Section A-Research paper

DEGRADATION AND REHABILITATIONOF REINFORCEMENT CONCRETE STRUCTURE IN INDUSTRIAL ENVIRONMENT AREA

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Abstract:

Reinforced concrete structures are commonly utilized in industrial environments, but their longevity is often threatened by several factors that can lead to their degradation over time. These factors include exposure to harsh chemicals like H_2S, CO_2, and SO_4, as well as high levels of moisture, humidity, and extreme temperatures. As a result, concrete structures in industrial settings are frequently found with damages like cracks, spalls, and surface degradation. Therefore, it is crucial to prevent degradation and rehabilitate concrete structures to prolong their service life. Various methods are available for repairing cracks and spalls in concrete structures, including epoxy injection, polymer concrete overlays, and shotcrete. To protect the reinforcing steel from corrosion, cathodic protection can be utilized. Additionally, surface coatings or sealants can be applied to improve the surface quality of concrete and inhibit the penetration of chemicals, moisture, and other degradation factors. Other effotrs, such as creating geopolymer concrete, adding additives, and using stainless steel instead of carbon steel, have also proven to be effective in reducing concrete failures. By implementing these various methods, the overall quality and longevity of reinforced concrete structures can be significantly improved, leading to a reduction in maintenance costs and downtime. Therefore, it is vital to prioritize the implementation of these works in the design, construction, and maintenance phases of concrete structures to achieve long-term sustainability and improve their overall performance.

Regenerate response
Keywords: Corrosion on reinforcement concrete, concrete rehabilitation, industrial environment.

1. INTRODUCTION:

Steel reinforcement is one type of material used in building construction to provide additional strength to reinforced concrete structures. Steel reinforcement in the form of rods or steel wire with a certain diameter are placed in the concrete to withstand the tensile loads that occur on the structure.[1-2] After the concrete has been fabricated, the concrete and steel reinforcement will join together to form a strong and durable structural unit. The advantage of using steel reinforcement is to provide additional strength to the concrete, so that the concrete structure can withstand greater tensile and bending loads.[3-4] Steel reinforcement is usually used in various types of building construction such as high-rise buildings, bridges, tunnels, and other infrastructure construction. Although reinforced concrete has high strength and durability.

Industrial areas have a corrosive environment that can affect reinforced concrete structures. Corrosion or rust on reinforcing steel embedded in concrete can occur due to environmental factors, such as humidity, low pH, and the presence of corrosive chemicals. Some factors that can cause a corrosive environment in industrial areas include:[5-11]]

- Air pollution: Air pollution from factories or industries can stick to concrete structures and damage their surfaces. Dust particles and acid gases contained in air pollution can erode the surface of concrete and reinforcing steel.
- Water contamination: Polluted water from industrial wastes can contain corrosive substances that can damage concrete and reinforcing steel structures.
- Chemical substances: Some chemical substances used in industry such as acids and salts can corrode reinforcing steel and damage reinforced concrete structures.
- Humidity: The industrial environment usually has high humidity, which can cause damp conditions in concrete structures. This humid condition can accelerate the corrosion of reinforcing steel.

1.1. Types of damages to reinforced concrete:

Alkalization

Alkalinity in concrete is a condition where the pH of concrete increases above 7.8. Alkaline conditions in concrete are very important because they affect the chemical reactions that occur in concrete. Alkaline concrete has the ability to protect reinforcing steel from corrosion because high pH can neutralize acids which can cause corrosion of reinforcing steel.Alkalization in concrete is influenced by the content of fillers in concrete such as cement, fly ash, slag, or other fillers. Portland cement, which is usually used as a binder in concrete, has alkaline properties and can increase the pH of concrete to more than 12. Fly ash and slag can also increase the alkaline nature of concrete because they contain minerals such as silica, calcium and magnesium which can neutralize sour.Alkalization in concrete can be influenced by several factors, such as humidity levels, temperature, and environmental conditions around the concrete. Inadequate conditions such as exposure to chemicals, corrosive environmental influences, or high humidity can reduce the alkaline nature of concrete.[12, 13]

Alkali-aggregate reaction (RAA)

RAA is a chemical reaction that occurs between the alkali contained in cement and aggregate or other additives in concrete. This reaction can produce swelling and cracking in the concrete, which can eventually cause structural damage and reduce the life of the concrete. RAA can also affect the strength, stiffness, and dimensional stability of concrete.RAA occurs when the alkalis in cement such as sodium oxide (Na_2O) and potassium oxide (K_2O) react with certain minerals present in the aggregate, such as silica (SiO_2) or the mineral feldspar. This reaction produces alkali-silica compounds or alkali-feldspar gels, which have a larger volume than the original components and can cause swelling and cracking in concrete. RAA occurs in a wide variety of concrete types and can affect both new and existing concrete.

Several factors that can affect the occurrence of RAA include the type and quality of aggregate materials, the amount and type of alkali in the cement, the environmental conditions around the concrete, and the temperature of the concrete.[14]

Prevention of RAA includes using aggregate materials that are resistant to RAA, reducing the amount of alkali in cement, controlling the environment around concrete, and using additives that can neutralize alkali in cement. In addition, testing of aggregates prior to use in concrete mixes can help identify aggregates that are susceptible to RAA.[14]

Surface damage

Surface damage to concrete can occur due to various factors, such as the influence of weather, overload, chemicals, and humidity. Surface damages affect corrosion rate. Damage to the concrete surface can affect the aesthetic appearance, concrete structure, and concrete life. Here are some types of concrete surface damage:

Cracks: Cracks can occur due to various factors, such as overload, rapid changes in temperature and imbalance in the concrete mix. Cracks on the surface of the concrete can affect the strength of the concrete and accelerate further damage.

Surface chipping: Damage to concrete surfaces can occur when the surface layer of concrete is chipped or removed. This can be caused by the influence of weather, flowing water vapor, or the influence of chemicals.

Efflorescence: Efflorescence occurs when salts dissolved in water run onto the concrete surface and leave traces of minerals. This effect looks like a white coating on the concrete surface, and can affect the aesthetic appearance of the concrete.

Porous: Porous on the surface of concrete occurs when concrete is exposed to a corrosive environment, such as acids or other chemicals. This can affect the strength of the concrete and accelerate subsequent deterioration.

To prevent damage to the concrete surface, it is important to pay attention to the quality of the ingredients used in the concrete mix, control the environment around the concrete, and carry out regular maintenance and repairs. In addition, the use of additives and surface coatings can help extend the life of concrete and prevent surface damage.

Sulfate attack

Sulphate attack on concrete is a type of concrete damage caused by reactions between sulfates and concrete components such as cement and aggregates. Sulfate attack can occur when concrete is exposed to sulfate-containing water, such as polluted groundwater or seawater, or when concrete is used in an industrial environment that is exposed to sulfate-containing gases. When sulfate enters concrete, a chemical reaction between the sulfate and the concrete components causes the formation of softer compounds, which significantly reduces the strength of concrete. This can cause cracks, breaks, or even collapse of the concrete structure.

Sulfate attack can be avoided by choosing the right concrete ingredients, such as sulfate-resistant cement or using additives in the concrete mix to increase the concrete's resistance to sulfate attack. In addition, it is necessary to carry out routine maintenance and supervision of the condition of the surrounding environment so that the concrete is not exposed to water or gases containing sulfates.[14]

Carbonization of concrete

Carborization is a type of damage to concrete caused by the reaction of carbon dioxide (CO_2) with calcium hydroxide ($Ca(OH)_2$) in concrete. This reaction causes the formation of calcium carbonate ($CaCO_3$), which significantly lowers the pH of the concrete and causes a decrease in the strength of the concrete. Carbonization of concrete can occur when concrete is exposed to air containing carbon dioxide, such as outside air or air containing vehicle fumes. This can cause the concrete to change color from white to gray or black, as well as damage to the concrete surface.[15,16]

To prevent carbonization of concrete, this can be done by choosing the right concrete ingredients, such as using high-quality aggregates and using cement with low levels of calcium hydroxide. In addition, it is necessary to carry out routine maintenance and monitoring of the condition of the surrounding environment to prevent carbonization of concrete.

Other damages that can occur to concrete, including:

- Cracks (cracking): Cracks are damage to concrete that occurs due to a tensile force that exceeds the tensile capacity of the concrete. Cracks in concrete can occur on the surface of the concrete or inside the concrete. Cracks can affect the performance of concrete structures and reduce their strength and bearing capacity.[17]
- Corrosion or rust on reinforcing steel: Corrosion or rust on reinforcing steel embedded in concrete can occur due to the presence of corrosive substances around the concrete or due to exposure to a corrosive environment. Corrosion of reinforcing steel can reduce the strength of concrete structures and even cause collapse of concrete structures.
- Softening: Softening occurs in concrete when a chemical substance damages the concrete structure or results from high temperature and humidity. Softening can cause the strength of the concrete to decrease and cause cracks in the concrete.
- Chemical attack: Chemical attacks on concrete can occur due to chemical substances that enter the concrete and cause chemical reactions in the concrete structure. Chemical attack can cause concrete strength to decrease and cracks in concrete.
- Abrasion: Abrasion or erosion occurs in concrete subjected to repeated friction, especially on the surface of the concrete. Erosion can cause loss of the concrete surface layer and reduce the strength of the concrete structure.
- Swelling or Breaking (spalling): Swelling or breaking in concrete occurs when the surface of the concrete cracks or peels off and causes the concrete to become uneven. Swelling or fracture can lead to susceptibility to attack by corrosive substances and exacerbate the damage to the concrete.
- Expansion: Expansion in concrete occurs due to the presence of materials that react with the concrete, such as sulfates or reactive alkalis. Expansion can cause cracks in the concrete and reduce the strength of the concrete structure.[18.19]
- In building concrete structures, it is important to pay attention to the factors that can affect the deterioration of concrete and carry out regular maintenance and repairs to maintain the strength and durability of concrete structures.

1.2. Factors causing damage in the industrial environment:

Excessive exposure to chemical elements in the air of industrial areas can cause negative impacts on human health and the environment, so efforts are needed to control emissions and reduce exposure to airborne pollutants. In the air of industrial areas there are various chemical elements, including:[20]

- Oxygen (O_2): Oxygen is an important element required by many industrial processes, such as combustion processes and oxidation processes. However, excessive levels of oxygen in the air can cause damage to organic matter and can also be harmful to human health.
- Carbon dioxide (CO_2): Carbon dioxide is a greenhouse gas produced by burning fossil fuels and other industrial processes. Excessive levels of CO_2 in the air can cause climate change and can also endanger human health.
- Nitrogen (N_2): Nitrogen is the most abundant element in the earth's atmosphere and is required by many industrial processes, such as the manufacture of fertilizers and ammonia. However, the level of nitrogen in the air can become a pollutant if it exceeds a set threshold, which can cause eutrophication and other environmental damage.
- Sulfur dioxide (SO_2): Sulfur dioxide is a toxic gas produced by burning fossil fuels that contain sulfur. High levels of SO_2 in the air can cause human health problems and can also cause damage to the environment and buildings.
- Hazardous particulate matter (PM): Harmful particles such as dust, smoke and aerosols generated from industrial processes can become air pollutants and endanger human health.
- Other gases: Air in industrial areas can also contain other gases such as hydrogen (H_2), methane (CH_4), and other gases produced from industrial processes.
- Chloride. Chlorine is ions from seawater can damages concrete in reduce rebar service life. [21-25]

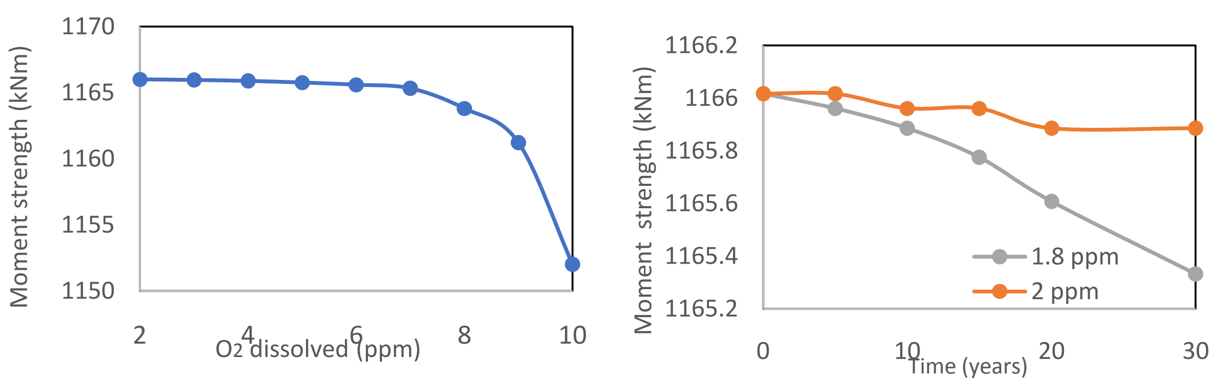

Figure 1: Effects of oxygen concentration and duration of O_2exposured time on moment strength of reinforcement concretes.[2,3]

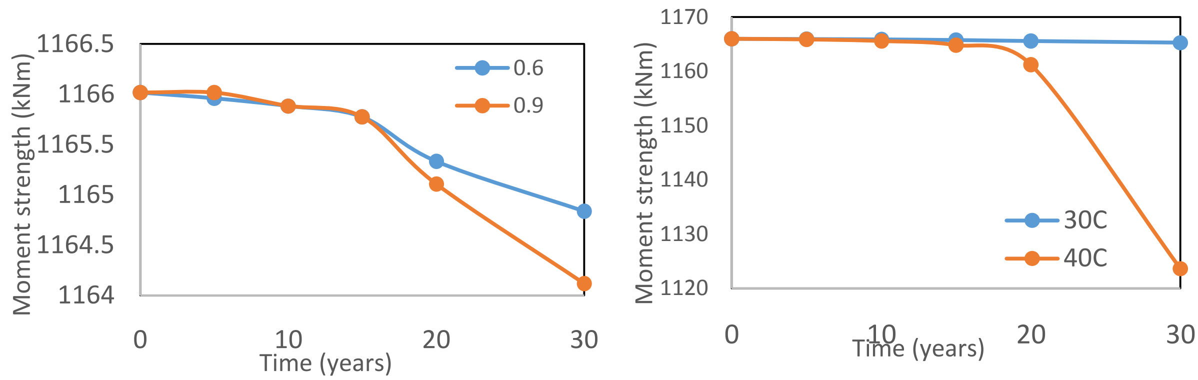

Figure 2: Relationship of chlorine ion concentration and temperature on moment strength of reinforcing steel bar over 30 years exposure time.[2,3]

2. PREVENTION OF DAMAGE TO REINFORCED CONCRETE:

De-alkalination

De-alkalization or de-alkalization of concrete occurs when the pH of the concrete decreases due to a chemical reaction with a corrosive environment. This can cause a decrease in the resistance of concrete to corrosion of reinforcing steel, as well as accelerate damage to concrete in building structures. De-alkalization of concrete mainly occurs in industrial environments exposed to acidic gases or in environments exposed to seawater. Acid gases contained in industrial environments can cause chemical reactions in concrete which cause a decrease in pH and increase the corrosion rate of reinforcing steel.[26]

Geopolymer concrete

Geopolymer concrete is a type of concrete that uses chemicals instead of Portland cement as a binder. This concrete uses materials that are usually considered as waste, such as fly ash, sand, or slag as a binder. The process of making geopolymer concrete involves a chemical reaction between these chemicals and alkaline solutions such as sodium hydroxide (NaOH) and silicate solutions, which produce dense and strong bonds. The advantages of geopolymer concrete are that it has high strength, good fire and acid resistance, and has a lower carbon footprint compared to Portland cement concrete. Geopolymer concrete is also considered as an environmentally friendly solution because it uses waste materials as binders, thereby reducing the amount of waste generated.[27]

Concrete inhibitors

Inhibitors are chemicals that are added to the concrete mix to prevent or reduce the corrosion process of reinforcing steel embedded in the concrete. These inhibitors work by forming a protective layer on the surface of the steel, thereby preventing chemical reactions that cause corrosion. Concrete inhibitors can be divided into two types, namely anode inhibitors and cathode inhibitors. Anode inhibitors work by slowing down the oxidation process on the steel surface, thus preventing the formation of metal ions which can accelerate the corrosion process. Meanwhile, cathode inhibitors work by reducing the concentration of ions which act as catalysts in the corrosion process. Concrete inhibitors can be applied to various types of concrete, such as precast concrete, precast concrete, and cast concrete. These inhibitors are generally added to the concrete mixture in the form of a solution or powder, and mixed with water before being mixed with other ingredients. Selection of the appropriate concrete inhibitor depends on the environmental conditions in which the concrete will be used. Several factors must be considered in choosing a concrete inhibitor, including the type of corrosive environment, the type of reinforcing steel, and the characteristics of the concrete to be used.[28]

Table 1: Effect of injection system on the performance of reinforcing steel inhibitors in concrete. [29,30]

System	Cement	ecorr (mV vs. SCE)	Icorr (mA.cm^{-2}) × 10^{-5}	Corrosion rate (mmpy) × 10^{-3}	Inhibitors efficiency (%)
Without electro injection	OPC	−591	91910	10,650	—
	PPC	−567	82080	9,512	—
	PSC	−478	30,690	3,556	—
With electro injection	OPC	−282	6034	0.699	93.43
	PPC	−345	2,276	0.263	97.22
	PSC	−295	2024	0.234	93.40

Concrete additives

Concrete additives can be used to improve or enhance the properties of concrete, so that the concrete can be better and last longer. However, the use of concrete additives must be careful and in accordance with the instructions for use, because if not used properly, concrete additives can worsen the quality of the concrete. Additives are chemicals added to the concrete mix to improve or enhance the properties of concrete, such as strength, stiffness, workability, water resistance, and so on. Concrete additives can be divided into several types, namely:

- Superplasticizer: is an additive that functions to increase the workability of concrete without increasing the air-cement ratio. Superplasticizers can reduce the need for water in concrete mixes and improve the rheological properties of concrete.
- Fly ash: is a by-product of burning coal. Fly ash can be used as a substitute for cement in concrete mixes, thereby increasing the strength of concrete and reducing the need for other binders.
- Silica fume: is a by-product of silicon manufacturing. Silica fume is used as a substitute for cement in concrete mixtures, so as to increase the strength and stiffness of concrete.
- Air-entraining agent: is an additive used to improve concrete's resistance to water and extreme weather conditions. Air-entraining agents can form air bubbles in the concrete mix, thereby improving the properties of the concrete.
- Accelerator: is an additive used to accelerate the process of hardening concrete. Accelerators are generally used in concrete that will be used in extreme weather conditions or in emergency situations.

Prevents reinforcement corrosion

Here are some ways to prevent corrosion in reinforced concrete:

- Use of quality concrete: Selection of materials and good quality of concrete can prevent corrosion of reinforcing steel. Good quality concrete must have sufficient compressive strength and density so that water and oxygen do not easily enter into the concrete.
- Coating of reinforcing steel: Reinforcing steel can be coated with a protective agent such as special paint, zinc, or chrome. This coating can protect the reinforcing steel from water and oxygen so as to prevent corrosion.[31]
- Use of concrete additives: Concrete additives such as fly ash, silica fume, or slag can reduce the water content in concrete and make it denser, so that water and oxygen do not easily enter the concrete and prevent corrosion.
- Environmental controls: Environmental controls around reinforced concrete can help prevent corrosion from occurring. One way that can be done is to pay attention to the humidity level around the concrete and avoid exposure to chemicals that have the potential to damage concrete.
- Regular maintenance and repair: Regular maintenance and repair of reinforced concrete can prevent further damage from corrosion. Regular inspection and repair of cracks or damage in reinforced concrete can help prevent corrosion and extend the life of reinforced concrete.
- Use of alternative constructions: The use of alternative constructions such as pre-stressed concrete and fiber reinforced concrete (FRC) can reduce the use of reinforcing steel in construction and prevent corrosion of the reinforcing steel.
- Using reinforcing metal other than carbon steel, namely stainless steel.

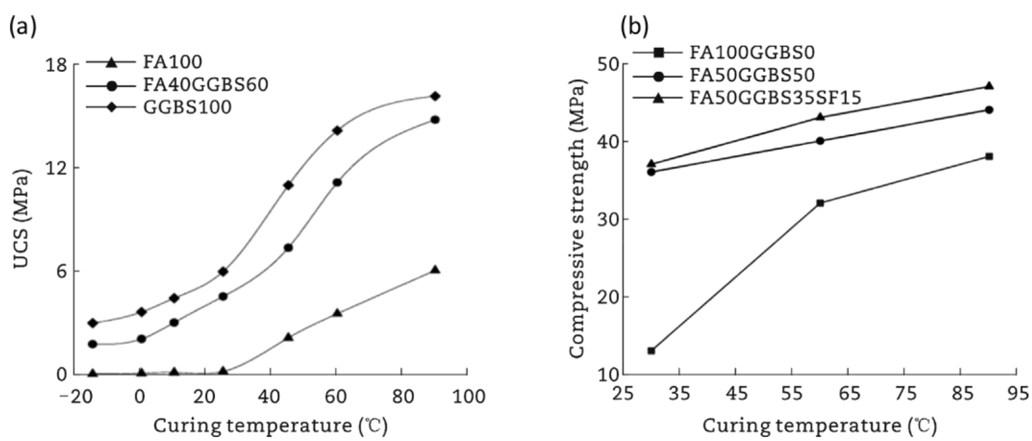

Figure 3: Effect of curing temperature on the strength of geopolymers concrete.[27]

3. Concrete treatment:

It is very important to ensure optimum concrete strength, durability and quality. The following are some common types of concrete treatment:[32,33]

- Curing: Is the process of retaining moisture in concrete to help harden and prevent cracks or damage to the surface of the concrete. Curing can be done by using special adhesives, such as curing compounds or protective films, or by spraying the concrete surface periodically.

- Coating: Is the process of coating the concrete surface with a protective or covering agent, such as concrete or epoxy paint. Coating aims to protect concrete from corrosion and damage due to weather or the environment.
- Cleaning: Is the process of cleaning the surface of the concrete from dirt, dust, or other stains. Cleaning concrete regularly can help maintain the appearance of concrete and prevent damage from contamination.
- Repair: Is the process of repairing or replacing damaged or cracked concrete. Repairs must be made as soon as damage is found to prevent further damage.
- Inspection: Is a process of regular inspection to detect early damage to concrete. Inspections are carried out to identify problems before they become serious and ensure optimal concrete quality.
- With proper care, concrete can last a long time and maintain optimum strength and durability.

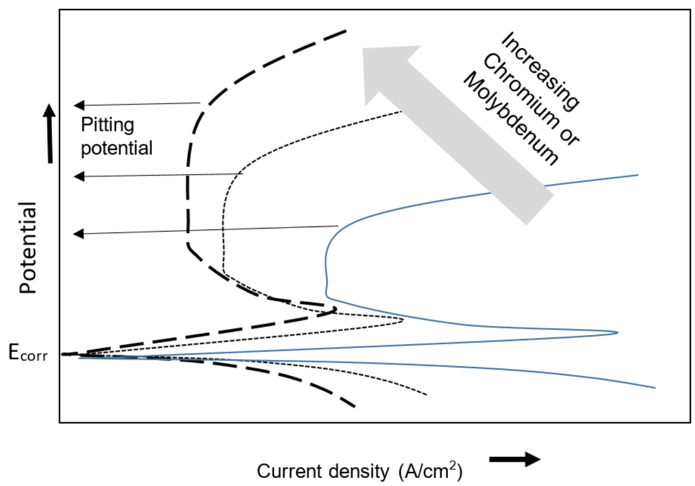

Figure 4: Effect of chromium and molyvdenum composition on the polarization diagram. Either chromium or molybdenum causes pitting potential and the corrosion potential increases while the corrosion rate decreases. [1]

4. CATHODIC PROTECTION

Cathodic protection is a technique used to prevent corrosion in steel reinforcement bars (rebar) embedded in concrete structures. This method involves the application of a low electrical current to the rebar, which effectively reverses the electrochemical reaction that causes corrosion. By creating an electrical circuit between the rebar and an anode, the cathodic protection system can effectively reverse the electrochemical reaction that causes corrosion, ensuring the longevity and durability of the structure. Schematic cathodic protection is shown in Figure 5.

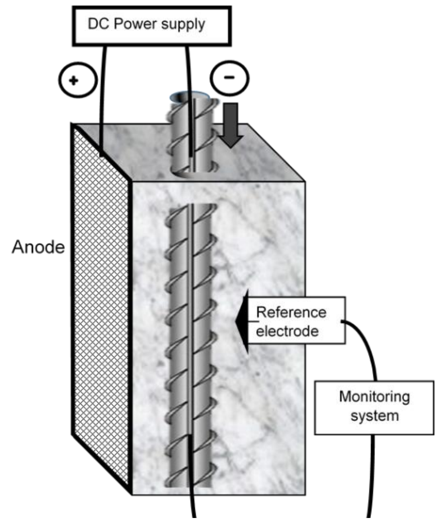

Figure 5: Scheme of steel reinforcement protection with the ICCP system. [1]

Designing the protection of reinforced concrete structures requires data on the characteristics of the metal being protected and the location where the structure is located. Each location has different characteristics in terms of electrical properties, water content, the presence of similar installations, and weather changes. These factors will determine the type of protection that must be selected. The following criteria are used to determine the type of reinforced concrete protection: protection plan time, electrical continuity. chemical elements around the site, possible alkali-silica reaction, and cost to install, monitor, and repair. Table 2 shows current required should be applied in designing cathodic protection.

Table 2: Current required for treatment of steel reinforcement structures.[34]

Protection Level	Objective	Large Current Density (mA/m^2)
Corrosion prevention	Prevents corrosion	0.25–2
Controlling corrosion	Reduces corrosion rate	1–7
Cathodic protection	Stops corrosion	2–20

5. CONCLUSION:

In summary, the longevity and durability of reinforced concrete structures in industrial environments can be significantly improved by adopting proactive actions that prevent or mitigate the effects of degradation factors. These works include proper maintenance, regular inspections, and the use of protective measures such as cathodic protection, surface coatings, and sealants. However, if degradation does occur, timely rehabilitation can be effective in extending the service life of the structure and preventing further damage. Moreover, to avoid risk of sudden damage, continuous maintenance and monitoring play a critical role in reducing the to the structure. Adopting a proactive approach that emphasizes continuous monitoring and timely rehabilitation can mitigate the negative effects of degradation factors and ensure the sustainability and durability of concrete structures.

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