tunnels, offshore-oil platforms, cross-sea bridges, and wharfs. Especially in the coastal areas and marine environment, the corrosive medium was found in high concentrations linked with dry-wet cycles exhibited on the concrete surface initiated by splashing and tiding, resulting in reinforced-concrete durability problems. In recent days, various methods such as bioremediation technology, surface-coating protection, grouting-repair technology, changing material mix-ratio, electrochemical rehabilitation methods, and much more used for durability enhancement in concrete structures. Therefore, inner structures enhancement and concrete resistivity are considered a significant factor in concrete structures that needs to be focused on in the future. At the same time, the reinforced concrete anti-corrosion resistance was still regarded as a weak factor and needed further enhancement (Pan et al., 2020) [34]. As discussed in the above sections, various categories of inhibitors, such as mixture, inorganic, and organic, are utilized in concrete to minimize steel deterioration. Even though organic inhibitors include imidazole corrosion and amino based inhibitors are oftentimes utilized to manage the corrosion occurring in concrete. Nevertheless, the inhibitors, such as amino-based, have a weak migration capability, and it is not possible for further migration to the steel surface.

Moreover, reinforced concrete structures are protected with the development of various techniques. When it comes to new construction, inhibitors play a significant role in adding to the mixture for structure protection that prevents corrosion. MCIs are used as surficial inhibitors that help minimize the corrosion of steel rebars by shaping a protective film through an adsorption mechanism. For example, amines, alkanol amines, and salts are included with organic inhibitors has been used in the researches. Finally, the report has examined and concluded that alkanol amine-based inhibitors improves corrosion resistance because of the carbonation and chloride ions. Certainly, natural organic compounds have been generated from various plant types that initialize green inhibitors. Various investigations are examined and processed on organic inhibitors extracted from plants, leaves, seeds, and stems (Guo et al., 2022) [35].

3.3 Experimental Tests for MCI

It is significant to test the additive concrete through the slump-cone, tension, and compression tests (Abd El Fattah, et al., 2020) [36] that measure certain factors, including consistency, air content, temperature, unit weight, and strength. Basically, these tests are executed and conducted consistently to predict the variation in the concrete and to find out the reason that affects the long-term performance of the concrete.

3.3.1 Slump cone test - This test is generally used in the superplasticizer concrete admixture to find the durability in the reinforced concrete in accordance with the concrete shape. Moreover, the standard slump test values can be calculated with the regular reinforced concrete placed with vibration with a 50-90 mm slump value. Furthermore, these tests can be conducted to calculate the concrete consistency that defines the fluidity. Eventually, the slump value for M30 can be considered as a minimum value

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of 25 to the maximum value of 75.

3.3.2 Tensile test - This test is utilized in an indirect way to estimate the concrete tensile strength with a specimen called standard cylindrical that is laid horizontally, and an external force has been applied on the surface to cause the vertical crack formation in the specimen.

3.3.3 Compression test - This test has been conducted to evaluate the concrete strength and has been tested based on the ASTM standards and procedures. The durability of the experimental concrete can be measured with Rapid Chloride Permeability - RCP is an electrical test utilized to evaluate the concrete durability. These test methods will be conducted in ASTM 1202 to supervise the electric charge transmitted via cylindrical specimens for almost six hours. Furthermore, the most crucial benefit of MCI is that when it is practically implemented in the construction phase or during the maintenance repair in the structure already exists.

3.3.4 Electrochemical Test- Electrochemical corrosion tests measure the corrosion state in a metal or concrete structure in accordance with the electrochemical theory, and corrosion testing represents corrosion damage and evaluates the corrosion rates. Therefore, these are used to define the Tafel plot, cathodic, anodic protection, passivation rates, solution system, and passive and active characteristics. Further, the electrochemical noise methods are used in the analysis of the current variations recorded in the open-circuit potential vicinity. The outcomes of the measurements define that different types of corrosion develop different sets of noise data with metastable pitting initiation, passivation, temporary repassivation, and repassivation (Bjegovic. D, 2000) [37].

3.4 Chemical composition

This research suggests three chemical compositions for corrosion inhibitors namely amino carboxylates, 3-aminopropyltriethoxysilane and 2-amino-2-methylpropanol. Amino carboxylates is a chemical compound includes more nitrogen atoms inter-connected via carbon atoms to two-or-more carboxyl groups. These compounds have lost acidic-protons form strong complexes with metal-ions. 3-aminopropyltriethoxysilane (APTES) supplies amino groups for modifying different materials. APTES is used as a coupling agent for pretreating the metals to protect zinc, iron, and steel surfaces. Recently, APTES is tested as a CI used for reinforcing steel in alkaline solution. When used as corrosion inhibitors, the rate of corrosion rate reduces with the increase in the concentration of 2-amino-2-methylpropanol.

The main reason behind selecting the chemical compositions is the ability of amino acids to mitigate the effect of corrosion in embedded reinforced metals. Carboxylates protect the metals from corrosion by forming a hydrophobic film by the carboxylate group adsorption (Lewis base) on the metal surface (Tang, 2019) [38]. This acts as a robust MCI along with better solubility in non-aqueous function fluids. On the other hand, 3-aminopropyltriethoxysilane and 2-amino-2-methylpropanol are suggested because of their excellent control over the solubility in water and its robustness as corrosion inhibitors (Lashgari et al., 2020) [39] (Xiang et al., 2019) [40]. Considering the superior attributes of these three individual chemicals as corrosion inhibitors, this research suggests that, a novel chemical composition can be prepared for decreasing the rate of corrosion.

 ISSN:1005-748X

3.5 Summary

This section, as mentioned earlier, explains the classification of corrosion inhibitors that helps reduce corrosion rate in the nonexistence of concentration variations of other corrosion agents. Next, the classification of inhibitors is explained with the categories such as natural, organic, inorganic, and green inhibitors. Finally, the experimental tests for MCI have been explained to identify the main reason that impacts the long-term performance of the concrete. And this SLR will provide an overview of the research works and understand the MCI technology benefits and advancements along with the issues and prospects.

4. Comparative analysis of methods and techniques in relevant articles considered in review:

Ref	Methodology Utilized	Results Achieved	Benefits	Observation
[41] Ersan et al., 2018	The current research utilized granules along with ACDC - Activated-Compacted denitrifying-core used for corrosion protection.	The utilization of ACDC - Activated-Compacted denitrifying- core and the nutrients such as Ca $(NO3)_2$ and Ca $(HCOO)_2$ has been used to in the research enhance the mortar specimens.	The ACDC-bacterial granules denitrified, developed from vegetable industry, adequate calcium-carbonate precipitation evaluation was obtained to identify and solve cracks in concrete.	The outcome of the research suggested that utilization of corrosion inhibitors simultaneously can be obtained in the microbial self-healing execution with ACDC-granules.
[42] Wang et al., 2019	This research utilized mass-transfer-numerical method that consist of the waterborne-migrating-corrosion-inhibitor includes PCI-2016 in structures and it was generated by utilizing chelate-induced and multi-compound methods.	The final outcome showed that the steel bar presented in the specimen included 1.25% (NACL) with 5g painting minimized before painting from 0.06 μA cm^2 to 0.25 μA $cm^{2.}$	The steel bar corrosion in mortar maximizes the chloride content. Once the coating PCI-2016 coated on the surface. Further, the	Recently, MCI effects and mechanism are studied. Nevertheless, still so much of research on the MCI mass transfer process in concrete is

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			steel bar corrosion repaired with the help of the rust inhibitor that transmits inward continuously. The outcome defined that PCI-2016 was procured with effective anti-corrosion and migration ability.	needed in the future.
[43] Shen et al., 2019	In the research, 3-Aminopropyltriethoxysilane - APS was chosen as a new CI utilized in electro-migration treatment for resolving corrosion reinforced-concrete building and the CI effectiveness was estimated.	The utilization of APS - Aminopropyltriethoxysilaneat a certain stable pH value in the electro-migration process didn't affect the concrete surface and can eradicate the chloride by recovering the alkalinity presented in the steel rebar. Once the completion of electrochemical treatments, the reinforcement linear polarization resistance was improved with the positive value on the open circuit defining the passive state recovery of steel rebar.	Normally, the minimization of chloride contents and the alkalinity presented in the concrete are minimized with reinforced concrete specificity resistivity enhancement.	Finally, it has been observed that the experiment on electrochemical treatment experimented minimized effectiveness on removal of chloride and recovery of alkalinity.

 ISSN:1005-748X

[44] Qadri et al., 2020	The HESC-repair durability has been enhanced using IC - Internal curing. Further, recycled-crushed concrete and saturated-lightweight aggregates were utilized in the virgin fine-aggregates replacement.	Durability testing has been consist of freeze-thaw cycling, drying-shrinkage, and autogenous with the evaluation of relative-dynamic modulus of mass change, elasticity, and expansion. These results exhibited that IC significantly enhances durability and shrinkage potential.	Autogenous -shrinkage test has been conducted and the results procured are showed that IC enhances durability and shrinkage potential.	The IC enables efficient outcomes to improve the HESC durability. Further, the batches contains low-cement content exhibits efficient F/T durability when compared with high-cement content.

The comparative table helps to understand the existing researches with the methodology utilized, results achieved, limitations, and observation to the durability enhancement of building structures. Further, the future directions of the existing research have been explained in the SLR.

5. Research gaps

Based on the existing literary works, this research identifies some of the research gaps that need to be addressed. The research gaps can be summarized as follows:

- There is a need for effective professional expertise for achieving better performance in terms of preventing waterproofing in structures to reduce corrosion of embedded metals.
- There is a need to explore more effective chemical compositions for developing CI to reduce the rate of corrosion in reinforced metals and to enhance the durability.
- The effect of chemical admixture (corrosion inhibitors) and minerals (pozzolans) needs deeper investigation to maximize the lifetime of reinforced metals (steel) and concrete structures.
- Despite the availability of several methods, the demand for an effective approach which can increase the corrosion time (for laboratory investigation) is still defiant and needs deeper investigation, which can be considered as a prominent research gap to be addressed.

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6. Conclusion

Several corrosion inhibitors have been discussed in the past to prevent corrosion in concrete structures, and reinforced metals. The corrosion inhibitors react and prevent the metals in the concrete from corrosion. This review briefs anodic, cathodic, and mixed inhibitors and their role in enhancing the performance of the reinforced metals. The performance of the migratory CI MCI technology in terms of durability enhancement is discussed with respect to experimental observations. In addition, this research suggests three different chemical compositions for corrosion inhibitors. Furthermore, corrosion inhibitors are divided into various types with different characteristics and parameters. Certainly, various preventive methods like corrosion inhibition techniques are utilized and experimented with in order to reduce the cost and efficiently execute corrosion protection. Various limitations persist in the existing system in order to prevent the metal from corrosion has been discussed in this review.

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