

REVIEW ON CORROSION BEHAVIOUR OF REINFORCED CONCRETE WITH SACRIFICIAL ANODES

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ABSTRACT

In-depth research programmes were started to understand the mechanisms of reinforcement corrosion in order to assess, repair, and maintain those structures appropriately. The corrosion of the reinforcement in concrete structures had been recognised as a serious problem on a global scale in the 1960s and 1970s, and the amount of damages continued to increase significantly in the 1980s. Although there hasn't been much interest in this study in INDIA. This review of the literature aims to examine the most recent developments in the cathodic protection of steel bars in concrete research being done globally for the protection and prevention of corrosion. This review is also done to find research gaps in sacrificial anode cathodic protection techniques.

Key Words: Corrosion, Cathodic Protection(CP), Steel Rebars, Sacrificial Anodes, Concrete Structures

1. INTRODUCTION

Rebar Corrosion in Concrete

The global infrastructure development that is taking place now is unprecedented. The most adaptable and maybe one of the most long-lasting materials a designer can use for practically any sort of project is reinforced cement concrete. It is because RCC is weather resistant, sturdy, and durable under typical exposure circumstances; it can be moulded into practically any desired form. The 'deterioration of RCC constructions' is the main issue now plaguing the building sector globally. The condition is so ubiquitous that it has essentially triggered a crisis and alerted the technical community. Early discomfort in RCC construction is caused by a variety of reasons. Rebar corrosion in concrete, on the other hand, is regarded as a significant source of structural distress and, as a result, a key problem in the construction of sustainable infrastructure. Today, it has been shown that there is always a significant danger of early rebar corrosion in concrete, even when precise national building code requirements for durability are met. Even when concrete cover and quality requirements are followed, rebar corrosion in concrete still happens, reducing the serviceability and safety of RCC structures. The issue is serious in both scope and magnitude.

According to Zumdahl [30], corrosion is a spontaneous process that uses oxidation-reduction processes to restore metals to their original condition. Rebar corrosion in concrete is due to "differential concentration cells caused by non-homogeneity of the concrete and its environment." Corrosion of metals results in a loss of both structural integrity and appealing look.

According to Hausmann [31], variations in pH, oxygen, and chloride concentration are the primary causes of cell potentials. Due to this disparity in potential, electrochemical corrosion cells may develop between the reinforcement's remaining surface and the portions where the protective coating has not yet been damaged. These tiny electric currents are produced by these cells and travel through the reinforcement in one direction before returning through the concrete through electrolytic conduction.

Here are some general facts concerning steel corrosion.

- Every 90 seconds, one tonne of steel rusts away globally.
- The energy needed to produce 1 tonne of steel is about equivalent to the energy used by a typical household over the course of three months.
- Around 2.9 tonnes of CO₂ equivalent greenhouse gases are released into the environment to produce one tonne of steel.
- About 40% of each tonne of steel produced worldwide is needed to replace corroded steel.

Cost of Corrosion

Repairs caused by corrosion cost close to 3% of the GDP of practically every nation. This sum is incredibly substantial, particularly for a developing country like India. The anticipated range for India's GDP in 2010 is \$1000 trillion to \$1300 trillion. If the cost of corrosion is estimated to be a reasonable 3% of GDP, a staggering \$30 trillion to \$40 trillion, or INR 1400000Cr to 1850000Cr, is spent on corrosion. According to estimates from 2004, the cost of corrosion in the US was around \$364 billion. Other subsequent losses and indirect costs are not included in this. According to Houston-based NACE International president George Hays [34] during a presentation at the NACE

International India Section conference in Mumbai on November 15, 2004, if this is taken into consideration, it would increase from the current level of 3.1% of GDP by a number of times. According to Mr. Hays, the cost of corrosion in India alone might reach Rs. 36,000 crore. We can only be happy that we have the money to lose this much, he said. Another reality is that we are not alone in this; rust costs the US economy more than \$360 billion.

Control of Corrosion

The following categories may be used to broadly group current developments in corrosion control. Each of the following concepts is mostly based on one of the aforementioned principles.

- Adding Agents to Concrete
- Coatings for Concrete
- Coatings for Rebar
- Sealants
- Manufacturing of Rebars
- Anode Cathodic Protection for Sacrifice
- Current Cathodic Protection (ICCP) Impressed
- Realkalization Electrochemically (ERA)
- The electrochemical removal of chloride (ECR)
- Galvanic Defence (GP)
- DGA, or discrete galvanic anodes
- The use of nanotechnology

Cathodic protection (CP), one of the many corrosion management techniques available, is a widely used method for preventing the corrosion of steel buried in concrete.

2. READING REVIEW

This review of the literature focuses on a number of issues related to corrosion and cathodic protection of reinforced concrete structures using various anodes, such as prestressed, corroded, and marine structures with magnesium, zinc anodes with conducting coatings, including current density and other issues involving environmental influences, passivation, and paying particular attention to cathodic protection and prevention. Zinc wired rebars and sacrificial zinc anodes are given special consideration. Cathodic protection and corrosion of reinforced concrete buildings There are two main circumstances in which corrosion of the reinforcing steel might occur.

Theory of Corrosion and Cathodic Protection-

According to Bushman [38], who examines the corrosion process, each metallic material has a certain inherent energy level or potential. Current will flow when two metals that have differing energy levels or potentials are connected together. Positive current will flow through the soil from the metal with the greater negative potential to the metal with the higher potential. When positive current exits the metal surface, corrosion will start to take place.

Basics of Cathodic Protection-Regardless of the amount of chloride in the concrete, cathodic protection (CP) is the only method that has been shown to halt corrosion in existing reinforced concrete buildings. CP is a popular and efficient technique for preventing corrosion. Theoretically, it is described as the decrease or eradication of corrosion by the use of an impressed direct current (DC), a sacrificial or galvanic anode, or both. In an electrochemical cell, cathodic regions do not corrode. The whole metallic structure would be a cathode and corrosion would be completely avoided if all the anode locations were made to act as current-receiving cathodes. A highly reactive metal (anode), such as zinc or aluminum-zinc-indium (Al-Zn-In), is used in a sacrificial or galvanic anode system for reinforced concrete to generate a current flow. The concept of dissimilar metal corrosion and the relative positions of various metals in the galvanic series are the foundations of sacrificial anode systems. When linked, the anode and reinforcing steel have a potential difference that produces direct current. During the procedure, the sacrificial anode will corrode and be consumed.

Control of concrete with steel reinforcement's corrosion-In his examination of the techniques, D.D.L. Concrete surface coating, admixtures in concrete, steel-reinforced concrete cathodic protection, and materials for corrosion control are some examples of corrosion control methods. In his work, he provides an overview of the techniques and supplies used to prevent corrosion in steel-reinforced concrete. recommendations for cathodic protection selection To help owners and design engineers choose the right cathodic protection systems to stop corrosion on reinforced and prestressed concrete buildings, Rod Callon et al. [1] have published recommendations. They have noticed that there are several options when cathodic protection is chosen as a rehabilitation approach for a concrete structure that might

affect the design, efficacy, longevity, and cost of the system. The selection of the system components is crucial to the performance and lifetime of the system if the structure has a complicated design and is exposed to a dynamic environment. They have also noted that factors including anode life, protective current densities, zoning, current distribution, and maintenance must be taken into account when choosing an anode.

Various alloy anodes

alloyed magnesium anodes-G.T. In order to investigate the utilisation of magnesium alloy anodes for the cathodic protection of steel buried in concrete, Parthiban et al. [2] conducted a research. They saw that the magnesium anode caused the steel's potential to move first, over all distances, to greater negative potentials, and then subsequently, towards less negative potentials. At all the sites, it was discovered that the chloride content dropped with the passing of time. The elimination of corrosive ions like chloride from the vicinity of steel might be linked to the mechanism of cathodic protection with the sacrificial anode. According to the research, longer times are needed for the cathodic protection to stabilise.

Anodes for alloy aluminium-The creation of high performance aluminium alloy sacrificial anodes supplemented with metal oxides has been researched by S.M.A. Shibli et al. Al+5% Zn alloy was reinforced with metal composites of alumina and zinc oxide, and the reinforced alloys served as effective sacrificial anodes for cathodic protection of steel objects. During extended galvanic exposure testing, they saw strong and constant negative potential, very little polarisation, and a significant decrease in anode self-corrosion. They discovered that adding 5 weight percent of zinc to an alloy of aluminium is the best way to create sacrificial anodes. These scientists came to the conclusion that ZnO reinforcement of Al-Zn alloy sacrificial anodes greatly enhanced their metallurgical properties. The Al+5% Zn alloy anode was strengthened with 0.5% ZnO, which raised the efficiency from 58% to as high as 83%.

Anode components

I.Gurappa [10] researched the best materials to use for cathodic protection. He investigated both current cathodic protection (ICCP) systems and sacrifice anodes, but he came to no conclusions concerning their use. He recommended using the expert system to provide cathodic protection that is effective. Additionally, he has indicated that while expert systems have been developed to choose the proper material for a certain environment and are commercially accessible, the materials still need to be validated both in a lab and in the field for more recent uses.

deteriorated construction-K. The possible use of zinc in the restoration of corroded reinforced concrete has been researched by Wang, concrete, and others [8]. Due to differences in chloride ion concentration, moisture content, and electrical conductivity between the repair patch and the old concrete, it has been found that the current practise for conventional patch repair, which involves replacing the deteriorated concrete with a highly impermeable chloride-free concrete mortar, increases the driving voltage of the corrosion cell. The reinforcing bar (rebar) next to the patch experiences faster corrosion as a result of this increase in driving potential. Because of this, such localised fixes may hasten the beginning of corrosion in other areas rather than resolving the issue. They also noticed that the corrosion of the reinforcing steel is significantly influenced by both the thickness of the concrete cover and the diversity of concrete cover cross sections. Throwing power of anodes Luca Bertolini and Elena Redaelli [5] have investigated the cathodic protection applied to marine reinforced concrete piles that are partly submerged using sacrificial anodes. This study examines how to estimate current and potential distribution in reinforced concrete components that are partly immersed in saltwater with the goal of estimating the cathodic prevention applied via sacrifice anodes' throwing strength. The outcomes of the numerical simulations are presented in this study. Additionally, authors noted that cathodic prevention has a greater throwing force than cathodic protection.

Anodes of zinc

protective zinc anode-A sacrificial zinc anode CP system was created by Risque L. Benedict et al. [28] for prestressed concrete cylinder pipes that often failed due to corrosion during the first 10 years of operation. As the most practicable method of preventing corrosion while minimising embrittlement damage to the high strength prestressed wires, zinc sacrificial anodes were chosen for the CP installation. About five anticipated corrosion failures in the first two years have already been avoided because to the trial installation of CP on a 4.25 km test stretch of the Cedar Creek line. By 2010, the Cedar Creek Pipe Line would probably have needed significant repairs or to be abandoned. Richland Chambers and Cedar Creek lines' usable lives were anticipated to be increased by CP for many years.

Zinc metallized as a sacrifice

R. According to Brousseau et al. [26], procedures used to repair corrosion-damaged infrastructure include removing salt-contaminated concrete, repairing, and installing waterproofing membranes. There are questions over the efficacy of implementing such a strategy to prevent reinforcement corrosion exclusively in salt-contaminated concrete. One potential rehabilitation option is sacrificial cathodic protection (CP) employing metallized zinc coatings. On the Yves Prevost, a highway in Montreal, Canada, findings were measured. Promising results were shown in the use of

metallized zinc as a sacrificial anode for the CP of reinforced concrete. But there is worry that pure zinc would not provide the necessary levels of CP in drier situations when the quantity of reinforcing and resistivity of the concrete is rather high.

Conductive finishes-K. Conductive coatings have been investigated for use as cathodic protection anodes by Darowicki et al. [6]. On the basis of impedance measurements, they calculated the electrochemical properties of conducting coatings. The statistical analysis of the findings allowed for the determination of the experimental results' scatter level. They have also noticed that zinc metal spraying produces superior protective characteristics as compared to applying aluminium coatings, which do not provide the desired results. The price of installing a cathodic protection system is also significantly lowered. In order to assess the appropriateness of specifically produced conducting coatings as anodes in cathodic protection of reinforced concrete structures, electric and electrochemical experiments were performed on the coatings. The selection of the ideal conducting component content for the epoxy coating was the primary goal in order to guarantee ideal anode operating conditions. They have also noted that the amount of graphite in coatings affects their electric and electrochemical characteristics. Despite having superior electric characteristics, coatings with higher graphite content (above 50%) cannot be utilised to protect concrete.

Aluminum/zinc alloy coatings-Z. The cathodic protection offered by different zinc/aluminum alloy coatings that have been utilised in place of zinc has been evaluated by Panossian et al. [15]. Although these coatings have certain benefits over zinc, they have found that in some natural environments, they are unable to cathodically preserve steel substrates. Based on experimental findings from their investigation, they have explored the cathodic protection offered by aluminium and zinc/aluminum alloy coatings in contrast to typical zinc coatings in this paper. Their research sought to understand how various coating types behaved in environments with a variety of corrosivities and pollution levels. The main goal of the investigation was to determine if this broad range of coatings could provide cathodic protection for the steel basis in a variety of natural environments. This research demonstrates that zinc, whether used alone or in very tiny quantities as an alloy, effectively and efficiently protects steel.

research into the electrochemistry of conductive coatings-J. Results of electrochemical studies of conductive coatings, based on the blending of pigmentary graphite in a polymer matrix, were given by Orlikowski et al. [21] in this paper. Long-term anodic polarisation on reinforced concrete allows for the determination of electrochemical parameters for the coatings under investigation. The electrochemical characteristics of conducting coatings are computed using impedance measurements. It is established that reinforced concrete may be cathodically protected using the researched coatings. According to the studies, coatings used to preserve concrete should include an ideal amount of graphite in the range of 40% to 45%. In order to assess the appropriateness of specifically manufactured conductive coatings as anodes in cathodic protection of reinforced concrete structures, the work's objective was to conduct electrochemical experiments on them. The findings demonstrate that the cathodic protection of reinforced concrete buildings may be achieved by conducting coatings acting as anodes. By altering the coating binder, one may improve the electric and electrochemical characteristics. However, there are still a lot of technical issues that need to be resolved, such as those related to the ageing process of coatings and the condition of the coating electric connection.

G.K. Glass and N. R. The current density needed to safeguard steel in concrete constructions exposed to the atmosphere has been researched by Buenfield [11]. They have noted that the corrosion rate has a significant impact on the current needed to cathodically preserve steel in concrete that has been exposed to the atmosphere. Normal design current densities would not reach the degree of cathodic polarisation necessary by widely recognised protection requirements at low corrosion rates. By eliminating chloride ions and raising the pH at the cathode, a cathodic current, on the other hand, significantly reduces the pace of unprotected corrosion. They claim that these protective effects are crucial for a cathodic protection system's ability to stop additional corrosion and reach a suitable degree of polarisation. They wanted to look at the current densities that the mixed potential theory predicted for a certain cathodic polarisation level and how it would affect the actual protection mechanism. They came to the conclusion that the protective effects of the current, which encourage steel passivity, are crucial to the cathodic protection of steel in concrete. This happens as a consequence of the pH at the steel contact rising and the elimination of chloride ions. Due to these effects, it is easier to meet the generally used 100 mV potential decay requirement; otherwise, the protective current density needed to stop mild corrosion rates would be much greater than the levels now in use. Galvanic sensor system development In their study of the corrosion behaviour of reinforcing steel, Zin-Taek Parka et al. [23] found consistency in the data obtained from measurements of electrochemical impedance spectroscopy (EIS), linear polarisation resistance (LPR), and open-circuit potential monitoring. In a concrete environment, a steel/copper sensor's output and the rate of steel bar corrosion demonstrated a strong association. The genuine corrosion damage of the reinforcing steel may be identified using the link between the steel/copper sensor output and the rate of corrosion of

the reinforcing steel. This demonstrates that the galvanic sensor system is an effective way to find corrosion in reinforced concrete.

Steel passivation in concrete caused by CP-In an experimental study, G. K. Glass et al. [22] investigated the applicability of mixed potential theory to forecast the rate of corrosion of steel in concrete using the negative potential shift brought on by a known cathodic current density. The set of findings are in good agreement with the polarisation resistance technique of calculating corrosion rate. An increased cathodic protection requirement for reinforced concrete exposed to the atmosphere is theoretically supported by this phenomenon.

Cathodic defence and cathodic avoidance

Pietro Pedeferra [25] provides an overview of the history of the CP method, its guiding principles, the requirements for prevention and protection, as well as certain operational circumstances, current distribution, hydrogen embrittlement danger, anodic system, and monitoring-related considerations. Permanent monitoring systems must be implemented in order to guarantee that protection or preventive requirements are met and overprotection situations are avoided, as well as more generally to assess the performance of the CP systems. The primary foundation of these systems is the measuring of the reinforced steel's potential in relation to reference electrodes.

Rebar Corrosion Is Caused by an Incorrect Cathodic Protection Connection-A case study of an oil loading wharf was published by Edoardo Proverbio et al. [27]. The issue was that the steel reinforcements were visible and the concrete surface of the platforms had extensive spalling during periodic maintenance checks. The top of the decks were heavily attacked, while the bottom of the deck was often in fair shape. The bottom of the deck was more vulnerable to sea spray, a more hostile environment, hence this fact was a bit unusual. The coatings and steel piles were both in excellent shape. The permeability of the concrete, which is often the source of rebar corrosion in concrete, was not the reason of the corrosion assaults, according to multiple field tests that were conducted. They came to the conclusion that the return power of the CP system, which was supposed to be linked to the steel piles, was instead connected to the concrete deck's rebar instead of the steel piles. The issues didn't start when the building was first built, when the concrete was in pristine condition and the rebar was undoubtedly electrically linked to one another and there were no signs of corrosion. Any electrical connections between the rebars eventually deteriorated or broke, allowing stray currents to flow between them. This led to the development of anodic regions and, ultimately, corrosion attacks. These assaults intensified to the point that huge parts of the deck's top surface were covered with spalled concrete. The authors also issue a warning that, in order to prevent corrosion, all technical considerations during the design and installation of CP systems must be understood and properly kept in mind.

3. CONCLUSIONS

Following a thorough examination of the literature and in-depth consultations with subject matter experts, the following research gaps are identified for further study.

- In order for the system to be employed successfully in big constructions, it is necessary to specify the effective distance between sacrificial anodes, or the location of anodes.
- Although expert systems are commercially available to choose the suitable material for a certain environment, for newer uses, the materials must be evaluated both in the lab and on a real-world application. In this situation, study or an inquiry are needed.
- Additionally, taking into account anode positioning, throwing force of sacrificial anodes, and many factors, viz. The intended level of research has not been done on cathode/anode area ratio, anode life, anode efficiency, side and shift of variations in current.
- The overall anode required for a given building and the attenuation in the cathodic protection system for sacrificial anodes have not been thoroughly examined.
- Additionally, there is a lot of room for exploration and research in the area of combined current attenuation in sacrificial anode cathodic protection systems, which has not yet been explicitly explored.

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