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BETONARME ÇELİĞİNİN DEFORMASYONUNUN ÖNLENMESİ İÇİN METOTLAR

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ÖZET

Betonarme, inşaat ve mimarlık dünyasına getirdiği yeniliklerle bu alanda vazgeçilmez bir yapı elemanı olmuştur. Fakat betonarme yapılar betonarmedeki demir donatıların paslanmasından dolayı deformasyona maruz kalıyorlar ve mali acıdan bu durumun getirdiği yük düşünüldüğünde bu sorunun değerlendirilmesi ve kontrol altına alınması kaçınılmazdır. Bu makale bu sorunun giderilmesinde kullanılan en yaygın metotların analizi ve en başarılı olan metodun tespiti üzerine bir çalışmadır. En yaygın metotlardan deformasyon önleyici araç olarak Kalsiyum Nitrat, ikinci olarak demir donatiya alternatif olarak fiber takviyeli polimer, son olarak demir kaplamasında kullanılan epoksi tekniğidir. Sonuçlar inşaatta sürdürülebilirlik açısından önemli bilgiler taşımaktadır.

Anahtar Kelimeler: *Demir donatı, korozyon, betonarme.*

METHODS FOR PREVENTING OF DEFORMATION OF THE REINFORCED CONCRETE STEEL

ABSTRACT

Reinforced concrete has become an indispensable structural element of modern construction and architecture as a result of the innovations reinforced concrete brought to construction field. However, reinforced concrete structures encounters corruption due to reinforcement steel corrosion in concrete and based on the economical worth of the problem the management of the corrosion methods should be taken into consideration. This paper is aimed to analyze the most common ways of what concluding the best method. The most efficient, applications of the three methods are discovered which are calcium nitrite as the most efficient corrosion inhibitor, fibre-reinforced polymer as an example of an alternative corrosion resistant reinforcement, and finally epoxy-coated reinforcing as rebar coating. This research provides significant information to obtain sustainability in constructions.

Keywords: *Rebar, corrosion, reinforced concrete.*

1. INTRODUCTION

The development of reinforced concrete started in late 19th century and after a short period of time reinforced concrete revolutionized the construction field. The innovations reinforced concrete brought to construction area have made this component a preferential structural element hence its superior quality compared to other structural materials. Zhou [1] states that reinforced concrete provided novel design methods which could not be managed with the present elements of steel, stone and timber. Numerous considerable features of reinforced concrete have changed architectural design concept, in other words decreased the design limitations and overall cost of construction. To entitle some properties of reinforced concrete, it sustains for long time without significant maintenance expenses, comparatively resistant to fire, it has considerably high compressive strength, easy to attain the constituent materials and the pattern can be produced in the desired shape that the reinforced concrete is molded [2]. These features could be considered as the response to the particular weaknesses of other structural materials such as steel, stone, concrete and timber. As a joint statement, several researchers assert that reinforced concrete is one of the most significant and fundamental structural element which has been effectively and extensively used in construction field [3, 4]. As a result, these characteristics make reinforced concrete as an indispensable structural element of modern construction and architecture.

Notwithstanding the respond of reinforced concrete to the needs of construction field as a structural substance, corrosion of reinforcing steel in concrete is a severe issue at the forefront of the construction sector which should be prevented for durable and sustainable structures. As a consequence of reinforced steel corrosion significant amount of reinforced concrete structures encounters corruption, hence it is a major problem civil engineers and broadly whole construction field are facing [5]. Moreover the problem is not limited only within the building area, the impact of this particular matter is significant in several areas wherever reinforced concrete is involved. Ref. [6] states that the impact of the corrosion on metallurgical, chemical and oil-industries brings the problem in a much significant controversial position which requires worldwide consideration. Beside the reinforced concrete's indispensable occupation as structural material, the impact of corrosion on economy lies behind this importance of the problem. Zhou [1] claims that the estimate of repair cost for existing highway bridges in the USA is over $50 billion, and $1 to $3 trillion for all concrete structures. They continue that in Europe, steel corrosion has been estimated to cost about $3 billion per year. Reinforced concrete's predominant role in construction field as a fundamental structural substance and prevalence of corrosion in the construction sector and also based on the economical worth of the problem the management of the corrosion should be taken into consideration.

To this end, this research is aimed to examine and evaluate the methods to manage reinforcement steel corrosion in concrete. The objectives engaged to accomplish the aim are; accessing the commonly used and trusted several methods to preventing corrosion in concrete, discussing the most successful, one particular element of each method regarding to their effectiveness to gather more accurate results, concluding on the most effective particular element as an example of these methods.

To maintain the significance of reinforced concrete in construction field which has become an indispensable structural element of modern construction and architecture with its innovative features compared to other structural elements, reinforcement steel corrosion in concrete should be managed. As a consequence of reinforced steel corrosion significant amount of reinforced concrete structures encounters corruption, hence it is a major problem civil engineers and broadly whole construction field are facing. Khatun [5] states that significant amount of reinforced concrete structures encounters corruption as a consequence of reinforced steel corrosion, hence civil engineers and broadly whole construction field are facing with this particular and significant problem. In addition, according to Abiola [6], the impact of the corrosion on metallurgical, chemical and oil-industries brings the problem in a much significant controversial position which requires worldwide consideration. Corrosion of reinforcing steel in concrete is a severe issue at the forefront of the construction sector that the management of the corrosion should be taken into consideration. The aim of this research is to analyze the most common three methods for managing the reinforcement steel corrosion in concrete. In this chapter all the accessible literature will be critically reviewed involving these three corrosion management methods.

Considerable amount of research has been made on the effect of calcium nitrite on corrosion as a successful and widely used example of corrosion inhibitor. Berke et al [7], Berke and Rosenberg [8], Burke [9], El-Jazairi and Berke [10], Pfeifer et al [11], Trepanier et al [12], Ann et al [13] evaluated the effect of calcium nitrite on preventing the corrosion in reinforced concrete, predominantly regarding to its compatibility with the concrete. In addition, Montes et al [14], Scott et al [15], Qian and Cusson [16], Al-Mehthel et al [17] compare the calcium nitrite's stand alone sufficiency on protecting the reinforced concrete against corrosion with calcium nitrite based admixtures. Berke's continuous single and collaborative studies [7, 8, 10] on the effect of calcium nitrite regarding to reinforcement steel corrosion in concrete has significant contributions to this literature. However, the studies on that subject also require long term results of tests and Berke's studies could suffer on that particular aspect.

The research results of El-Jazairi and Berke [10] indicated that Calcium nitrite was accurate in suspending the symptoms of reinforcement corrosion in the concrete samples incorporating seawater, chloride solution or chloride plus sulfate solution. These findings were disagreed with Montes et al [14]. They reported that calcium nitrite could not be considered as a successful corrosion protector for reinforcing steel in the concrete when it is used alone. In addition Montes et al [14] findings were supported by Scott et al [15]. They conducted a study of corrosion which was to assess the long-term effectiveness of calcium nitrate, silica fume, fly ash, ground granulated blast furnace slag, and disodium tetrapropenyl succinte (DSS) in reducing corrosion of reinforcing steel in concrete when they are mixed with calcium nitrite comparatively to alone calcium nitrite and DSS admixture present greater results than the other admixtures in corrosion prevention. The order of the research dates and contributive results of Montes et al [14] and Scott et al [15] shows a strong stance against Al-Amoudi et al [10]. However the difference in the results could be a consequence of variant adoptions of methodology such as testing by subjecting the material to seawater in laboratory as Al-Amoudi et al [10] or testing on field as Montes et al [14] and Scott et al [15].

On the other hand, El-Jazairi et al [10] stated that, calcium nitrite is widely tested and present positive result in terms of preventing corrosion as long as it is combined in a good quality concrete. Furthermore in their collective research El-Jazairi et al [10] claimed that even in good quality concrete if the concentration ratio of chloride to nitrite ions is not proportioned right the effect would not be significant. As a correct ratio they reported a ratio of 1 to 2. This contrasted with a more recent study that evaluated the chloride to nitrite ratio range from 1.5 to 3 [13]. Compared to research of Ann et al [13], El-Jazairi et al [10] studies is fairly outdated, nonetheless as mentioned before Berke's studies are considered as reliable sources.

Fibre-reinforced polymer consists of three elements and as a principal fibrous substance carbon, glass or aramid is commonly used which consolidate the component. To support the bending loads second element, resinous synthetic polymer is fixed into the fibrous substance and to stick them together third element as a coupling agent is mixed into the compound [18]. Fibre-reinforced polymer is a promising, tested and already applied structural element as one the alternative reinforcement material. The focus in the literature, Liao et al [19], Phong [18], Bakis et al [20] is on the durability and cost efficiency of fibre-reinforced polymer when it is used instead of steel as reinforcement regarding to corrosion. The most up to date research is conducted by Eyre and also the author's diversity which are both from academic and practical working life establishing more reliability.

Eyre claims that fibre-reinforced polymer has been found remarkable corresponding to fatigue life. This claim is conflicting with Thippeswamy statement which based on a test results that even though the short term performance of fibre-reinforced polymer is reliable, required time has not been elapsed to have a sufficient parameter related to long term durability of the material. As a response to these studies Liao et al [19] results suggests that under long term loads with exposure to water and salt solutions, the life of fibre-reinforced polymer decreases depended on their long term durability tests. Whilst Liao et al [19] are supporting their argument with test result, Eyre are not even using references to strength their claim. Furthermore lack of supportive citation is a drawback throughout their research.

In terms of cost comparison with fibre-reinforced polymer and steel as reinforcement in concrete indicated that while fibre-reinforced polymer costs are higher than the traditional steel reinforcement, nonetheless because of fibre-reinforced polymer's relatively lightweight, easy handling and facility of application on construction yard reduces need of labour amount, fulfillment of construction time and even transportation cost and as a result, to conclude cost efficiency more detailed calculations have to be done.

On the other hand another research conducted by Bakis et al [20] concludes that fibre-reinforced polymer would be adequately cost efficient if it is primarily used in case of possible corrosion occurrence where it is essential to use, otherwise it would not be preferred related to its high cost. Bakis et al [20] is a comprehensive research that nine participants involved from different parts of the world and they test and comparatively evaluate the fibre-reinforced polymer on its various properties in several different environments and supported their results with great amount of other researches. These criteria are reinforcing the reliability of Bakis et al [20] research.

Epoxy-coated reinforcing (ECR) is the primary corrosion protection system for bridge decks. It is produced by applying epoxy powder on freshly blasted steel surfaces at high temperatures. ECR functioning in 2 ways:

firstly, as a barrier that keep oxygen and chloride ions from reaching the surface of the steel, secondly, as a substance that increasing the electrical resistance in steel.
Many researchers (Manning [21]; Sagues et al. [22]; McCrum et al. [23]; Clear [24]) claim the use of epoxy-coated reinforcement as a method for preventing corrosion damage cannot be a long-term solution and state that the failures of epoxy-coated steel in structures are indicative of generic shortcomings in the technology, and that additional problems will develop as structures continue to age. On the other hand several researches (Edgell & Riemenschneider [25]; McDonald et al. [26]; Poon&Tasker [27]) believe that epoxy-coated steel is a viable option for long-term protection of reinforced concrete structures. In their opinion, reports of problems with epoxy-coated reinforcement are isolated, and each problem is caused by some shortcoming in the specific materials or construction in the particular structure.

Manning [21] and Sagues et al. [22] referring to researches that has been made in 1970s claim that epoxy coating tend to disbanding due to number of different factors such as anodic conditions, mild levels of cathodic polarization and exposure to salt water. According to field studies, signs of corrosion in ERC steel begin to appear only six years after construction. Also Pyc et al. [28] agree with previous authors and add that epoxy coating will not maintain its bond to reinforcing steel in moist concrete environments. Moreover, study of McCrum et al. [23] shows that if ERC steel is exposed to deicing salts corrosion progress begins under the coating and ERC steel perform even worse than black steel. However, the studies provided by Manning [21] and Sagues et al. [22] examine only short-term effect of ERC. On the other hand, study in Poon&Tasker [27] have shown that ERC is an effective corrosion protection method even if these were extracted from locations of heavy cracking, shallow concrete cover, high concrete permeability, and high chloride concentrations. These controversial results could be due to differences of environmental conditions where studies took place. The majority of problems that have been reported with epoxy-coated reinforcement have occurred in environments where the concrete is continuously wet, yet oxygen is still available, also these environments have high average temperatures.

Nonetheless, results of study provided by Clear [24] on 20-30 years bridges show that number of holidays per meter of the bar was much higher than expected, averaging more than 20 per meter, a measure of the contamination of the coated bars was on average 25%, which is considered as a maximum level. On following lab study the researcher criticises the method of measure that has been used in previous studies and provides a new methodology that determined service life for epoxy-coated steel as 16.5 years, rather than 53 years, as has been ascertained before. Moreover, Clear [24] concluded that in the northern US and Canada, comparing to the South USA, the time before corrosion damage to a structure will occur is only improved by three to six years by the use of ERC steel. The research of Clear [24] represents a long-term effect of ERC use which could be considered as reliable regarding to significance of long term effects of structural components in construction industry. Nevertheless, the results of study in McDonald et al. [26] are controversial to results provided by Manning [21], Sagues et al. [22], Pyc et al. [28], McCrum et al. [23] and Clear [24]. In the lab study [26] new effective types of ERC such as non-bendable coatings were developed to provide a corrosion-free design life of 75 to 100 years, following by field studies showed that non-bendable coatings provided high electrical resistivity and, as a result, better corrosion protection. Besides, even though deck cracking was prevalent, it did not appear to be corrosion related, even if the chloride concentration at the level of the bars was above the threshold level. Although the research do not represent long-term effect of ERC and took a place in laboratory, the results could be considered as highly reliable due to evaluating the performance of epoxy-coated reinforcement on a total of 92 bridges and 3 barrier walls in 11 states in the USA.

Corrosion inhibitor, rebar coating and alternative reinforcement are among the most common and effective corrosion prevention methods. In this project, particular elements of each three trusted prevention method were assessed in related literature. Calcium nitrite, epoxy reinforcement coating and fiber reinforcement polymer were selected in the same order, as an example of corrosion inhibitor, rebar coating and alternative reinforcement. Even though, epoxy coating and fiber reinforced polymer are also effective on prevention of corrosion, calcium nitrite's flexibility to adopt in different environments with additional chemicals and facility of application makes calcium nitrite more accurate component regarding to corrosion prevention of reinforcement steel in concrete. Further chapters will be focused on describing the methods used in this research, the results and findings of the study, and limitations of the research process.

2. METHOD

The study is aimed to investigate and evaluate the methods to manage reinforced steel corrosion in concrete with examination of the factors of efficiency such as effectiveness, durability, cost and flexibility of application for different environmental conditions. Hence, the qualitative approach is employed.
The research method for this study is the secondary research. The reasons for applying this method are given below:

- Time limitation. The time frame for this research is 12 weeks;
- Economic aspect. Since primary research would require substantial investment and the research is not funded;
- Sources. The number of researches undertaken previously is considered as significant; moreover, the studies are reliable, valid and up to date.
- Quality. The primary study of the methods to manage reinforced steel corrosion in concrete required long-term research in numerous environmental conditions and considerable investment. Investigating primary research in present conditions would lead to poor quality of the results;

Therefore taking into consideration time constraint, economic aspect and specificity of the research, the secondary research can be the optimal method for this study.

To achieve the aim of the study, different types of sources have been examined to gain particular information. Firstly, to clarify the topic and rational of the research academic literature has been searched. Secondly, due to range of the methods to manage reinforced steel corrosion in concrete, highly tailored sources such as books have been researched. Finally, to gain detailed data appurtenant to efficiency of each particular method government reports, primary field and laboratory research have been examined. The information has been gained thorough Internet sources such as Google scholar and City library.

The limitations for this research were time constraint and economic aspect. Moreover, the main source of the information used was City Library which did not provide sufficient access to the articles and other academic sources. Hence, there is a possibility that the data used is not complete. The advantages for the research are accessibility of primary researches through government reports and low cost of the study.

To conclude the chapter, there are few particular methods and approaches related to a research. This research adopted qualitative approach due to data requirements and such method as secondary research. The reasons of employing secondary research were limitation of time, lack of investment and availability of studies conducted previously. To achieve the aim of the study, few particular sources were used, such as academic literature and government reports. However, due to limitations, the collected data cannot be considered as comprehensive.

3. FINDINGS AND DISCUSSIONS

3.1. Findings

The significance of the reinforcing steel corrosion problem required immediate and effective solutions to avoid further losses. The solutions were focused on two separate aspects to establish a comprehensive management of the situation. First one was aiming to suggest a recipe concerning the rehabilitation of corroded steel in concrete in existing buildings to prevent the possible critical hazards such as collapse of a structure which even could consequence with loss of lives due to corrosion. On the other hand, second approach to solution was to prevent the corrosion of steel for future constructions by protective applications on rebars. Numerous researches have been conducted to be able to suggest an efficient solution to the problem and to advance the protection methods for reinforcement steel corrosion in concrete. The present methods for managing this specific type of corrosion were analysed in terms of the literature and from the secondary information obtained.

The aim of this paper is to focus on the findings based on the research and discuss the outcomes of the different methods adopted to manage the corrosion of reinforcing steel in concrete with comparison to each other.

3.2. Methods of Managing the Rebar Corrosion

Within the last century the researches have concluded with three main corrosion protection methods as a result of field and laboratory experiments and observations. These three methods currently being used in the construction industry include the addition of corrosion inhibitors into the concrete, use of alternative corrosion resistant reinforcement types, and rebar coating to provide extra shelter. These methods can be used separately or together for improved corrosion performance and longer service lives. This study will look at the most efficient, specific applications or components of these three methods. These methods are calcium nitrite as the most efficient corrosion inhibitor, fibre-reinforced polymer as an example of an alternative corrosion resistant reinforcement, and finally epoxy-coated reinforcing as rebar coating.

3.2.1. Calcium nitrite as corrosion inhibitor

Corrosion inhibitors have been acknowledged as one of the most successful corrosion management method in reinforced concrete [16]. Use of these inhibitors can result with either the decrease of the corrosion rate or with complete protection by chemical reactions. Hence, the inhibitors become an integral part of concrete which makes their protection mechanism unique among the methods of managing the corrosion [7]. Chemical reactions delay or prevent the corrosion by affecting several factors which are; reinforced concrete's chloride threshold level, chloride penetration rate, resistance of concrete to electricity, chemical bound level of chlorides in the concrete cover, and the electrolyte's chemical composition. The effect depends on the focus of inhibitors, whether on decreasing the permeability of the concrete or chemically stabilizing the steel surface as most inhibitors do or both. Thus, corrosion inhibitors are categorized in three different types: anodic inhibitors, cathodic inhibitors, and organic inhibitors [17]. Anodic inhibitors delay and control the corrosion rate by improving the electrical resistance of steel or creating a barrier of oxide film on reinforcing steel's anodic surfaces [12]. Calcium nitrite is the most commonly used anodic inhibitor that reduces corrosion in chloride contaminated environments by equation (1) [8].

$$2Fe^{2+} + 2OH^{-} + 2\,NO_2^{-} \rightarrow 2\,NO + Fe_2O_3 + H_2O \qquad (1)$$

Al-Amoudi and friends indicated that calcium nitrite was explicitly effective in retarding corrosion and reducing corrosion rates in chloride and chloride plus sulphate contaminated concrete based on his tests of various corrosion inhibitors in concrete that was contaminated with brackish water, sulphates, chlorides, unwashed aggregates and seawater. Figures 1 and 2 below illustrate the distinct difference in case of calcium nitrite usage for preventing the corrosion of reinforcing steel in concrete.

Fig. 1. Steel bar extracted from the concrete specimen contaminated with 2% chloride [17].

Fig. 2. Steel bar extracted from the concrete specimen contaminated with 2% chloride and incorporating CI-1 inhibitor [17].

However there are two important factors which are affecting the efficiency of calcium nitrite. First one is the concentration ratio of chloride to nitrite ions. Calcium nitrite increases the threshold of chloride concentration to start corrosion by contending with the chloride ions reacting with the steel, thus the concentration ratio of chloride to nitrite ions becomes an important matter to prevent corrosion. Different studies reported different chloride to nitrite ratios for corrosion prevention which fluctuates between 1.1/1.4 to 1.5/3.0 [10, 13].

Another factor is the quality of concrete. Since the calcium nitrite focuses treatment on reinforcement itself as increasing the corrosion threshold rather than blocking the penetration of chloride ions to concrete, the use of quality concrete becomes important as an initial protection phase to reduce the amount of chloride ions that can reach the reinforcement. Extensive testing proved that the efficiency of calcium nitrate increases by using quality concrete hence significant resistance to corrosion can be yielded [9, 10, 12].

In addition, by different chemical admixtures to calcium nitrite better results could be obtained. Moreover, calcium nitrite is also used in the replacement concrete as well as for repairing the corrosion-damaged structures by applying directly to the reinforcing steel and concrete which are exposed after the concrete is removed. When concrete is removed, calcium nitrite is applied directly to exposed reinforcing steel and concrete, as well as being used in the replacement concrete [14, 15].

3.2.2. Fiber-reinforced polymer as alternative reinforcement

Since the alternative reinforcements are not just additional applications to the concrete or reinforcement the focus is not only managing the corrosion but also, because they are the reinforcement itself, providing a sufficient reinforcement. A preferable alternative reinforcement to steel must be resistant to external factors during transportation, storage at the construction site, application, and pouring the concrete and also the reinforcement should also be able to maintain its functional integrity even in severe conditions for the service life of the structure. Finally, alternative reinforcement must be the economically reasonable when compared to traditional reinforcement [30]. After all, fibre-reinforced polymer is considered as a successful example of alternative reinforcement as it obtains most of the required features.

Fibre-reinforced polymer consists of three elements and as a principal fibrous substance carbon, glass or aramid is commonly used which consolidate the component. To support the bending loads second element, resinous synthetic polymer is fixed into the fibrous substance and to stick them together third element as a coupling agent is mixed into the compound [18].

Fibre reinforced polymer was used as an alternative reinforcement for the first time in 1996. The structure is currently being monitored and tested for its durability against to loads, aging and climate changes. Considering the test results Sagues et al [22] stated that, even though the short term performance of fibre-reinforced polymer is reliable, required time has not been elapsed to have a sufficient parameters related to long term durability of the material. Regarding the durability measures against loads, Liao et al [19] reported that under long term loads with exposure to water and salt solutions, the life of fibre-reinforced polymer decreases depended on their long term durability tests and deflection rather than strength usually governs design as a result of fibre reinforced polymers insufficient tensile strength [18].

In terms of cost comparison with fibre-reinforced polymer and steel as reinforcement in concrete [4] indicated that while fibre-reinforced polymer costs approximately $700/m2 ($65/ft2) for 7/kg ($3/lb) of material, traditional materials cost is $322/m2 ($30/ft2) which is under the half cost of fibre-reinforced polymer. He continuous that, nonetheless because of fibre-reinforced polymer's relatively lightweight, easy handling and facility of application on construction yard reduces need of labour amount, fulfillment of construction time and even transportation cost and as a result, to conclude cost efficiency more detailed calculations has to be done. Bakis et al [20] concludes that fibre-reinforced polymer would be adequately cost efficient if it is primarily used in case of possible corrosion occurrence where it is essential to use, otherwise it would not be preferred related to its high cost.

3.2.3. Epoxy-coated reinforcing as rebar coating

Coatings are categorized in two basic types: organic and metallic. The most common coating for reinforcing steel is epoxy coating, which is organic. Epoxy coating provides an electrical isolation between the steel and the concrete and creates a physical barrier to chloride ions.

The method of coating reinforcing steel with epoxy is basically cleaning the steel bar rigorously to obtain a smooth surface. Then, charged, dry epoxy powder is sprayed to the preheated steel to typically 230°C. Epoxy melts and spreads on the steel equally [21].

Tests have shown that when quality epoxy coating is applied with sufficient thickness (177 µm, 7 mils) the diffusion rates of oxygen and chloride ions, even in severe exposure conditions, are considerably low. Epoxy coatings function in two ways, firstly, as a barrier that prevents oxygen and chloride ions to reach the steel (Fig. 3), secondly, as a substance that increasing the electrical resistance in steel Virmani [30]. To establish the protection integrity three factors should be taken into consideration.

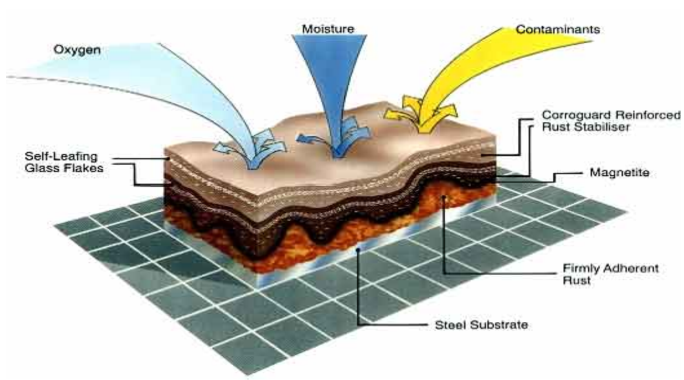

Fig. 3: Working mechanism of epoxy coating.

The first line of defence against the corrosion of reinforcing steel is high quality concrete for greater results as in calcium nitrite case.

On the other hand, adhesion of epoxy on steel is another factor which yields the physical barrier which can be improved by greater surface roughness. The main reason of adhesion loss is seemed to be the water penetration to the coating which could displace the epoxy from the steel surface [24]. Furthermore, when chloride ions arrive at the surface of the reinforcement through reduced adhesion of epoxy, corrosion will take place under the coating which is faster than the corrosion of bare steel in concrete [30].

Finally, performance of epoxy-coated reinforcement is related to the number of defects in the coating. These defects directly affect the electrical resistivity of the reinforcement. To protect the steel bar, the coating requires to provide a high electrical resistance, which depends on the rate of holidays on epoxy coating. According to Ref. [24], the deterioration that is the reason of holidays on epoxy, could happen during transportation, storage or application. Because the protective ability of epoxy coatings depends on their ability to act as both a physical which depend on the adhesion level of epoxy and electrical barrier that could be affected by the amount of holidays on epoxy coating, effective quality control measures must be taken during coating of the bars and subsequent handling, shipping and storage of the bars [24]. Because of these reasons efficiency of epoxy coating is under debate. Particularly long term results due to adhesion loss decreases the reliability of epoxy coating.

3.3. Discussions

Findings of the three most effective and commonly used solutions for corrosion protection are mentioned above and to address the best approach, these solutions will be discussed with their drawbacks regarding different criteria which are durability, cost and flexibility of application and overall effectiveness for different environmental conditions (Table 1).

Table 1: Comparative evaluation of the three corrosion protection methods.

	Calcium Nitrite	**Fibre Reinforced Polymer**	**Epoxy Coated Reinforcement**
Effectiveness	Very positive.	Very positive. Long term tests require.	Very positive. Failure in long term.
Cost	Easy to afford.	Expensive material. Easy maintenance.	Affordable material. Expensive maintenance.
Durability	No significant failure.	Weak to the fatigue loads.	Water penetration caused by loss of adhesion

Regarding durability of the methods, while epoxy coating is successful for short term effects, it has major failures in the long term effects as a result of the weakening adhesion by time which allows chloride ions to penetrate and cause even faster corrosion compared to bare steel reinforcement. Epoxy coating fibre reinforced polymer performed well for short term, however not enough time has passed to allow for determining the long-term response of the application. Furthermore, not as a corrosion prevention aspect but for reinforcement qualities some faults started to occur. On the other hand calcium nitrite which is in use for over thirty years has proved its long term performances reliability with extensive and various tests.

In terms of costs, calcium nitrite's cost has not even been taken into consideration as it is considerably easy to afford. Likewise calcium nitrite, epoxy coating has also a reasonable price whereas, because the protective ability of epoxy coatings depends on their ability to act as both a physical and electrical barrier, effective quality control measures must be taken during coating of the bars and subsequent handling, shipping and storage of the bars and this maintenance or required precautions for the integrity of the material are time consuming and increases the cost. Conversely, fibre reinforced polymer is twice expensive than traditional steel reinforcement. Nevertheless, fibre-reinforced polymer's several superior features reduce need of labor amount, fulfillment of construction time and even transportation cost and as a result, it is inferred that the cost will be lower when all aspects are considered.

Calcium nitrite has also flexible application measures which could be obtained by arrangements on chloride to nitrite ratios that would promote the accuracy in different environmental conditions. In addition, by different chemical admixtures to calcium nitrite better results could be received for various circumstances. Epoxy coating on the other hand cannot resist when it is exposed to water as a result of loss of the adhesion and similar result in moisture environment. In fibre reinforced polymer case, especially when it is used in infrastructure applications water and salt solutions reduce the life of the material when it is exposed to long-term fatigue loading. When it is considered that the major reason of corrosion is water or seawater exposure, these materials are expected to be efficient predominantly in those conditions which fibre reinforced polymer and epoxy coating fails.

As a result of comparative evaluations among three different methods, implementing calcium nitrite as an effective solution to corrosion problem seems to be the most appropriate approach to fulfil the comprehensive management of reinforcement steel corrosion in concrete regarding the required features of durability, cost and flexibility of application and overall effectiveness for different environmental conditions.

4. CONCLUSION

In conclusion, this research was aimed to examine and evaluate the methods to manage reinforcement steel corrosion in concrete by accessing the commonly used and trusted several methods to preventing corrosion in concrete, discussing the most successful, involving one particular element of each method regarding to their effectiveness to gather more accurate results, concluding on the most effective particular element as an example of these methods. Thirty one relevant literatures were reviewed that covers almost thirty years of researches regarding corrosion protection methods. Review of extensive range of research dates that also includes up to date researches was to provide a comprehensive understanding of the case as it is required to evaluate the short and long term effects of each method. Evaluation was based on three main criteria that are effectiveness, cost and durability. As they are considered as the most successful methods, the determining criteria for their overall performance were predominantly based on the flaws of each method.

It was discovered that the significance of the issue regarding the corrosion of reinforcement steel in concrete required immediate attention on finding an effective solution to prevent further harms. Three methods which are considered as the most successful and common ones were found out and one particular application of each were evaluated by their features including from transportation to application of them. Based on the research, calcium nitrite was found as the most effective method for managing the corrosion of reinforcing steel in concrete.

This research is expected to be useful about determination of the best management method for reinforcing steel corrosion in concrete who involved to the construction field. Furthermore, foundation of these researches by governments, construction companies and where the reinforced concrete is used in industry would enhance the experiments and tests that could fasten the process to obtain better results, therefore a substantial industry that involves several different fields could prevent concrete failures or expensive maintenance costs.

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