Complex Use of Mineral Resources. 2024; 329(2):92-102 ISSN-L 2616-6445, ISSN 2224-5243

DOI: 10.31643/2024/6445.20
Engineering and Technology

Analytical Review of Conductive Coatings, Cathodic Protection, and Concrete

[1*]Ainakulova D.T., [1]Muradova S.R., [2]Khaldun M. Al Azzam, [3]Bekbayeva L.K., [4]Megat-Yusoff P.S.M, [5]Mukatayeva Z.S., [6]Ganjian E., [1,7]El-Sayed Negim

[1] School of Materials Science and Green Technologies, Kazakh-British Technical University, Almaty, Kazakhstan
[2] Pharmacological and Diagnostic Research Centre (PDRC), Faculty of Pharmacy, Al-Ahliyya Amman University, Amman 19328, Jordan
[3] National Nanotechnology Open Laboratory, Al-Faraby Kazakh National University, Almaty, Kazakhstan
[4] Universiti Teknologi Petronas, Bandar Seri Iskandar 31750, Perak, Malaysia
[5]Institute of Natural Science and Geography of KazNPU named after Abai, Almaty, Kazakhstan
[6]Concrete Corrosion Tech LTD, 12 Humphrey Middlemore Drive, Birmingham, England B17 0JN
[7]School of Petroleum Engineering, Satbayev University, Almaty, Kazakhstan

** Corresponding author email: da_ainakulova@kbtu.kz*

Received: *July 9, 2023*
Peer-reviewed: *August 15, 2023*
Accepted: *August 24, 2023*

ABSTRACT

The principal and most expensive type of degradation that currently affects the performance of reinforced concrete bridge constructions is the corrosion of steel reinforcement. Strong financial losses result from the corrosion of reinforced concrete structures. One popular technique for preventing corrosion in reinforced concrete structures is cathodic protection. Since it can give necessary current in a situation where reinforced concrete buildings have high resistance, impressed present cathodic protection (ICCP) provides strength and adaptability. Conductive coatings, discrete anode systems, titanium-based mesh in cementitious overlay, conductive overlay with carbon fibers, and flame-sprayed zinc are examples of anode materials that are often used for impressed current cathodic (ICC). Chloride ions, in particular, are exceedingly difficult to permeate through a continuous epoxy coating on steel, making an epoxy coating a very effective barrier to these hostile chemicals. Epoxy resins are a great option for shielding metal surfaces from the environment and hostile environments because of their outstanding anti-corrosion qualities, good adherence to a variety of surfaces, and chemical resistance. In this work, the cathodic protection, ICCP, various conductive coatings, and epoxy coating as anode material are reviewed.

Keywords: protection, impressed current, reinforced concrete corrosion, epoxy coatings.

	Information about authors:
Ainakulova Dana Tulegenkyzy	*Ph.D. student at Materials Science and Technology of New Materials, School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Email: da_ainakulova@kbtu.kz*
Muradova Sabina Rustamkyzy	*Master's Degree in Materials Science and Technology of New Materials, School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Email: sab.muradova.01@mail.r*
Khaldun M. Al Azzam	*Ph.D., Associate Professor Department of Pharmaceutical Sciences, Pharmacological and Diagnostic Research Center (PDRC), Faculty of Pharmacy, Al-Ahliyya Amman University, Amman 19328, Jordan. Email: azzamkha@yahoo.com*
Bekbayeva Lyazzat Kairatovna	*Ph.D., Lecturer at National Nanotechnology Open Laboratory, Al-Faraby Kazakh National University, 71, Al-Faraby av., 050040, Almaty, Kazakhstan, Almaty, Kazakhstan. Email: lyazzat_bk2019@mail.ru*
Puteri Sri Melor Megat-Yusoff	*Ph.D., Assistant professor at Mechanical Engineering Department, Universiti Teknologi Petronas, Bandar Seri Iskandar* 31750, *Perak, Malaysia. Email: puteris@petronas.com.my*
Mukatayeva Zhazira Sagatbekovna	*Candidate of Chemical Sciences, Associate Professor of the Institute of Natural Sciences and Geography of Abai KazNPU. Email: jazira-1974@mail.ru*
Ganjian Eshmaiel	*Ph.D., Professor, Concrete Corrosion Tech LTD, 12 Humphrey Middlemore Drive, Birmingham, England B17 0JN. Email: concorrosion@gmail.com*
Negim Attia El-Sayed	*Ph.D., Professor at School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Professor at Geology and Oil-gas Business Institute named after K. Turyssov, Department of Petroleum Engineering, Satbayev University, Almaty, Kazakhstan. Email: a.negim@kbtu.kz*

Introduction

One of the major issues contributing to significant economic losses worldwide is metal corrosion. Due to the early collapse of structural elements, corrosion of metals in engineering equipment might result in accidents [1]. Concrete structures, like all building materials, are gradually and irreversibly destroyed. This happens not only under the yoke of time but also because of many factors. Corrosion destruction is one of the significant reasons for the decrease in durability and damage to reinforced concrete structures. External and internal influences on concrete lead to the destruction of the structure of the hardened mixture and the loss of quality characteristics such as strength, density, and so on. In simpler terms, they lead to the corrosion of concrete. Corrosion of concrete is the process of destruction of the structure of concrete and its embrittlement under the influence of environmental factors. It occurs under the influence of some aggressive substance, and the penetration of this substance into the concrete structure through the pores or cracks of the concrete structure. An adverse setting refers to the consequences of water and cold temperatures, the process of dampening and subsequent drying of concrete, as well as the effects of both clean and mineral-laden waters [[1], [2]].

Since it might eventually affect structural performance and integrity, steel corrosion in concrete structures is still considered the major obstacle in the construction industry. When steel in a concrete building deteriorates as a result of exposure to a corrosive environment, corrosion takes place [2]. Corrosion is an electrochemical process. Steel's mechanical qualities, specifically its bond strength, deteriorate due to rust. The most significant issue is how to prevent corrosion in structures made of concrete and reinforced concrete, and finding a solution will help structures, buildings, and structures used for a variety of functions last longer. For diverse technological domains, there are numerous strategies to stop metals from corroding [3].

One popular technique for preventing corrosion in reinforced concrete structures is cathodic protection. Cathodic protection is considered a technique used to stop corrosion occurring in metal surfaces, which involves making a metal surface the cathode of an electrochemical cell. Bridges and jetties are two reinforced concrete constructions that may be repaired using the embedded cathodic steel reinforcement from this process. Nonetheless, of the amount of chloride present in the concrete, it has been demonstrated that this approach prevents corrosion from occurring in reinforced concrete structures [3]. By cathodic polarizing a metal surface that has rusted, cathodic protection (CP) slows down corrosion [4].

Anodes connected to a power source that continually produces electrical flow make up systems for influenced current cathodic protection. In the sacrificial anode method of protection, active metals other than the base metal are utilized to "sacrifice" ions. These "sacrificial anodes" have a higher electrochemical potential than typical alloys like magnesium, aluminum, or zinc. When compared to a sacrificial anode, this technique frequently presents substantially longer protection. An endless power source powers the anode [4].

The ICCP consists of a monitoring system, an anode system that corrodes slowly, and an outer current power source that pushes a small amount of electric current during the reinforcing steel to balance the current flow from the effect of corrosion. Although RC structures may be repaired using any of the two CP systems, the ICCP system offers more adaptability and durability due to its current output's ability to be changed to generate the required current in situations of high concrete structure resistivity [5].

Conducive coatings, independent anode systems, titanium-based mesh in cementitious overlay, conductive overlay with carbon fibers, and flame-sprayed zinc are some examples of anode components for the ICCP system [5]. The selection of anode materials, which is largely based on the life cycle of the structures, the kinds of corrosion and structure, anode installation techniques, operation, the requirement for routine maintenance, and the life cycle price of the CP system, has not yet been proven to be efficient and appropriate for the majority of anodes currently in use [6]. Epoxy-based materials are considered one of the best in the line of anti-corrosion materials. They have excellent adhesion to ferrous metals, many types of plastics, and glass [7].

Coatings are traditionally distinguished by high protective properties, hardness, chemical resistance, excellent water resistance, and resistance to oil products. Materials of this group of chemical curing, as a result of which they are resistant to solvents and petroleum products, the coating film does not soften under the influence of high temperatures [8].

Epoxy resins have high adherence to metals and are resistant to halogens, and some acids (strong acids, particularly oxidizing acids, have poor resistance). Various types of glue, plastics, electrical insulating varnishes, and textolite (glass and carbon fiber plastics) are prepared from epoxy resins. Epoxy resins are promising products for the production of anti-corrosion coatings. Coatings based on them are characterized by high hardness, abrasion, and chemical resistance, and excellent adhesion to various substrates [9].

Corrosion process in Reinforced Concrete Structures

Typically, the alkaline concrete environment passivates the reinforcing steel in concrete, shielding it from corrosion. Environmental factors, however, have the potential to eliminate the passivating layer from the surface of steel, cause substantial corrosion in reinforced concrete structures, and take away the passivating layer from the surfaces of steel [10].

There are some main reasons why steel in concrete passivates and corrodes. First of all, the pH of the concrete where the rebars are inserted is decreased by atmospheric carbon dioxide consumption. If the pH drops below 11, corrosion might begin. This process is known as the carbonation of the concrete overlay.

Secondly, chloride infiltration of the concrete overlay, such as that caused by exposure to seawater or deicing salts. Chloride intrusion can be brought on by direct contact with de-icing salts on surfaces like bridge decks, balconies, and pavement as well as by aerosols from bridge decks and roadways on nearby civil buildings [10].

Depassivation of the reinforcing steel causes the establishment of a local corrosion cell that works similarly to the battery (Figure 1). Local areas that have been depassivated serve as anodes and passive areas serve as cathodes. Rust is produced when oxygen is reduced to hydroxyl ions at the cathodic sites and iron is oxidized at the anodic sites. Chlorides cause pitting corrosion, which can cause the rebars to deteriorate quickly and lose their integrity in localized areas. Carbonation causes regular corrosion on the steel surface, but this process is rather slow. Particularly, corrosion brought on by carbonation results in the production of several corrosion products, which weaken and break the concrete overlay [10].

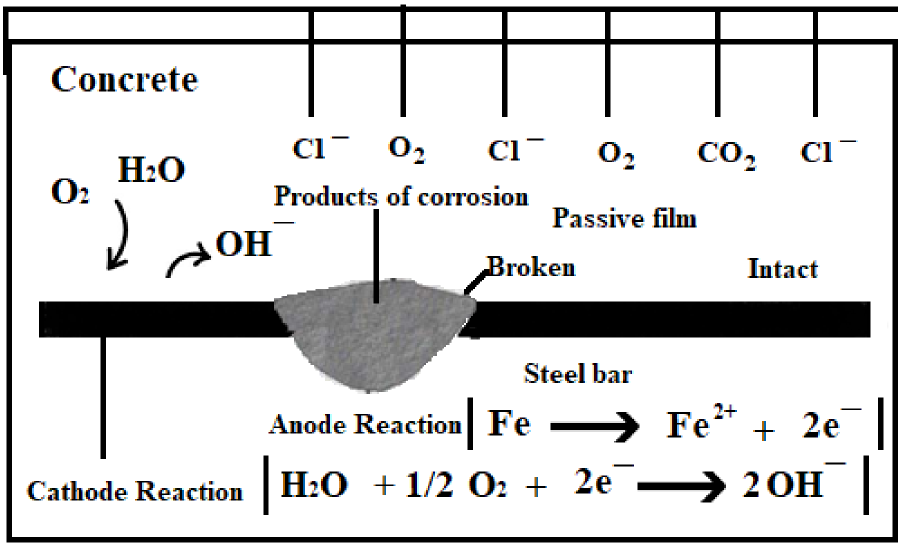

Figure 1 - Schematic image of a corrosion cell

Steel corrodes in concrete structures when it starts to degrade after being exposed to an environment that can do so [11]. When a structure is subjected to corrosion, current leaves it at the anode site, moves across an electrolyte, and then returns to it at the cathode site. The electrolyte, a liquid that conducts electricity, is utilized to transfer electrons from the anode to the cathode [12]. Figure 2 shows a visual representation of the corrosion that occurs in the steel process at the anode and cathode.

Electrochemical reactions, such as the oxidation of iron, can be used to characterize corrosion. These electrochemical reactions are anodic (produce electrons). The electrolyte's characteristics influence the cathodic process, which consumes electrons.

The oxygen reduction cathodic reaction is what causes corrosion in concrete. Steel corrosion in concrete has the following reactions as

Anodic reaction, oxidation of iron

$$2Fe \longrightarrow 2Fe^{2+} + 4e^- \qquad (1)$$

Cathodic reaction, oxygen reduction

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^- \qquad (2)$$

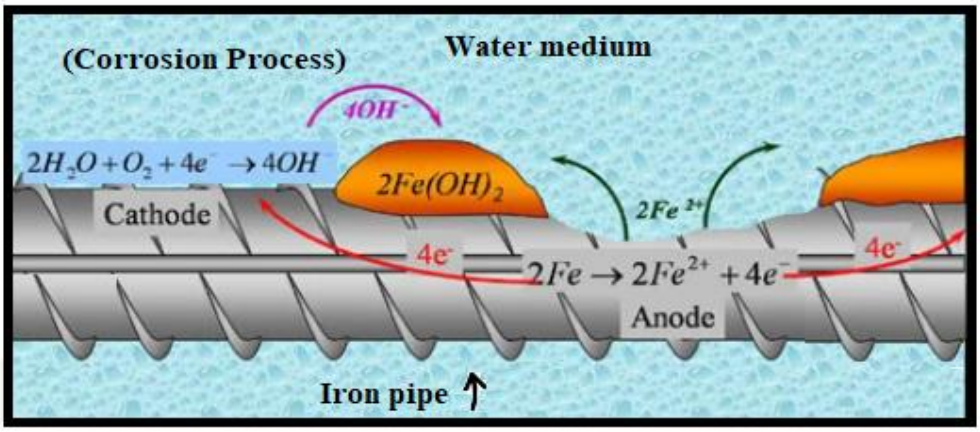

Figure 2- Diagram of the corrosion occurring in the corrosion process

Simultaneous reactions occur in the cathodic and anodic zones on the surface of steel. An exposed steel surface in concrete that forms an electrochemical cell is referred to as a corrosion system. A cathodic and anodic region, an electron conductor (rebar), an ion conductor (electrolyte), and a conductor for ions make up an electrochemical cell. Concrete pore water serves as an electrolyte [13].

Iron (II) hydroxide is created by combining two distinct processes, as shown in equation (3), while iron (III) hydroxide is created by additional oxidation, as shown in equation (4). Iron (III) hydroxide is shown to dehydrate in equation (5) to generate Fe_2O_3.nH2O, also known as rust. These are the equations written as,

$$Fe_2\,O_3.nH_2O \quad \text{(Iron (II) hydroxide)} \qquad (3)$$

$$4Fe(OH)_2 + O_2 + 2H_2O \longrightarrow 4Fe(OH)_3 \quad (4)$$

(Iron (III) hydroxide)

$$Fe(OH)_3 \longrightarrow Fe_2O_3.nH_2O \qquad (5)$$

(Rust)

Cathodic Protection

Impressed Current Cathodic Protection (ICCP)

In protected concrete constructions, a passive oxide coating stops steel from corroding. However, the oxide coating may become less effective or even disappear due to corrosion brought on by chloride- or carbonation-induced contamination of the concrete around the steel bar. Concrete cracking and spalling may result from additional corrosion [14]. Corrosion is typically prevented by corrosion-product- or oxygen-adsorbed film (or protective layer), and the rate of corrosion that occurs on steel surfaces can be slowed down by highly alkaline water. Utilizing an existing repair technique, such as cathodic protection, can stop or reduce steel corrosion in RC structures [15].

Cathodic protection offers greater benefits than other methods for restoring RC structures since it requires less time for monitoring and inspections, a wider range of anode systems, and less time for removing concrete and repairing it [16].

The key advantages of cathodic protection over the other anti-corrosion treatment techniques are that it may be used by simply maintaining a dc circuit and that its effectiveness can be monitored continually. A coated structure is frequently treated with cathodic protection to prevent corrosion in potential coating-damaged areas. It can be used to extend the life of existing constructions [17].

By using galvanic (sacrificial) anodes or "impressed" current, cathodic protection can be provided in one of two methods.

Sacrificial Anode Cathodic Protection (SACP)

As displaced in Figure 3, the SACP system is composed of an outside sacrificial anode, such as a metal having a greater potential for the electrode than steel reinforcement, that is electrically linked to another metal that acts as the anode.

However, due to the high concrete resistivity, galvanic anodes typically are unable to economically produce sufficient current. Therefore, the RC structures are repaired using current cathodic protection (ICCP) [18]. This strategy is thought to be more costly and requires a reliable source of low direct current (DC) power to provide the system with current.

Impressed Current Cathodic Protection (ICCP)

In the situation of ICCP, an external power source is used to initiate a modest amount of current via the reinforcing steel to reverse the flow of the metal, which commonly employs platinum used as a node because of the slow rate of corrosion, as seen in Figure 3. Steel reinforcement in RC structures will accept electrons from the external anode, causing it to become cathodic and so prevent more corrosion [19]. A true system in practical applications often includes a DC power supply, monitoring devices, and cabling [18].

The optimum use for ICCP is in large buildings in which galvanic CP would not create enough current to guarantee total protection. The ICCP is widely utilized in concrete projects due to its improved capacity to deliver high voltages when compared to the SACP. A 1-5A and 2-24V DC power source will normally power each separately controlled anode zone [18]. To permit current to pass and flow through the ICCP, the shielding metal, and anode must be in contact with an electrolytic medium (concrete). Although concrete has a high electrical impedance, the presence of the pore solution, which behaves as an electrolyte, allows current to pass through.

Although it is significant to consider hydrogen embrittlement in steel, alkali-silica reaction in aggregates, and interactions with nearby structures when utilizing the technique, ICCP outperforms the SACP system in terms of flexibility and durability [18].

The ICCP system needs a constant direct current (DC) power supply despite being more effective, in particular, for concrete in high-resistance environments. Furthermore, it is critical to ensure that the anode material used in the ICCP system is a good electrical conductor with a low corrosion rate and mechanical properties, is affordable, is easily produced in a range of shapes, is simple to install, and can handle large current densities [15]. The advantages of ICCP are depicted in Figure 3.

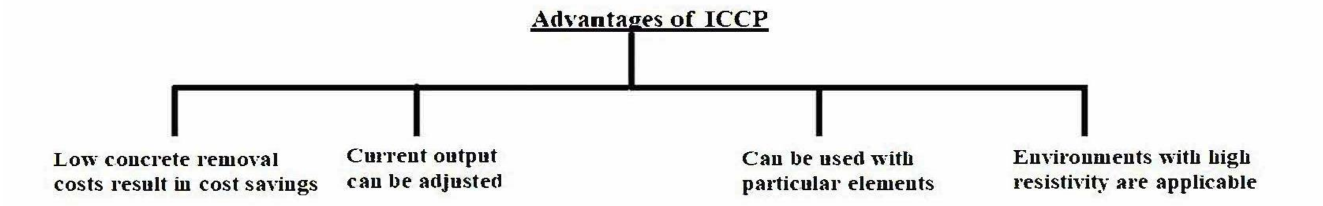

Figure 3 - Advantages of Impressed Current Cathodic Protection (ICCP)

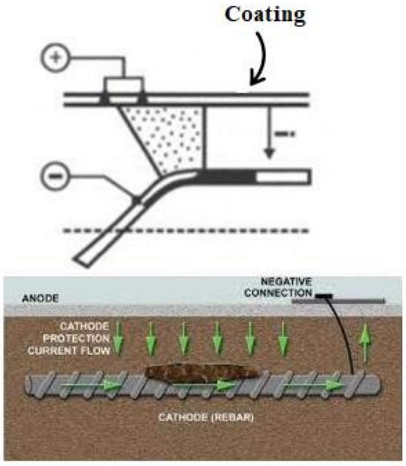

Figure 4 - A schematic diagram of cathodic protection used for the corrosion prevention of rebars steel in concrete: conductive coating

The principle of protection of cathodic using conductive coating is shown schematically in Figure 4.

Applying the polymer/graphite dispersion to the concrete surface will install the anode. The conductive coating is devoted to a secondary anode. The secondary anode's current distribution is controlled by a "primary anode" that is embedded into it at a distance of one to two meters apart and made of materials that can withstand anodic reactions, like platinum-clad titanium, copper-cored niobium, or MMO-titanium. Applying conductive coatings is simple and less expensive [[20], [21], [22], [23]]. Additionally, coatings that conduct conductive can be utilized on any structure of concrete structures.

Conductive Coatings

One of the most popular and well-known anode technologies for the protection of the cathodic of reinforced concrete structures is the conductive-coated anode. It is reasonably simple to maintain and affordable. The installation of anodes at certain locations is necessary for the majority of used systems for the current protection of the cathode. The fundamental drawback of such a solution is poor protective current distribution, which is mostly caused by the anodes' constrained surface area. Additionally, cutting apertures and removing the external concrete layer are relatively expensive construction tasks associated with anode installation. Another issue is the potential harm to anodes during assembly. The majority of issues can be resolved by using conductive coatings as anodes.

The alternative method of solving this issue makes it possible to implement coating and cathodic protection simultaneously, hence enhancing the efficiency of protection. The following benefits come with this solution, such as installation simplicity, the ability to guard difficult-to-reach areas, and the assurance of a sizable anodic system surface permitting similar spreading of the protective current. Additionally, there is a significant decrease in the cost of installing cathodic protection systems (applying coatings is far less expensive than installing anodes in points) [[24], [25]].

The industry is encouraged by the speed of technological advancement to look for improved anode materials for CP systems. Anode materials that are typically utilized for ICCP consist of coatings that are conductive, titanium-based mesh used in cementitious overlays, discrete anode systems, and conductive overlay with carbon fibers [26].

There are two types of coatings as inorganic and organic coatings. The dispersion of zinc dust in an inorganic or organic binder might be spherical, lamellar, or a combination of both [27]. The binder is used to separate organic coatings from inorganic ones, which is frequently epoxy for organic coatings and silicate for inorganic coatings. The most popular technique for preventing the corrosion of metallic elements in transportation and infrastructure is the use of organic coatings [28].

Roller, Brush, or air spray methods are used to apply organic anode coatings to thicknesses of 0.25 to 0.50 mm [29]. Disbandment is a common failure mode that can be brought on by-products obtained from the anodic reaction that may be acidic to the alkaline concrete, causing the coating to lose adhesion [30]. Although wet adhesion and cathodic disbonding resistance can be improved by applying an epoxy coating to a substrate that has already had 3-glycidoxyy propyl silane treatment, Sofian and Noda disagree [31].

Based on the inclusion of pigmentary carbon in a coated polymer matrix, Darowicki *et al.* [32] were given electrochemical tests for conducting coatings. Impedance measurements have been used to calculate the electrochemical characteristics of conducting coatings. Using data from coatings' electric and electrochemical investigations, the following result has been reached. The amount of graphite in coatings affects their electric and electrochemical characteristics. Over 50% of graphite content coatings are distinguished by minimal resistances and potential stability under prolonged anodic polarization.

Nevertheless, they also have worse mechanical qualities, and after 12 days of exposure, they start to become porous. Due to this, high graphite content coatings despite having outstanding electric properties cannot be used to cover concrete. Low barrier qualities and quick increases in resistance and potential during prolonged anodic polarization are characteristics of coatings with tiny graphite concentrations (35% and less). The development of the steel-graphite cell can significantly reduce the electrode potential, indicating the porosity of these coatings [32].

Epoxy Coating as Anode Material

Corrosive substances, especially chloride ions, are effectively blocked by an epoxy coating on steel because the latter will not easily diffuse through a solid epoxy covering. Consequently, the steel surface is shielded.

There are two hypotheses have evolved regarding the protective potential of epoxy-coated reinforcement.

Firstly, acording to the physical barrier theory, the epoxy coating serves as a barrier to keep chloride ions and other abrasive materials from coming into touch with the steel surface.

Secondly, the epoxy coating functions as a high-resistance coating, decreasing corrosion by raising electrical resistance between nearby coated steel sites where cathodic reactions can occur [33].

These two hypotheses provide a convincing justification for the usage of epoxy-coated reinforcement as a safety measure for structures found in marine settings.

The application, however, hasn't received adequate research. Epoxy coating is a top base of concrete, particularly when used as anode material for an ICCP system.

ERs as Anti-Corrosive Coating

The qualities of epoxy resin rely on factors such as resin quality, hardener, and curing circumstances. Figure 5 displays the primary characteristics of epoxy resins. - High strength. It is this property that has provided a stable demand for epoxy resins for many years. The tensile and compressive strength of the hardened mixture is comparable to the strength of typical grades of heavy concrete.

- Excellent adhesive properties: Epoxy resins have excellent adhesive properties, which, combined with strength, made them an excellent adhesive.
- Good waterproof properties: cured epoxy resin is practically waterproof.
- Resistant to a wide range of aggressive chemicals
- Physical and mechanical parameters at a higher level.

Gujjar SV *et al*. [33] looked into the best resin coating among the ones currently in use for mild steel surfaces. The resins such as polyurethane, epoxy, phenolic, and polyester) were applied to the mild steel surface using pneumatic spray coating. The corrosion rate and mechanical characteristics of mild steel covered with various resins were also evaluated and compared to a bare steel surface through the execution of numerous experiments (including an immersion test, a salt spray test, a test of tensile strength, and a test of scratch hardness).

It was found that mild steel samples coated using epoxy resin got good corrosion resistance. Epoxy resin-coated mild steel specimens had a considerably higher tensile strength. The surface morphology of the surface of the mild steel specimens covered with epoxy resin exhibits minute rust particles when compared to other resins and plain mild steel. FESEM analysis showed that samples coated with epoxy resin had the least damaged surfaces when compared to other resin-covered surfaces. Epoxy resins were used to create the coated samples, which outperformed samples composed of polyurethane, phenolic, and polyester resins. A polyamide hardener is used to cure the two-component epoxy clear lacquer known as FINECOAT-EP 200. Epoxy resin is considered the ideal resin used for coating mild steel surfaces to block corrosion and improve mechanical properties [33].

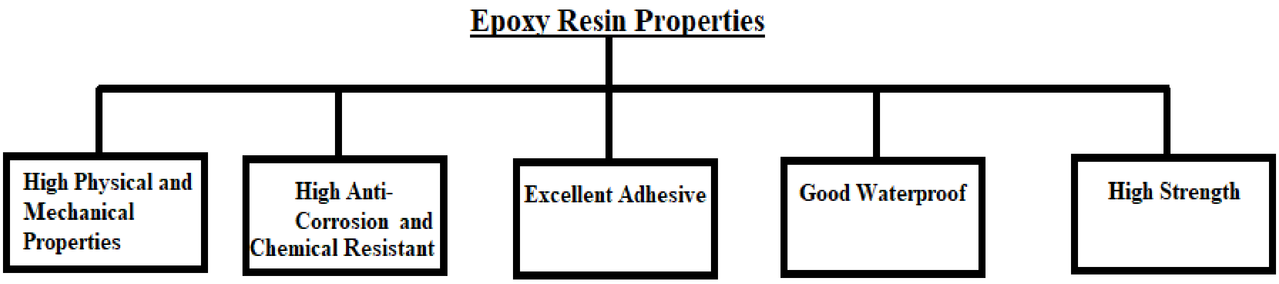

Figure 5 - The main properties of epoxy resins

Conclusions

It is clear from the review that corrosion of concrete reinforcing is a significant problem and must be considered when constructing concrete structures exposed to harsh conditions. One of the main factors harming reinforced concrete (RC) constructions is corrosion of the steel reinforcing the concrete. Designing an effective protection plan requires an understanding of the corrosion process, including its thermodynamic and kinetic characteristics.

One of the most broadly applicable and economically advantageous methods for preventing steel corrosion in reinforced concrete has been demonstrated to be cathodic protection. Conduit coatings can protect difficult-to-reach areas and provide a broad surface area for the anode system to ensure regular distribution of the protective current. They are also simple to install. The cost of installing a cathodic protection system is also significantly reduced since the coating is far less expensive than installing spot anodes. Epoxy coating can be employed as an anode material in an ICCP system owing to its outstanding anti-corrosion and mechanical qualities.

Acknowledgments. This work was supported by the Ministry of Science and Education of the Republic of Kazakhstan, a competition for grant funding for scientific and technical projects 2023–2025. Project No. AP19676595 “Development of high electrically conductive paint for corrosion prevention in concrete structures”.

Conflicts of interest. The authors declare no conflicts of interest, financial or otherwise.

Cite this article as: Ainakulova DT, Muradova SR, Khaldun MAl Azzam, Bekbayeva LK, Megat-Yusoff PSM, Mukatayeva ZS, Ganjian E, El-Sayed Negim. Analytical Review of Conductive Coatings, Cathodic Protection, and Concrete. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2024; 329(2):92-102. https://doi.org/10.31643/2024/6445.20

Өткізгіш бояуларға, катодты қорғауға және бетонға аналитикалық шолу

[1*]Айнакулова Д.Т., [1]Мурадова С.Р., [2]Халдун М. Аль Аззам, [3]Бекбаева Л.К., [4]Мегат-Юсуф П.Ш.М., [5]Мукатаева Ж.С., [6]Ганжиан Э., [1,7]Негим Эльсайд

[1] Материалтану және жасыл технологиялар мектебі, Қазақ-Британ техникалық университеті, Алматы, Қазақстан
[2] Фармакологиялық және диагностикалық зерттеу орталығы (PDRC), Фармацевтикалық ғылымдар бөлімі, Фармацевтика факультеті, Амман университеті Әл Ахлия, Амман, 19328, Иордания
[3] Нанотехнологиялардың ұлттық ашық зертханасы, Әл-Фараби Қазақ ұлттық университеті, Алматы, Қазақстан
[4] Петронас технологиялық университеті, Бандар-Сери-Искандар 31750, Перак, Малайзия
[5] Абай атындағы ҚазҰПУ, Жаратылыстану және география институты
[6] ЖЩҚ «Concrete Corrosion Tech», Хамфри Миддлмор Драйв, 12, Бирмингем, Англия B17 0JN
[7] Қ.Тұрысов атындағы Геология және мұнай-газ ісі институты, Сәтбаев Университеті, Алматы, Қазақстан

Мақала келді: *9 шілде 2023*
Сараптамадан өтті: *15 тамыз 2023*
Қабылданды: *24 тамыз 2023*

ТҮЙІНДЕМЕ

Қазіргі уақытта темірбетон көпір құрылымдарының жұмысына әсер ететін бұзылудың негізгі және ең қымбат түрі-болат арматураның коррозиясы. Темірбетон конструкцияларының коррозиясы айтарлықтай қаржылық шығындарға әкеледі. Темірбетон конструкцияларында коррозияны болдырмаудың қажетті әдістерінің бірі-катодты қорғаныс. Катодты қорғаныс (ICCP) беріктік пен бейімделуді қамтамасыз етеді, өйткені ол темірбетон ғимараттары жоғары қарсылыққа ие болған жағдайда қажетті ток бере алады. ICCP үшін әртүрлі өткізгіш жабындар мен анодты материалдар, мысалы, көміртекті талшықты өткізгіш жабындар мен мырыш, сондай-ақ дискретті анодтар түріндегі анодтық жүйелер және цементтеу жабынындағы титан негізіндегі торлар жиі қолданылады. Хлорид иондары, әсіресе, болатқа қатты эпоксидті жабын арқылы ену қиын, бұл оны қатты химиялық заттардан қорғау үшін өте тиімді тосқауыл етеді. Эпоксидті шайырлар металл беттерін коррозияға қарсы қасиеттерінің, әртүрлі беттерге жақсы адгезиясының және химиялық төзімділігінің арқасында қоршаған орта мен коррозиялық ортаның әсерінен қорғаудың тамаша нұсқасы болып табылады. Осылайша, бұл жұмыс анод материалы ретінде катодты қорғауды, ICCP, әртүрлі өткізгіш жабындарды және эпоксидті жабындарды қарастырады. Бұл әдістер мен материалдар темірбетон конструкцияларын коррозиядан қорғау және жұмыс жағдайында олардың беріктігі мен сенімділігін жақсарту үшін үлкен маңызға ие.

Түйін сөздер: қорғаныс, келтірілген ток, темірбетон коррозиясы, эпоксидті жабындар.

	Авторлар туралы ақпарат:
Айнакулова Дана Тулегенқызы	*Ph.D. докторант Материалтану және жаңа материалдар технологиясы, Материалтану және жасыл технологиялар мектебі, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан. Email: da_ainakulova@kbtu.kz*
Мурадова Сабина Рустамқызы	*Магистр, Материалтану және жаңа материалдар технологиясы, Материалтану және жасыл технологиялар мектебі, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан. Email: sab.muradova.01@mail.ru*
Халдун М. Аль Аззам	*Ph.D., доцент, Фармацевтикалық ғылымдар кафедрасы, Фармакологиялық және диагностикалық зерттеу орталығы (PDRC), Фармация факультеті, Амман Әл-Ахлия университеті, Амман, 19328, Иордания. Email: azzamkha@yahoo.com*
Бекбаева Ляззат Кайратовна	*Ph.D., Лектор, Нанотехнологиялардың ұлттық ашық зертханасы, Әл-Фараби Қазақ ұлттық университеті,71, Әл-Фараби көшесі а. в., 050040, Алматы, Қазақстан. Email: lyazzat_bk2019@mail.ru*
Путери Шри Мелор Мегат-Юсуф	*Ph.D., доцент, Механикалық инженерия кафедрасы, Петронас технологиялық университеті, Бандар-Сери-Искандар 31750, Перак, Малайзия. Email: puteris@petronas.com.my*
Мукатаева Жазира Сагатбековна	*Химия ғылымдарының кандидаты, Абай атындағы ҚазҰПУ, Жаратылыстану және география институтының қауымдастырылған профессоры. Email: jazira-1974@mail.ru*
Ганжиан Эшмайл	*Ph.D., Профессор, ЖЩҚ «Concrete Corrosion Tech», Хамфри Миддлмор Драйв, 12, Бирмингем, Англия B17 0JN. Email: concorrosion@gmail.com*
Негим Аттиа Эльсайд	*Ph.D., Материалтану және жасыл технологиялар мектебінің профессоры, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан; Профессор Қ. Тұрысов атындағы Геология және мұнай-газ ісі институты, Мұнай Инженериясы Кафедрасы, Сәтбаев Университеті, Сәтбаев көш. 22а, 050013, Алматы, Қазақстан. Email: a.negim@kbtu.kz*

Аналитический обзор проводящих красок, катодной защиты и бетона

[1*] Айнакулова Д.Т., [1] Мурадова С.Р., [2] Халдун М. Аль Аззам, [3] Бекбаева Л.К., [4] Мегат-Юсуф П.Ш.М., [5]Мукатаева Ж.С., [6] Ганжиан Э., [1,7] Негим Эльсайд

[1] Школа материаловедения и зеленых технологий, Казахстанско-Британский Технический Университет, г. Алматы, Казахстан
[2] Центр фармакологических и диагностических исследований (PDRC), отделение фармацевтических наук, фармацевтический факультет, Амманский университет Аль-Ахлия, Амман 19328, Иордания
[3] Национальная открытая лаборатория нанотехнологий, Казахский национальный университет им. Аль-Фараби, Алматы, Казахстан
[4] Технологический университет Петронас, Бандар-Сери-Искандар 31750, Перак, Малайзия
[5] Институт Естествознания и географии КазНПУ имени Абая, г. Алматы, Казахстан
[6] ООО«Concrete Corrosion Tech», Хамфри Миддлмор Драйв, 12, Бирмингем, Англия B17 0JN
[7] Институт геологии и нефтегазового дела им. К. Турысова, Сатбаев Университет, г. Алматы, Казахстан

Поступила: *9 августа 2023*
Рецензирование: *15 августа 2023*
Принята в печать: *24 августа 2023*

АННОТАЦИЯ

Основным и наиболее дорогостоящим видом разрушения, который в настоящее время влияет на эксплуатационные характеристики железобетонных мостовых конструкций, является коррозия стальной арматуры. Коррозия железобетонных конструкций приводит к значительным финансовым потерям. Одним из востребованных методов предотвращения коррозии в железобетонных конструкциях является катодная защита. Катодная защита (ICCP) обеспечивает прочность и адаптивность, так как может выдавать необходимый ток в ситуации, когда железобетонные здания обладают высоким сопротивлением. Для ICCP часто используются различные токопроводящие покрытия и анодные материалы, такие как токопроводящие покрытия с углеродными волокнами и цинк, а также анодные системы в виде дискретных анодов и сетки на основе титана в цементирующем покрытии. Ионы хлорида, особенно, трудно проникают через сплошное эпоксидное покрытие на стали, что делает его очень эффективным барьером для защиты от агрессивных химических веществ. Эпоксидные смолы представляют собой отличный вариант для защиты металлических поверхностей от воздействия окружающей среды и агрессивных сред благодаря их выдающимся антикоррозийным свойствам, хорошей адгезии к различным поверхностям и химической стойкости. Таким образом, в данной работе рассматриваются катодная защита, ICCP, различные токопроводящие покрытия и эпоксидное покрытие в качестве материала анода. Эти методы и материалы имеют большое значение для защиты железобетонных конструкций от коррозии и улучшения их долговечности и надежности в условиях эксплуатации.

Ключевые слова: защита, наложенный ток, коррозии железобетона, эпоксидные покрытия.

	Информация об авторах:
Айнакулова Дана Тулегенқызы	*Ph.D. докторант Материаловедения и Технологии Новых Материалов, Школы материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Email: da_ainakulova@kbtu.kz*
Мурадова Сабина Рустамқызы	*Магистр, Материаловедения и Технологии Новых Материалов, Школы материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Email: sab.muradova.01@mail.ru*

Халдун М. Аль Аззам	*Ph.D., Ассоциированный профессор кафедры фармацевтических наук, Центр фармакологических и диагностических исследований (PDRC), фармацевтический факультет, Амманский университет Аль-Ахлия, Амман 19328, Иордания. Email: azzamkha@yahoo.com*
Бекбаева Ляззат Кайратовна	*Ph.D., Лектор Национальная открытая лаборатория нанотехнологий, Казахский национальный университет им. Аль-Фараби, 71, ул. Аль-Фараби А.В., 050040, Алматы, Казахстан. Email: lyazzat_bk2019@mail.ru*
Путери Шри Мелор Мегат-Юсуф	*Ph.D., Ассоциированный профессор кафедры Механической Инженерии, Технологический университет Петронас, Бандар-Сери-Искандар 31750, Перак, Малайзия. Email: puteris@petronas.com.my*
Мукатаева Жазира Сагатбековна	*Кандидат химических наук, Ассоциированный профессор Института Естествознания и географии КазНПУ имени Абая. Email: jazira-1974@mail.ru*
Ганжиан Эшмайл	*Ph.D., Профессор, ООО «Concrete Corrosion Tech», Хамфри Миддлмор Драйв, 12, Бирмингем, Англия B17 0JN. Email: concorrosion@gmail.com*
Негим Аттиа Эльсайд	*Ph.D., Профессор Школы материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Профессор Института геологии и нефтегазового дела им. К. Турысова, Кафедра Нефтяной Инженерии, Сатбаев Университет, ул. Сатбаева 22а, 050013, г. Алматы, Казахстан. Email: a.negim@kbtu.kz*

References

[1] Sun P, Wang Z, Lu Y, Shen S, Yang R, Xue A, Parker T, Wang J, Wang Q. Analysis of the corrosion failure of a semiconductor polycrystalline distillation column. Process Safety and Environmental Protection. 2020; 135(12):244-256. https://doi.org10.1016/j.psep.2020.01.007

[2] Bertolini L, Carsana M, Gastaldi M, Lollini F, Redaelli E. Corrosion of steel in concrete and its prevention in aggressive chloride-bearing environments, 5th International Conference on Durability of Concrete Structures, Shenzhen, Guangdong Province, China, Jun 30–Jul 1 2016. Shenzhen University. 2016, 13-26.

[3] Callon R, Daily SF, Funahashi M: Selection Guidelines for Using Cathodic Protection Systems for Reinforced and Prestressed Concrete Structures, In Corrosion 2004, NACE International. 2004.

[4] Mosaieb MFH, Monfaredi K. Novel Cathodic Protection System based on Photovoltaic Cells. Transaction of Electrical and Electronic Circuits and Systems. Materials Science. 2014; 4(20):117-123.

[5] Wilson K, Jawed M, Ngala V. The selection and use of cathodic protection systems for the repair of reinforced concrete structures. Construction and Building Materials. 2013; 39:19-22. https://doi.org/10.1016/j.conbuildmat.2012.05.037

[6] Das SC. Zinc rich paint as anode system for cathodic protection (CP) of reinforced concrete structures and development of corrosion. CP monitoring probes. Unpublished PhD thesis. Coventry University. 2012.

[7] Makhmetova A, Negim ES, Ainakulova D, Yeligbayeva G, Khatib J. An Overview of Epoxy Resins as coating to protect metals from corrosion. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex use of mineral resources. 2024; 328(1):20-32. https://doi.org/10.31643/2024/6445.03

[8] Syrmanova K, Negim E, Kaldybekova J, Tuleuov AM. Epoxylitane Compositions Modification with Using Thermoplastic Polyurethane. Oriental Journal of Chemistry. 2016; 32(1):1.

[9] Syrmanova K, Negim E, Kaldybekova J, Suleimenova M, Baizhanova S. Study of modification process of the epoxylitane composites. Industrial Technology and Engineering. 2015; (3):75-83.

[10] Schwarz W. Cathodic Corrosion Protection of Steel Reinforced Concrete Structures with a New Conductive Composite Paint System, Bauinstandsetzen und Baudenkmalpflege 6. Jahrgang. 2000; 6:597-618.

[11] Raupach M. History of EFC-WP11, “Corrosion in Concrete”. Institute for Building Materials Research of Aachen University, Aachen, Germany. 2014.

[12] Zaki A. Principles of Corrosion Engineering and Corrosion Control, Butterworth-Heinemann. 9th ed. Elsevier. 2006.

[13] Bhuiyan S. Effectiveness of impressed current cathodic protection systems in concrete following current interruption. Thesis. Master of Engineering. School of Civil, Environmental and Chemical Engineering. RMIT University. 2015.

[14] Johan A. Corrosion of steel in concrete at various moisture and chloride levels, Lund University and Swerea/Kimab, ISBN 978-91-7673-[133-8]. 2015.

[15] Nadzri NIM, Amin NM. A Review of Cathodic Protection in Repairing Reinforced Concrete Structures, Journal of Mechanical Engineering. 2019; 16(2):183-198.

[16] Design Manual for Roads and Bridges, Cathodic Protection for Use in Reinforced Concrete Highway Structures, 3, Highways Agency, London, UK. 2002.

[17] Eur Ing RL. Kean of ARK Corrosion Services, NPL for the Department of Trade and Industry. 1981.

[18] Wilson K, Jawed M, Ngala V. The selection and use of cathodic protection systems for the repair of reinforced concrete structures. Construction and Building Materials. 2013; 39:22-25. https://doi.org/10.1016/j.conbuildmat.2012.05.037

[19] Broomfield JP. The Principles and Practice of Galvanic Cathodic Protection for Reinforced Concrete Structures. Technical Note 6. Corrosion Prevention Association, Bordon, UK. 2000.

[20] Broomfield JR. Corrosion of Steel in Concrete, E&FN Spon, London; 1997 615 W. Schwarz 5W.F. Perenchio, U.R. Landgren, R.E. West and K.C. Clear, Cathodic Protection of Concrete Bridge Substructures, NCHRP Report 278. 1985, 61.

[21] Davies K. Impressed current cathodic protection systems for reinforced concrete, in Cathodic Protection of Steel in Concrete, ed. P.M. Chess: E&FN Spon, London. 1998, 59-91.

[22] Lambert P. Economic aspects, in Cathodic Protection of Steel in Concrete, ed. P.M. Chess, E&FN Spon, London. 1998, 177-184.

[23] Society for the Cathodic Protection of Reinforced Concrete (SCPRC), Cathodic Protection of Steel in Concrete - Status Report, Report No SCPRC/001.95, SCPRC, PO Box 72, Leighton Buzzard, Bedfordshire, LU7 7EU, UK. 1995.

[24] Muradova SR, Negim El-Sayed, Makhmetova AR, Ainakulova DT, Mohamad NMI. An Overview of the Current State and the Advantages of using acrylic resins as anticorrosive coatings. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex use of mineral resources. 2023; 327(4):90-98. https://doi.org/10.31643/2023/6445.44

[25] Goyal A, Pouya HS, Ganjian E. A Review of Corrosion and Protection of Steel in Concrete. Arab J Sci Eng. 2018; 43:5035-5055. https://doi.org/10.1007/s13369-018-3303-2

[26] Wilson K, Jawed M, Ngala V. The selection and use of cathodic protection systems for the repair of reinforced concrete structures. Construction and Building Materials. 2013; 39:19-20. https://doi.org/10.1016/j.conbuildmat.2012.05.037

[27] Lyon SB, Bingham R, Mills DJ. Advances in corrosion protection by organic coatings: What we know and what we would like to know. Progress in Organic Coatings. 2016; 102:2-7.

[28] BSI. ISO 12696:2012: Cathodic protection of steel in concrete. BSI, London, UK. 2012.

[29] Wicks ZW, Jones FN, Pappas SP. Organic Coatings: Science and Technology. 2nd ed. John Wiley and Sons, New York. 1994.

[30] Sofian AHB, Noda K. The Investigation of Zinc-Rich Paint (ZRP) Behavior in NaCl Solution by Electrochemical Methods. In The Malaysia-Japan Model on Technology Partnership, Springer Japan. 2015; 3-7.

[31] Epoxy Coated Reinforcement: Part One. 2008. (Accessed 25 July 2023).
https://www.totalmateria.com/page.aspx?ID=CheckArticle&site=kts&NM=227

[32] Darowicki K. Conducting coatings as anodes in cathodic protection. Progress in organic coatings 2003; 46(3):191-196. https://doi.org/10.1016/S0300-9440(03)00003-1

[33] Gujjar SV, Nadar N, Choudhary K, Hunashyal AM, Shahapurkar K, Mujtaba MA, Asadullah M, Soudagar MEM, YunusKhan TM, Ismail KA, Elfasakhany A. Investigation of Various Coating Resins for Optimal Anticorrosion and Mechanical Properties of Mild Steel Surface in NaCl Solution. Advances in Materials Science and Engineering. 2022; 2:9(2203717). https://doi.org/10.1155/2022/2203717