Partial Repair in Reinforced Concrete using Corrosion Inhibitor

José Emidio Alexandrino Bezerra*

Department of Civil Engineering, UNIFOR University of Fortaleza, Fortaleza, Brazil

Research Article

Received: 17-Aug-2023, Manuscript No. JOMS-23-110572; **Editor assigned:** 21-Aug-2023, PreQC No. JOMS-23-110572 (PQ); **Reviewed:** 04-Sep-2023, QC No. JOMS-23-110572; **Revised:** 11-Sep-2023, Manuscript No. JOMS-23-110572 (R); **Published:** 18-Sep-2023, DOI: 10.4172/2321-6212.11.3.006.

***For Correspondence:** José Emidio Alexandrino Bezerra, Department of Civil Engineering, UNIFOR University of Fortaleza, Fortaleza, Brazil

E-mail: joseemidiobezerra@outlook.com

Citation: Bezerra JEA. Partial Repair in Reinforced Concrete using Corrosion Inhibitor. RRJ Mater Sci. 2023;11:006.

ABSTRACT

In general, the standards recommend that repairs in places affected by corrosion have done by removing the concrete around the oxidized reinforcement. However, this can pose risks to the integrity of the structure, especially in relation to the pillars, and here, they were present in abbreviated form. To evaluate the difference in effectiveness between the two options for structural repairs, a qualitative laboratory research carried out, based on the variation of corrosion potentials measured with a $Cu/CuSO_4$ semi-cell, in prismatic specimens submitted to corrosion tests induced by chlorides. Then, the use of anodic or cathodic corrosion the partial repairs, although they presented inferior results to the total repairs, in relation to the initiation of the corrosion, they are better that the common structural concrete. This, indicating that, they can be a good option for extending the useful life of the structure, with lower risks and costs.

Keywords: Reinforced concrete; Corrosion; Chlorides; Structural recovery; Total repair; Partial repair; Corrosion inhibitor

INTRODUCTION

Several institutes deal with pathologies and recovery of reinforced concrete structures, such as the Rilem Technical Committee, 1994; EM Series 1504: Stabilization of Construction Research, 2000; American Institute of Concrete, 1996 and new ACI-562 code that emphasizes performance over prescriptive requirements, encourages creativity and flexibility, promotes innovation and new materials, sets parameters to increase life safety (safety equivalent), extends service life and seeks sustainable and economically viable alternatives (ACI-19, 2016).

The Portuguese standard NP EN 1504-3, [1]: Products and systems for protection and repair of concrete structures, incorporates the main recommendations made by several European institutions aimed at the repair and protection of reinforced concrete structures, including definitions, specifications of products, test methods, quality control and compliance check.

RILEM 124–SRC [2] recommends that it is necessary to decide on restoration options and consider the degradation processes that may influence the intensity of corrosion in concrete reinforcement.

Corrosion of reinforced concrete reinforcement is one of the main causes of cracks in reinforced concrete structural elements, demanding repairs, recoveries and structural reinforcements. But as Souza, et al. [3] state "The fact that a structure at a given time does not present satisfactory performance does not mean that it is necessarily condemned".

It is common sense that corrosion of concrete reinforcement is mainly due to concrete carbonation and interaction with chlorides. Although good concrete provides good protection for its own reinforcement, it is subject to cracking from internal and external causes, including stresses due to the loads it must support.

Gjørv [4] states that “The ability of concrete to protect reinforcement against corrosion is well known, which is mainly due to the electrochemical passivation of reinforcement by the alkaline solution present in the concrete pores. In this regard, Helene [5] states that the loss of natural protection of the reinforcement by the concrete coating can occur through several mechanisms, with a predominance of depassivation by carbonation and by the action of chlorine ions. In general, the chemical attack starts at the surface of the concrete and then penetrates causing changes, such as increased porosity and permeability, creating internal stresses that affect the resistance and integrity of the material, through aggressive reactions such as leaching and ionic exchange resulting in the formation of aggressive compounds [6].

Although much progress has been made in understanding the complex mechanisms that involve the formation of corrosion cells in electrochemical reactions and standardized procedures have been found for structural recovery, it is still possible to seek safer and more economical ways in this area.

In structural recovery services, the removal of carbonated concrete or concrete contaminated by aggressive agents that are in contact with the steel bars is an important factor to consider due to the structural risks inherent in section reductions and the consequent weakening of structural elements, particularly, of the pillars.

Bertolini [7] adds, based on the RILEM 124-SRC recommendations, that to control the corrosion rate in reinforced concrete and interrupt the anodic process by repassivation of the iron, the contaminated or carbonated concrete must be removed and the cover layer rebuilt with mortar or alkaline concrete, perform cathodic protection by impressed current or block the electric current by increasing the resistivity of the concrete, reducing internal humidity, through the application of water repellents. However, it points out that the corrosion rate in carbonated concrete is irrelevant in environments with relative humidity below 70%.

Bertolini warns that “aspects related to safety must be given serious consideration. The risks to the preservation and safety of people must be assessed”, and that “localized collapses” may occur. Specifically, in the case of localized repairs, particularly in residential buildings, a critical point of the process is the removal of the concrete around the steel bars in the process of corrosion in the structural elements, which causes cracking due to the expansion of the products generated by the electrochemical reaction in the steel bars. It is evident that steel, once depassivated by the carbonation of the concrete or attacked by ions, undergoes the process of electrochemical corrosion that could destroy it if not stopped and even lead to the collapse of the structure.

Andrade [8] in turn, states that "to repair reinforced concrete reinforcement, contaminated or deteriorated concrete must be removed 1 cm to 2 cm behind the corroded reinforcement in order to carry out deoxidation". On the other hand, Helene [9,10] recommends that the damaged concrete must be removed, but does not explain that it should be completely removed around the affected bar and does not even determine a numerical value for the depth of the concrete cut. The European standard that deals with methods of repair and protection of reinforced concrete warns that the preparation of the repair site must be rigorous, that the deteriorating agents must be completely removed and that the repair must involve the entire bar, however it recognizes that it is difficult if you get this. (EN–1505. Principle 11. Control of anodic areas).

Although the removal of concrete around the oxidized bar is practically unanimity, it is suggested that one should always assess whether this is really necessary, for any possible states of structural degradation, and whether it makes a difference if it is in pillars, beams, slabs or foundations and, in which environment the structure is inserted.

It is stated that the removal around the reinforcement is necessary to allow cleaning around the bar without leaving corrosion cells. However, it is possible that part of the steel bars may be in contact and strongly adhered to the cementitious matrix of the concrete to the alkaline oxide film and chemical protector. Therefore, depending on the degree and extent of corrosion, it should not be necessary to excessively remove concrete.

However, when the structure is taken into account broadly, it can be a considerable risk to remove a considerable amount of concrete, even for a short period of time. Souza, et al. [3] warns that depending on the extent of the cut and the residual resistance capacity, it may be necessary to shore up the structural element.

There is no doubt about this measure, however, it is necessary to consider that shoring the beams and/or slabs that are supported by any pillar in multi-floor buildings, generates an enormous inconvenience for users, not to mention the financial costs, not always available. Assessing the need for shoring is therefore of great importance because corrosion in buildings occurs more frequently in the lower third of the pillars, as explained by Helene [10].

LITERATURE REVIEW

It is important to point out that any structural recovery involves risks, since there is a need to cut contaminated concrete, resulting in the reduction of the cross-section of the structural components. Therefore, it is necessary to carefully assess the capacity of the structure to support the services without collapsing. Andrade [8] advises that "Faced with a suspicion or visible existence of reinforcement corrosion, there is a primary circumstance that must prevail over all others, which is the verification of the integrity of the structure as a whole".

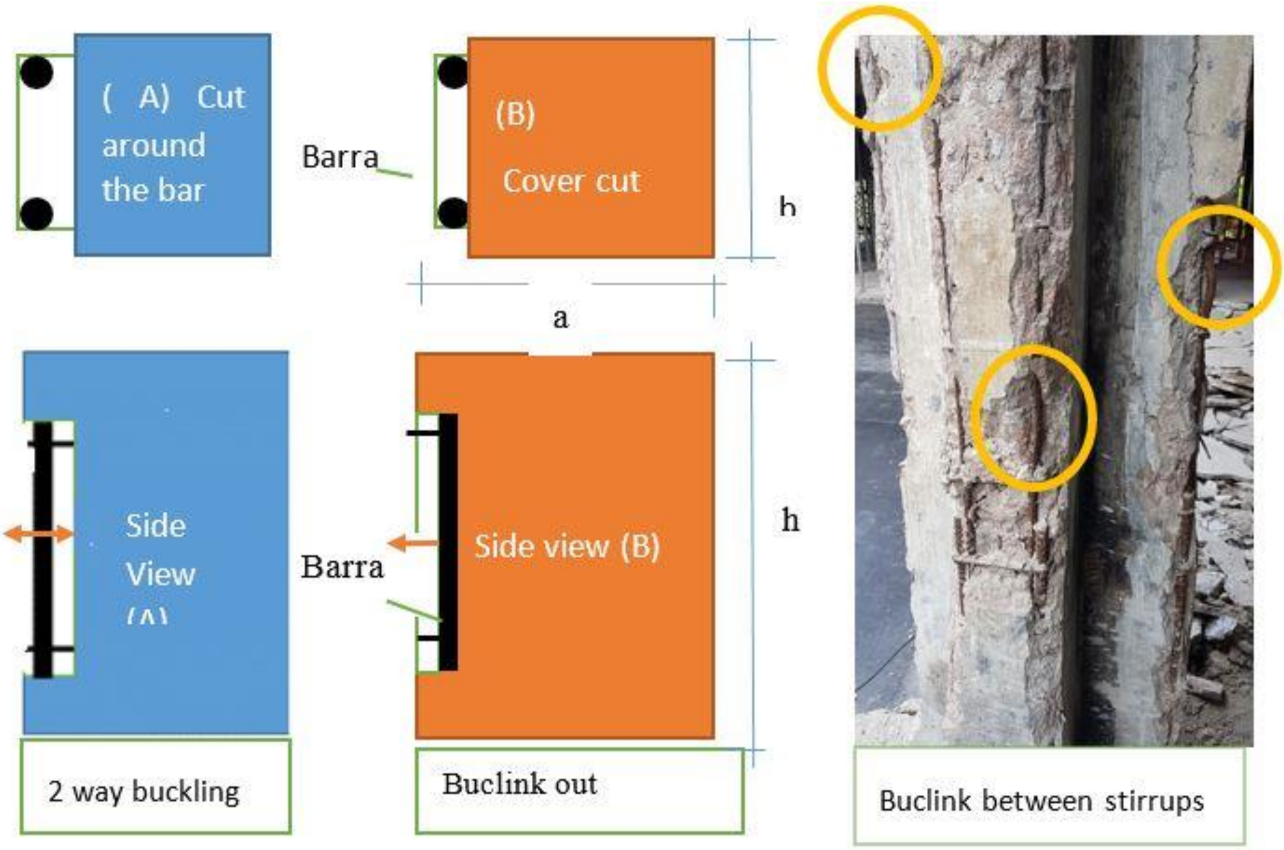
It is essential to analyze the structure in general and not limit yourself to the affected element. Repair can never be more important than overall structural stability. Every structural repair is a surgical intervention, where damaged or contaminated materials are removed and, therefore, there will always be a momentary loss of resistance that will be restored as soon as the service is finished.

It should be considered that building structures are composed of slabs, beams, pillars and foundations and that each of these elements has a different function and behavior. Concrete removal has different consequences on each of these structural elements. On a slab, removal affects its bearing capacity, but is unlikely to affect the overall safety of the structure. The failure of a beam will affect the slab that rests on the beam and may secondarily affect some columns on which the said beam rests.

However, in pillars, it can cause the collapse of the structure, because the pillars support the accumulated weight of all the floors above the considered level, while the beams and slabs only support the loads of a single floor.

Furthermore, in columns, due to compressive forces, the danger of buckling of the main reinforcement is always present. When removing the concrete around the longitudinal steel bars, these bars, in the section under repair, become loose and may buckle, as they will be held only by the stirrups, without being broken by corrosion. On the other hand, by removing only the cover layer of the affected reinforcement, the possibility of buckling is significantly lower, because the bar remains in contact with the concrete mass (Figure 1).

Figure 1. Possibility of bar buckling due to concrete cutting, in any column of section x, y and height h.



Silva [11] studied the behavior of concrete pillars during the repair process performed with cement-based mortar modified with polymers and synthetic fibers and found that the repair material resists part of the load, but there is also a redistribution of the load to the other regions of the concrete section. However, it is important to consider that the adhesion of the repair to the substrate is not always perfect and there is always the possibility of detachment at the interface of the repair with the substrate.

Another important aspect to consider is the time for the corrosion products to produce the efforts capable of cracking the covering layer of the reinforcement and with this information, to infer the time necessary for the loss of mass to compromise the structural stability. That is, if a time t is required to break a small diameter stirrup, this time will be longer to break larger diameter longitudinal bars.

For example, if in any column the 5 mm stirrup broke after 30 years, you can assume that to break a 12.5 mm bar it will take approximately 70 years. This calculation is not accurate, however, exaggerated removal of concrete (which can easily reach 30% of the cross section) at the base of a column can have an immediate effect, worse than that caused by the corrosive process.

Based on these considerations, it is possible to consider that an intervention in which only the cover thickness is removed, in addition to being less risky from a structural point of view, allows for a repair that will contribute to extending the useful life of the structure, especially when no chloride contamination.

It is also important to adopt extra protection measures, such as the use of corrosion inhibitors, clarifies Lourenço, et al. [12]. These products can reduce the corrosion rate without changing the concentration of corrosive agents, as pointed out by Söilev, [13]. The EN ISO 8044:2020 standard states that corrosion inhibitors can slow the rate of corrosion without changing the concentration of the corrosive agent [14].

Cathodic, anodic and mixed inhibitors are available that can act by absorption or as blockers forming passive films on the metal or as stabilizers of the passive layer. The most used, according to Lourenço are nitrites (inorganic), amines and alcoholamines (organic).

They can be added to concrete, where they act as anodic, cathodic or mixed inhibitors by absorption, by film formation or by induced passivation and that, in existing structures, the inhibitors can be used in repair mortars, applied on the surface or in the voids of the concrete.

There are also galvanic sacrificial anodes formed by pieces of zinc encapsulated with high alkalinity mortar (pH>14) according to ASTM C 1202 standard, coupled to steel bars to avoid corrosion at the repair interface with the rest of the structure [15].

In the form of paint applied to reinforcement, they have been widely used in repairs, due to their ease of acquisition, application and low cost. Those using paints with zinc particles dispersed by the paint vehicle, generally epoxy-based, are easily applied and create a physical barrier against carbonation and the entry of chlorides.

In addition, active corrosion inhibitors in the form of paints or anodes electrically bond to the steel bar, creating localized protection, even if the concrete has not been completely removed, as the electric current spreads across the metal surface, as demonstrated Faraday, in 1836 (Faraday Cage), regardless of having removed all the concrete surrounding the reinforcement bar.

MATERIALS AND METHODS

Among other non-destructive methods, electrical methods allow evaluating the corrosion rate in reinforced concrete structures. This method requires the use of an electrical system with configurations of two, three or four electrodes to determine three main parameters: corrosion potential Ecorr, concrete resistivity and the polarization resistance Rp. In this program, it was only possible to compare and analyze the variations of corrosion potentials in the prismatic specimens.

Thus, to analyze the differences between the two ways of removing concrete, partial and total, a survey was carried out with prismatic specimens (5 cm × 8 cm × 9 cm) of concrete, polymeric mortar and grout, with two CA 60 steel bars, 5 mm in diameter, in its natural state without protective paint, with protective paint based on zinc and nitrite. They were subjected to twelve cycles of drying and wetting in an oven for 5 days and in a 3.5% NaCl solution for 2 days to induce corrosion accelerated by chlorides.

Corrosion potentials were measured with a device equipped with a high impedance voltmeter and a $Cu/CuSO_4$ half-cell. This method, which is endorsed by ASTM C976 as a standard semi-cell test for reinforced concrete, according to Rodrigues, et al. [16] was used to qualitatively monitor and compare the corrosion potentials of specimens in the laboratory (Figure 2).

Figure 2. Induced corrosion test: NaCl solution; oven 50ºC; Measurements of potentials.

The physical properties of concrete in the 1:2:3:0.4 ratio (according brazilian technical standards, of polymeric mortar and grout are presented in Table 1.

Table 1. Summary of the physical properties of the materials used.

Properties	Unit	Concrete	Polymeric mortar	Grout
Capillary water, absorption. S=19,64	g/cm^2	0.47	0.26	0.31
Water absorption, immersion. 72 hours	%	7.96	6.68	8.13
Empty index. 72 hours	%	20.8	14.67	17.54
Specific mass, dry sample. 72 hours	%	2.16	2.53	2.16
Specific mass, saturated sample. 72 hours	%	2.34	2.69	2.33
Compressive strength at 28 days	MPa	25	33	40
Modulus of elasticity	GPa	27	37	29

The cathodic corrosion inhibitor used was a product based on synthetic resins with zinc chromate, flammable liquid, with a density of 1.39 g/cm^3, in red color according to technical data provided by the manufacturer.

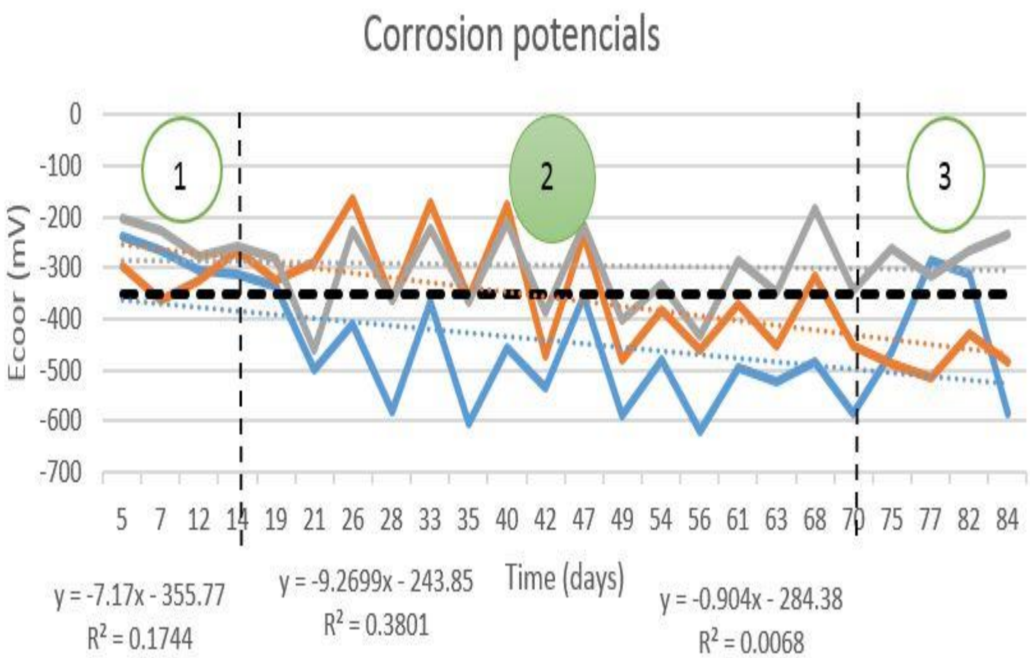
Anionic Corrosion Inhibitor was a cement-based, two-component, flexible coating modified by polymer and corrosion inhibitor additive, composed of silica, quartz silica and Portland cement, a pasty liquid with a density of 1.60 g/cm^3 to 1.70 g/cm^3, in red color, with nitrite-based corrosion inhibitors, according to the manufacturer.

RESULTS AND DISCUSSION

Research results with specimens that represent the total repair with concrete, polymeric mortar and grout

The evolution of the corrosion potential in the steel inserted in the specimens of concrete, polymeric mortar and grout, under the attack of chlorides, without anticorrosive paint, presented the behaviors shown in Figure 3.

Figure 3. Corrosion induced by chlorides in CP concrete, polymeric mortar and grout. **Note**: C, PM, G, Error -350 mV, Linear (C), Linear (PM), Linear (G).



The electric potential in the steel inserted in the concrete specimen reached the corrosion threshold in the 1st cycle, in the polymeric mortar in the 5th cycle (40 days) and in the grout, after 12 cycles (84 days) there was still no corrosion. These performances can be attributed to the properties of capillary absorption, immersion absorption, void ratio and specific mass of each material.

Note that in the first two cycles (sector 1) and in the last two cycles (sector 3) there are large variations in potentials. Regarding this phenomenon, Cascudo [17,18] in an experiment carried out in 1991, with specimens submitted to wetting and drying cycles, clarifies that in the beginning the curves are very noisy due to the consolidation of the passive film, followed by a period of stability and finally change to more negative potentials, as can be seen in Figure 3.

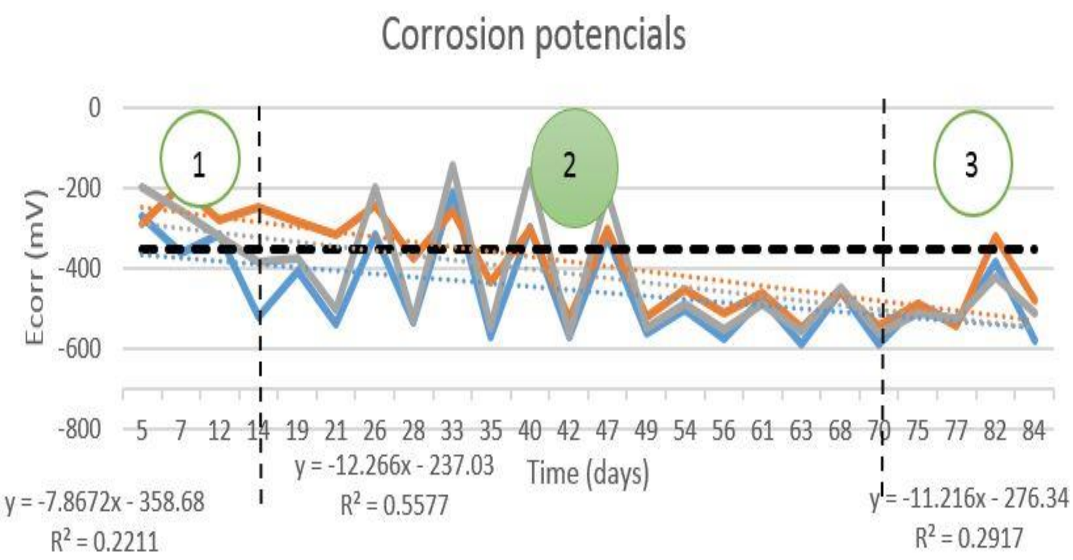
Research results with specimens that represent the partial repair of reinforced concrete with polymeric mortar

It is considered a partial repair when only the covering layer of concrete reinforcement is removed and a full repair when all the concrete around the steel bar is removed. In general, polymeric mortar is used in repairs of up to 30 mm and grout for thicker repairs. The steel, on the exposed part, is usually deoxidized and protected with a zinc or nitrite based corrosion inhibitor.

In partial repairs with polymeric mortar, with steel in natural condition, as in reinforced concrete structures, corrosion appeared in the 1st cycle, however, when painted with paint rich in zinc, it started in the 4th cycle at 26 days and with nitrite at 28 days [19-21].

In partial repairs of reinforced concrete with polymeric mortar and natural steel, with zinc-based protection and nitrite-based protection, the evolution of corrosion potentials in the specimens submitted to the tests is shown in Figure 4.

Figure 4. Corrosion induced in reinforced concrete repaired with polymeric mortar. Steel without and with protection. **Note**: C+PM (WP), C+PM (Ni), C+PM (Zn), Error -350 mV, Linear (C+PM (WP)), Linear (C+PM (Ni)), Linear (C+PM (Zn)).



The similarity of behavior in terms of potentials, in the 1st and 2nd cycle, can be observed among all the options of test specimens, however, between the 3rd and 7th cycle, there were intense variations between the dry and wet states around of the line -350 mV, with lower amplitude in irons with nitrite and higher in irons with zinc. Between the eighth and tenth cycle, the protection provided by the inhibitors expires and corrosion continues to increase at the same rate. Unprotected irons have a more uniform behavior, but always less than protected irons.

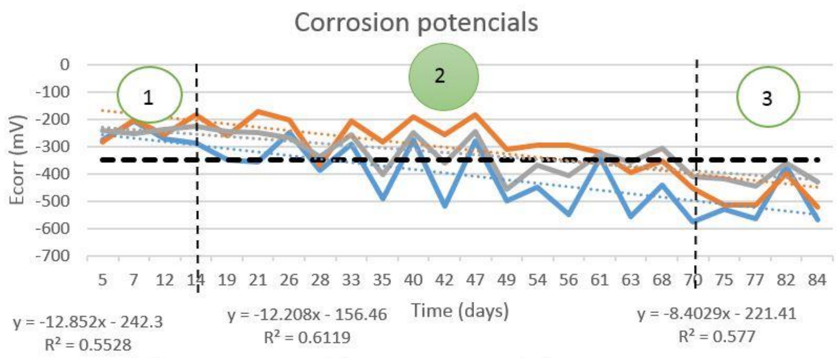
It is important to point out that in partial repairs there are two materials with different void and absorption rates (Table 1) involved, which are concrete (the core) and polymeric mortar (the repair), in addition to having an interface that may eventually provide a path for the penetration of water and oxygen depending on the quality of adhesion of the polymeric mortar to the concrete.

Research results with specimens representing the partial repair of reinforced concrete with grout

The grout, due to its composition, is found between a mortar and a concrete, and can be considered a micro concrete modified by fluidizing additives and shrinkage moderators formulated for filling holes and fixing fixings, it is recommended to reconstitute parts of structural elements when repairs are required with thicknesses greater than 30 mm [22,23].

It was verified that in the specimens submitted to the accelerated chloride induction tests, the barrier created by the grout was superior to the normal concrete in the three reinforcement conditions, as shown in Figure 5.

Figure 5. Corrosion induced by chlorides in reinforced concrete repaired with grout. Steel without and with protection. **Note:** C+G (SP), C+G (Ni), C+G (Zn), Error -350 mV, Linear (C+ G (SP)), Linear (C+ G (Ni)), Linear (C+ G (Zn)).



In partial repairs with grout, the times for the beginning of corrosion in the reinforcement without corrosion inhibitors, started in the 4th cycle (28 days) and, using the paint protection with zinc and nitrite, the time was extended to the 8th cycle (58 days) for both.

CONCLUSION

Research has shown that grout and polymeric mortar perform better than reference concrete in protecting steel, either because of the formation of a passivating film due to the alkalinity of their cementitious matrices, or because of the lower void ratio and lower water absorption rate.

It was also found that in total repairs, the time to start corrosion of steel bars subjected to corrosion induced by chlorides is greater than in partial repairs, in which the bars were in contact with the original concrete and with the repair material. Still, partial repair gives a better condition than usual reinforced concrete.

Obviously, if all carbonated or chloride-contaminated concrete is removed, there is no need to apply corrosion inhibitors to the reinforcement, as the steel and concrete will return to their initial state. However, it is necessary to consider that carbon-dioxide is part of the earth's atmosphere and that in coastal regions, chlorides are part of the environment, and can be incorporated into the concrete during the execution of the work and after completion, by other forms of inclusion, such as adsorption, if the concrete does not have the protection by coating or painting.

It is concluded that, using corrosion inhibitors, based on zinc or nitrites and recomposing the section of the structural element with polymeric mortar or grout, partial repairs can be adopted, as they have better performance in protecting the steel and in controlling the advance of the corrosive process than concrete itself, without increasing the risk of collapse of the structure.

Organic inhibitors can delay the start of corrosion induced by chlorides by reducing the penetration rate of chlorides in concrete by filling the concrete pores through the formation of complex compounds, as reported by Ormelese.

Repairs with the use of corrosion inhibitors and reconstitution of the structural element section, with polymeric mortar or grout, due to its adherence and compactness qualities, will provide a good extension of the useful life of the structure.

Thus, new practices must be sought for structural repair, as emphasized by the new code of the American Concrete Institute, ACI-318-19, (22), which recommends prioritizing performance over rigid prescriptive requirements, such as total removal of concrete. around the reinforcement, and encourages creativity, flexibility, innovation and the search for new materials, to increase structural safety (equivalent safety) and thus obtain an increase in the useful life of the structure, with more sustainable and economically viable alternatives, however the main objective should always be to maintain structural stability above all other considerations, including the removal of contaminants.

REFERENCES

1. NP EN 1504-3:2005 Products and systems for the protection and repair of concrete structures–Definitions, requirements, quality control and conformity assessment. Part 3: Structural and non-structural repair. European Standard CEN. 2006.
2. RILEM TC 124-SRC. Draft recommendation for repair strategies for concrete structures damaged by reinforcement corrosion. Mater Struct. 1994;27:415-436.
3. Souza VC, et al. Pathology, recovery and reinforcement of concrete structures. PINI. São Paulo. 1998.
4. Gjøv OE. Durability and design of concrete structures in several enviroments. Taylor and Francis. 2014.
5. Helene PRL. New NB 1/2003 (NBR 6118) and the service life of concrete structures. 2014.
6. Maldonado NG, et al. That material called concrete. Argentine Association of Concrete Technology. 2016.
7. Bertolini L. Building materials: pathology, rehabilitation, prevention. 3rd ed. Text Office. São Paulo. 2017.
8. Andrade C. Manual for diagnosis of works deteriorated by corrosion of reinforcements. PINI, Sao Paulo. 1992.
9. Helene PRL. Manual for repair, reinforcement and protection of concrete structures. Pini, São Paulo. 1992.
10. Helene PRL. Corrosion in reinforcement for reinforced concrete. ReP. 1986.
11. Silva TJ, et al. Behavior of prototypes of reinforced concrete columns post-partial repair executed under load. Constr Engi Mag. 2006:21.
12. Lourenço MZ, et al. Methods of protection and increase of durability of reinforced concrete. Corrosion in reinforced concrete structures: theory, control and analysis methods. 2018.
13. Söylef TA, et al. Corrosion inhibitors for steel in concrete: state-of-the-art report. Science Direct. Construction and Materials. Elsevier. 2006.
14. EN ISO 8044. Corrosion of metals and alloys. Basic terms and definitions. ISO. 2015.
15. ASTM C 1202. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. ASTM. 2004.
16. Rodrigues R, et al. Reinforced concrete structures: A review of corrosion mechanisms and advances in electrical methods for corrosion monitoring. Constr Build Mater. 2021;269:121240.
17. Cascudo O. Inspection and diagnosis of reinforced concrete structures with reinforcement corrosion problems. Concrete teaching, investigation and achievements. 2005.
18. Cascudo O. Corrosion control of concrete reinforcement. 2nd ed. PINI. 1997.
19. Ormellese M, et al. Corrosion inhibitors for chlorides induced corrosion in reinforced concrete structures. Cem Concr Res. 2006;36:536-547.
20. ABNT, NBR 6118. Design of concrete structures–Procedure. Brazilian association of technical standards, Rio de Janeiro. 2014.
21. ABNT. NBR 15.575-1:2013. Housing buildings-Performance: general requirements. Brazilian association of technical standards. 2013.

22. ASTM–C 876. Standard test method for corrosion potentials of uncoated reinforcing steel in concrete corrosion potential. American Society for Test Materials. Philadelphia. 1991.
23. National Building Inspection Standard. IBAPE Brazilian institute of evaluations and expertise. 2012.