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Performance Of Carbon Fibers Integrated To The Coating As Anode In The Cathodic Protection Of The Reinforcing Steelof Concrete Contaminated With Chloride

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ABSTRACT
In reinforced concrete structureswith active corrosionprocessesbothitsfunctionality and itsusefullife are reduced. TheadditionofCarbonFiber (CF) integratedtothe concrete coatingmakesit a multifunctional material withmechanical and electricalpropertiessuitableforapplyingtechniquessuch as cathodicprotection (CP) ofreinforcingsteel.In thepresentinvestigation, the performance ofthe CF integratedtothe concrete coating as ananode in the CP wasevaluated, having as referencethetraditionaltechniquewhereTitaniummeshisused as anexternalanode in concretes previouslycontaminatedwithSodiumChloride.Theexperimentationparameterswereaccordingtorecommendationsof NACE Standard RP 0290-90.Whenthe concrete coatingofthereinforcingsteelbecomes a multifunctional material, itpresentsadditionalbenefitstothecorrosionprotection, reducingthepossibleappearanceofcracksduetothegreatermechanicalresistancetothetensionprovidedbythe CF.
KEYWORDS: anode, multifunctional material, concrete rehabilitation, corrosion.

I. INTRODUCTION

In reinforced concrete structureswherechloridesreachthesurfaceofthesteeldueto a diffusionprocess, depassivationofthereinforcingsteel can be caused and a pittingcorrosionprocessisinitiated.
In thisprocess, thecorrosionproducts cause deterioration in the concrete, formingfisures, cracksordetachmentsof material, reducingtheusefullifeofthestructure.There are various destructive repairmethodswherereplacementofdamaged concrete sectorsisperformed, generatingareaswithvaryingconcentrations and puttingthestructure at riskofcorrosion.Non-destructive repairmethods do notreplace material, focusontherehabilitationof concrete and/orprotectionofsteelbyelectrochemicalmeans, methodssuch as: electrochemicalextractionofchlorides, realcalinization and cathodicprotection (CP).In thelatter, currentissuppliedbyanauxiliaryelectrodefromanexternalsourceforthepurposeofprintingcurrent and achievingcorrosionprotectionofthestructure.CP originatesanoppositeforcetotheelectromotiveequalto and oppositetothatofthe metal dissolutionreaction, basedontheexistenceofanimmunitypotential**[1-4]**.

Ontheotherhand, cement-basedmaterialssuch as concrete and mortarhaveverylowelectricalconductivities, whichiswhythey are classified as insulatingmaterials.However, theadditionof conductive material tothematrixofcementitiousmaterials causes themtobecome semiconductor materials. CF is a conductive material that can be addedto concrete toincreaseitselectricalproperties and convertitinto a multifunctional material, becauseit has adequatemechanicalproperties in additiontoelectricalproperties**[5-10].**Multifunctionalmaterialshavealreadybeenused as anodewithadditionsofcarbonaceous material such as graphite and CF in electrochemicaltechniques, obtainingadequate performances in theirelectricalproperties**[11-25].**There are practical cases ofapplicationofcathodicprotectionwithasphalt-basedmultifunctionalmaterials: concrete: coke-crushed in elementscontaminatedwithchloridesof vehicular bridges

[26]. Thisinvestigationevaluatesthe performance of CF integratedtothe concrete coatingofthereinforcingsteel, used as ananode in theelectrochemicaltechniqueofcathodicprotectionbyimpresedcurrentapplied in concrete contaminatedwithchlorides.

II. EXPERIMENTAL PART

2.1 Materials

2.1.1 Specimensofreinforced concrete withchloridecontent

TheCP techniquewasappliedtospecimensofreinforced concrete with 28 daysofcuring in distilledwater and 2.7% SodiumChloridecontent in relationtotheweightofthecement.Thespecimenswereprismaticwithdimensionsof 15x15x50 cm, reinforcedwith 6 steelrodsof Ø3/8" withanexposedareaof 640 cm2 per specimen, complyingwiththestandards ASTM C 136 **[27]**, ASTM C 33 **[28]** y ASTM C 125 **[29],** as shown in figure 1.

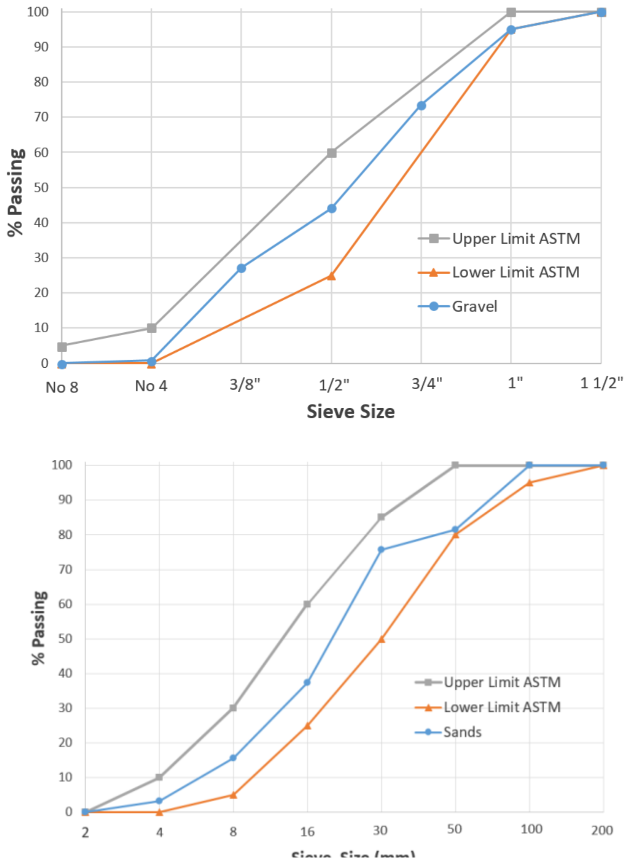


Figure 1 Granulometry of the graveland sands

The concrete mixwasdesignedusingthe*Portland CementAssociation* absolute volumemethodwithdosageaccordingto table 1.Thecarbonfiberswere placed integratedtothe concrete coatingofthereinforcingsteel in itsmiddlepart in 7 lines at a rateof 0.015 g/cm2, leaving 2 pointstomaketheelectricalconnectionoftheCP as shown in Figure 2.

Table 1. Dosageofthe concrete mixture bym^3

Component	Quantity (kg)
Water	207.25
Sand	673.58
Gravel TMA 1"	1160.78
PortlandCement 30R	386.00
Sodiumchloride	10.36

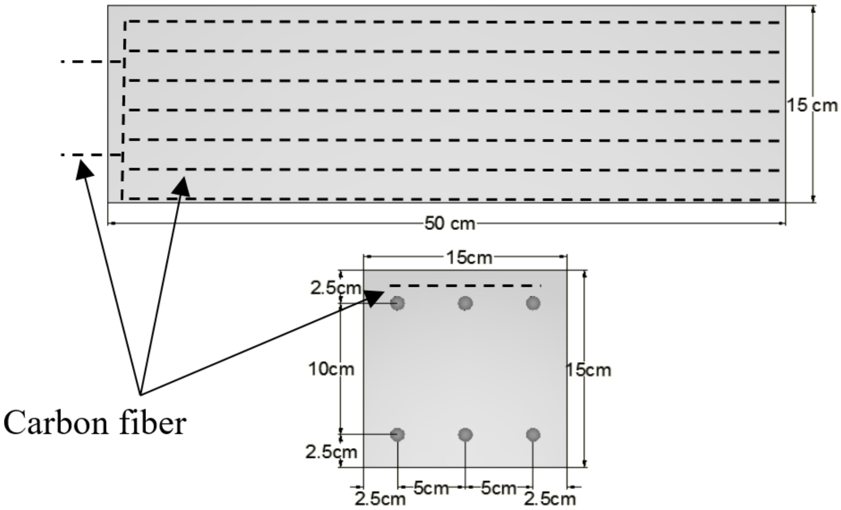


Figure2 Specimen dimensions and placement of CF

2.1.2 CarbonFiber

CF used as ananodeintegratedtothecoatingisshown in Figure 3, thediametersof CF wereuniform and minimalcutsweremade in orderto favor adequatecontinuity and conductivityofthesame, thepropertiesof CF are shown in Table 2.

Table 2. Carbonfiberproperties

Property	Quantity (kg)
Specificdensity	1.76
Superficial area(m^2/gr)	0.227
Diameter (μm)	8.0

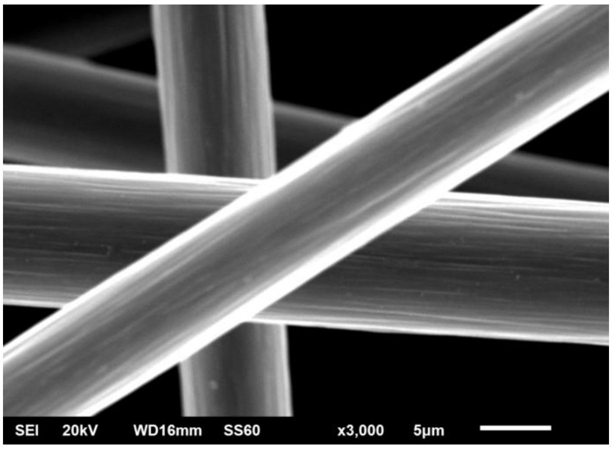
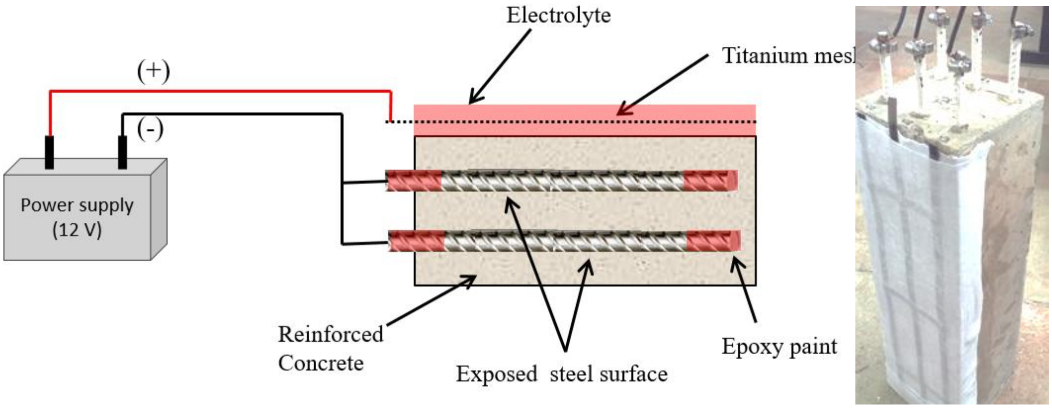


Figure3 Carbon fiber used as anode

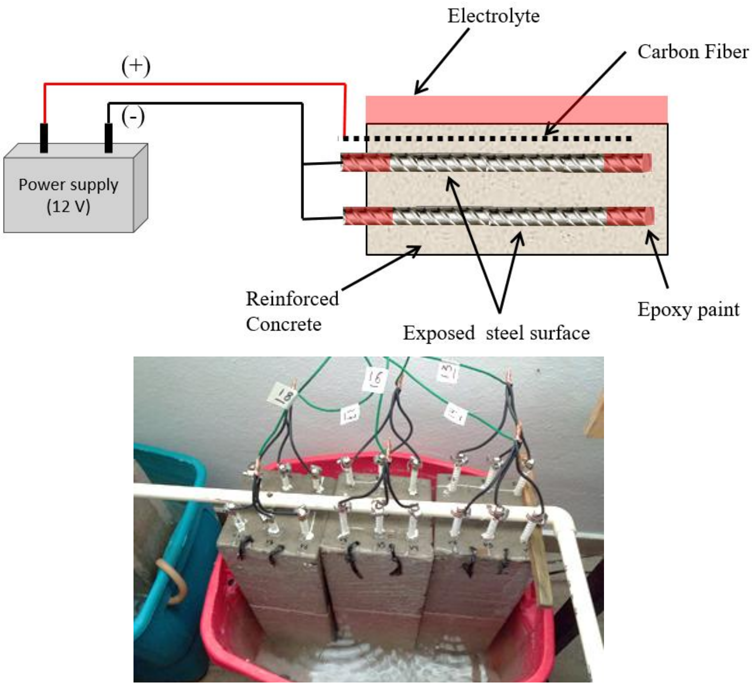
2.2 Methods

2.2.1 Cathodicprotectionofreinforcementsteelbyimpressedcurrent

Theapplicationof CP wascarriedoutbytwotechniques: (a) Reference techniqueusinginertanodeoftitaniummesh and (b) Techniquewith CF integratedtothecoating as aninertanode, the experimental arrangementbeingtheoneshown in Figure 4. In addition, distilledwater, currentdensity at thesteelsurfaceof 20 mA/m2, wasused as electrolyte, accordingtorecommendationsof NACE Standard RP 0290-90 **[30]**for a periodofapplicationof CP of 35 days.



a) With titanium mesh as anode



b) With CF as an anode

Figure4 Experimental arrangement for CP and the different anodes

2.2.2 Monitoringofcorrosionratedensities (CR) and corrosionpotential (Ecorr)

CR wasdetermined in twoevents, beforetheapplicationofthe CP and 14 days after withdrawingtheapplicationof CP in the concrete specimens. In addition, thecorrosionpotentialwasrecorded in 3 stages, 7 daysbefore CP, duringthe 35 daysof CP and depolarizationperiodof 14 days after CP, in accordancewith ASTM C – 876-91 (reapproved in 1999) and using standard calomel electrode (SCE) **[31]**.

Thelabelsusedforthespecimens are XN-n, where "X" correspondstothetypeoftechnique, R beingthereferencespecimenswithout CP, T thespecimenswhereTitaniummeshwasused as ananode and F where CF wasused as ananode."N" isthenumberofthespecimen, a valuerangingfrom 1 to 3 and "n" correspondstotheproximitytotheanode, 1 forthenearestface and 2 forthefarthestface.

III. RESULTS AND DISCUSSION

3.1 Propertiesofthemetrials

Figure 5 shows the chemical analysis of the surface composition of CF, where you have C, Cu, Si and Zn in different proportions, with C being the one with the highest signal and Cu, Si and Zn with signals of lower intensity.

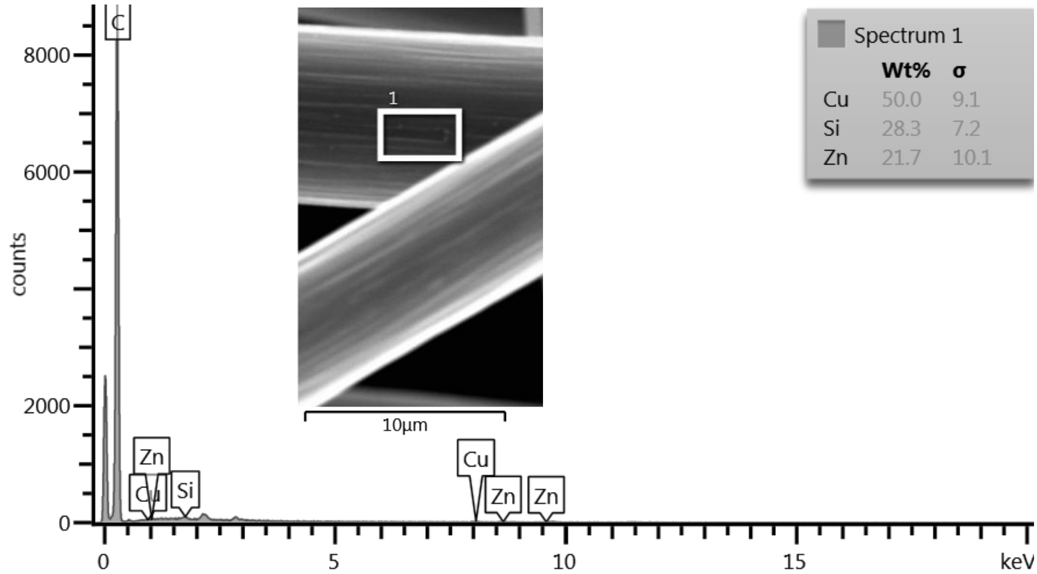


Figure5 Components

3.2 Ecorrmonitoringof test pieceswithout CP

Reinforcementofreinforced concrete structures can be damagedbychloridesdiffusedbythe concrete coatinguponreachingthesurfaceofthesteel**[32]**.Figure 6 shows theEcorrmonitoringofspecimenswithouttheapplicationofCP,Ecorrdecreaseddueto anelectronlossprocessduringthe analyzedperiodof time.Thisisattributedtothefactthatthereferencespecimensremainedimmersed in anelectrolytewithoutanyprotectionforthereinforcingsteel, causingan active corrosionprocessto be maintained.

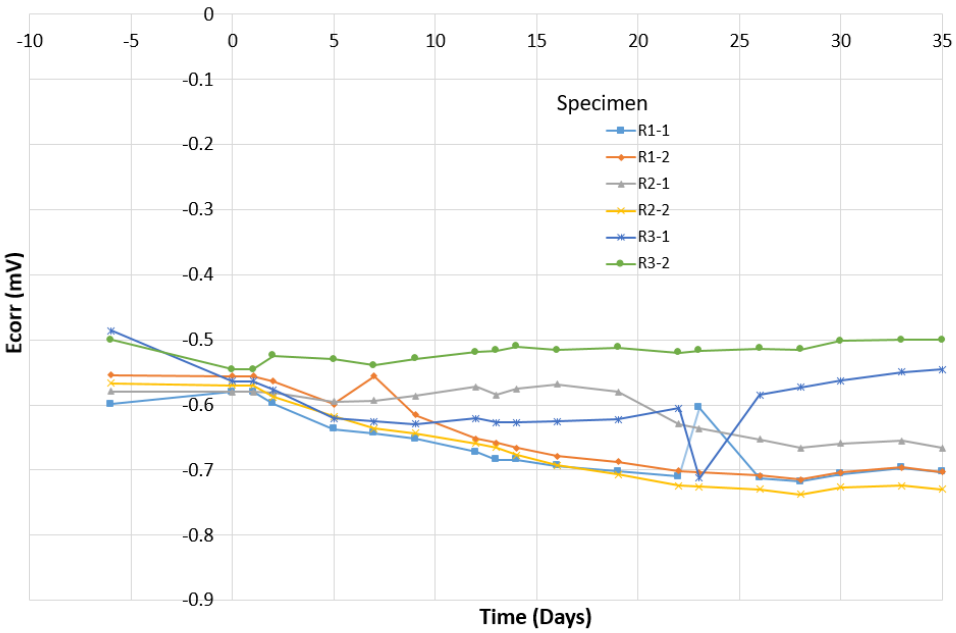


Figure6. Ecorr for test pieces without CP

CR of reinforced concrete structures increases considerably when they are in aggressive environments and there are no protective measures to avoid or reduce this process [**33**]. Figure 7 shows thecorrosionrate in specimenswithout CP before and after applying CP in titaniummeshtechniques and CF,withanincrease in CR in mm/yearfrom 13% to 47%, attributedto active corrosionprocessgenerated in thetotallyhumidenvironmentofthespecimens and thepresenceofchlorides in the concrete mass.In all cases thecorrosionrateincreased, makingclearthe active processofpittingcorrosiongenerated.

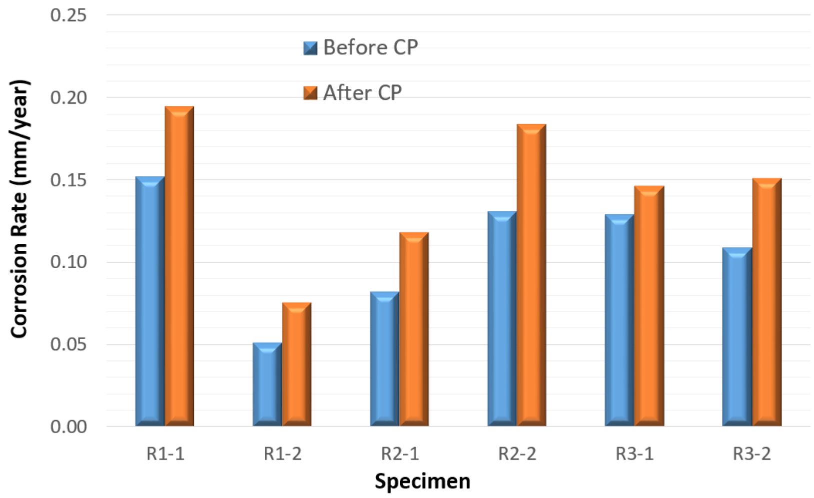


Figura 7. CR in specimens without CP

3.3 MonitoringofEcorr and CR with CP

3.3.1 CP referencewithTitaniummesh as anode

Reinforced concrete structures can be protectedagainstcorrosionbydifferentmethodsusing as anodesmaterialsthat are belowthesteel in theelectromotive series **[34]**. Figure 8 shows Ecorrofspecimenswith CP application in thetraditionaltechniqueusing as a anodetitaniummesh, before, during and after CP.Ecorrdecreasesduringthe 35 daysofthe CP applicationduetotheapplied load density, after CP and a depolarizationperiod, Ecorrtakesless negative values, modifyingitsvaluesbetween -501 mV and -606 mVbeforetheapplicationofCP at valuesbetween –343mV and -484mV after applicationoftheprotectionsystem and a periodof 14 daysfordepolarization. Thisbehaviorisattributedtothedifference in potentialbetweenthereinforcingsteel and thetitaniummesh, which, whenbeingapplieda currentdensitytotheanode, thetitaniummesh, loses electronsthatadheretothecathode, reinforcingsteel, tothroughtheelectrolyte, thedistilledwater.Unlikethereferencespecimens, thetraditionaltechniquedidpresentprotectionagainstcorrosion, reducingthelikelihoodofan active corrosionprocess.

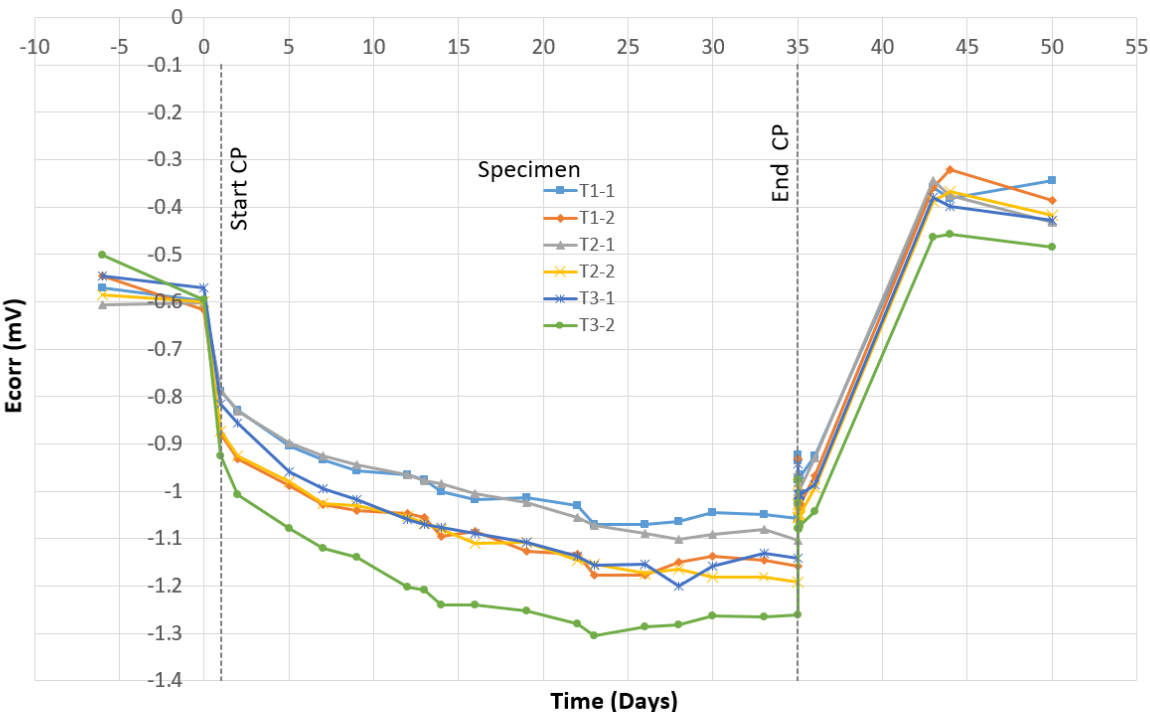


Figure8. Ecorrforspecimenswith CP and Titaniummesh.

Reinforced concrete structuresthat are protectedwithdifferentmethodsto reduce therateofcorrosionincreasetheirusefullife and thussaveeconomic and material resources**[34]**. Figure 9 shows CR in thespecimensofthetraditionaltechniquewithTitaniummesh as ananode, before and after CP, in general thereis a decrease in CR of up to 60% and anaverageof 37%.Attributedtotheprotectionprovidedduringthe 35-day periodof CP, allowingto reduce theeffectsofthepresent active process.

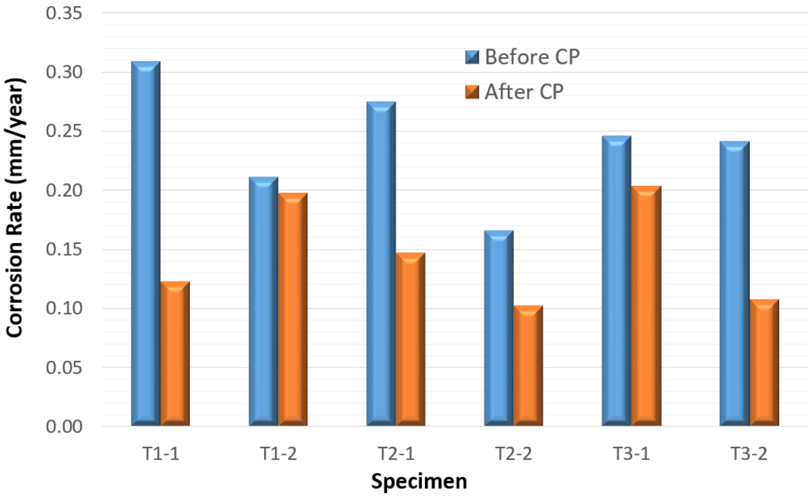


Figure9. CR in specimens with CP and Titanium mesh

3.3.2 CP withCarbonFiber as anode

Duetothesignificanteconomic and material lossesthatthecorrosionphenomenonentails, thereis a needtoseekincreasinglyefficientmethodsfortheprotectionofreinforced concrete structures**[33]**. Figure 10 shows Ecorr in specimensoftheproposedtechniqueusingas CF anodestrips in thecoating, before, during and after theapplicationof CP.Similar tothe use as anodeof a Titaniummesh, Ecorrdecreasesduringthe 35 daysoftheapplicationof CP, after CP and a periodofdepolarization, Ecorrpresented more positive valuestotheinitialsbetween -500mV and -605mV beforetheapplicationoftheCPtovaluesbetween –424mV and -473mV after CP and a periodof 14 daysfordepolarization,thisattributedtotheelectronsgainedbythesteelduringtheapplicationofthetechnique, whichthe CF lostperformingtheanodefunction.Unlikethereferencespecimens and, liketraditionaltechnique, corrosionprotectionwaspresented in theproposedtechnique, reducingtheprobabilityofthepresenceof active corrosionprocesses.

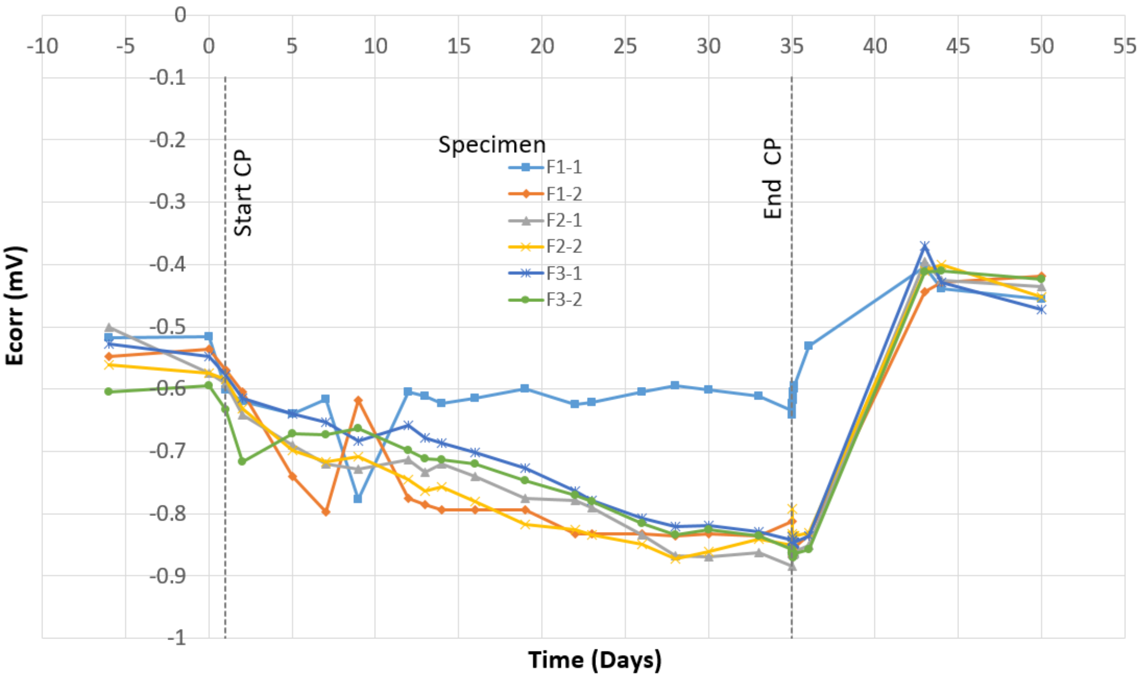


Figure10. Ecorrforspecimenswith CP and CarbonFiber.

Whenlookingformethodsto reduce therateofcorrosion in reinforced concrete structures in anincreasinglyefficientway,thedecreaseofcollapsedstructuresisachieved and withthistheproductionofmaterialssuch as cement and metallurgythat cause damagetotheenvironment in itsproductionisreduced, so thateconomic, social and environmentalbenefits are obtained**[35-39]**.Figure 11 shows CR in specimenswiththeCarbonFibertechnique as anode, before and after CP, in general thereis a decrease in CR of up to 77% and onaverage 49%. Thisisattributedtotheprotectionprovidedduringthe 35-day periodof CP, allowingto reduce theeffectsofthe active processpresent inthesystem.

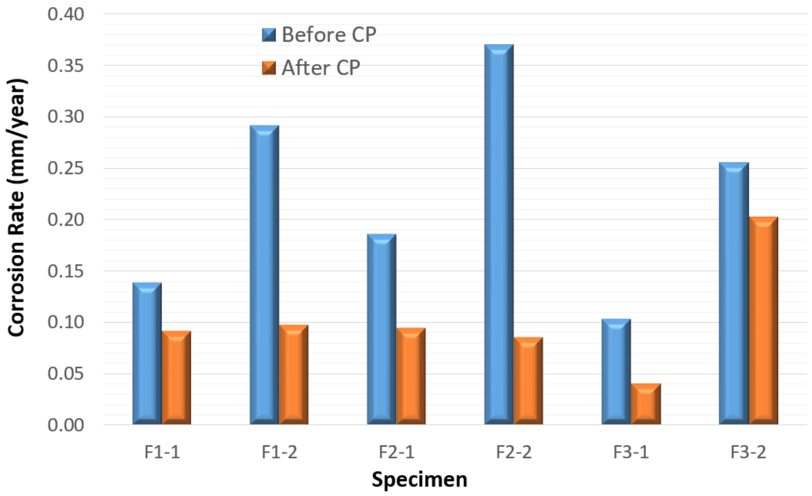


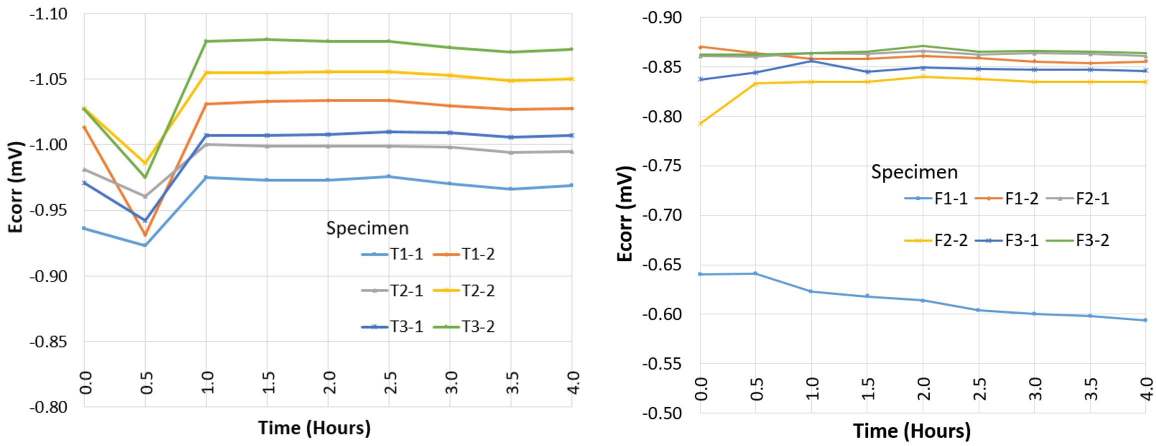
Figure 11. CR in specimens with CP and Carbon Fiber

Multifunctionalmaterialshaveadditionalbenefitstotheprotectionofsteel, reducingthepossibleappearanceofcracksduetothegreatermechanicalresistanceto stress providedbythe CF**[40].** The concrete coatingwithCF additiontookpropertiesof a multifunctional material withmechanicalpropertiessuitableforstructural use and electricalpropertiesacceptablefor use asanode in electrochemicaltechniques

3.4 Depolarizationmonitoring

3.4.1 First 4 hours

Toobtainreliable data, a depolarizationofthespecimenswasperformedtoeliminatealterationsduetopolarizationthatcouldaffecttheinvestigation**[41]**.Figure 12 shows Ecorrofthespecimenswiththe use ofbothanodes.In thefirst 4 hours, the use of CF as ananodeshowed more stableEcorr and less negative values, with notable lessdispersioncomparedtothe use ofTitaniummesh as ananode.

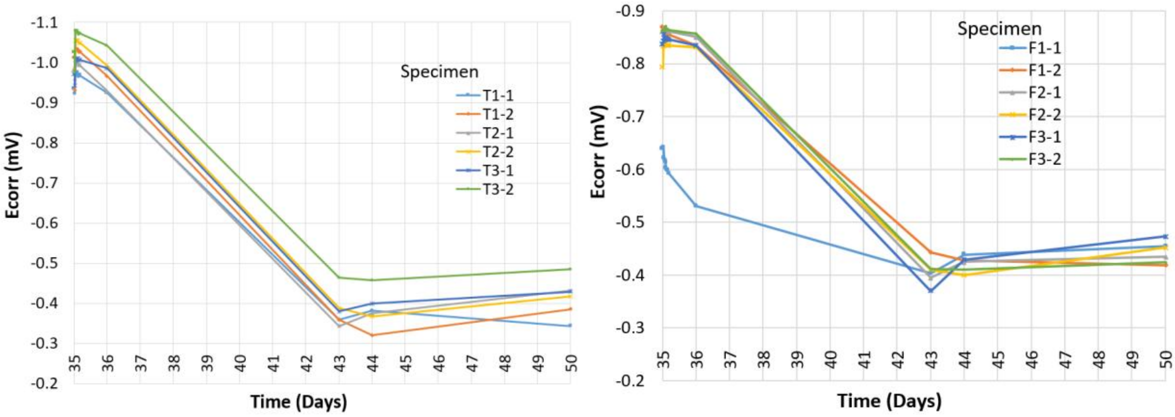


a) Titaniummesh as anode b) Carbonfiber as anode

Figure 12. Depolarization of specimens, first 4 hours after CP

3.4.2 14 days after CP

TheEcorrremainedstablethedays after CP, Figure 13 shows theEcorrofthespecimenswiththe use ofbothanodes.Theproximityofthe CF anodetothereinforcingsteelallowedEcorrvaluesto be lessdispersedcomparedtothe case ofthe use oftheTitaniummeshanode, allowingtopresentthepreviousbehavior in corrosionrates.



b) Malla de Titanio como ánodo b) Fibra de Carbono como ánodob) Titaniummesh as anode b) Carbonfiber as anode

Figure 13. Depolarization of specimens, 14 days after the CP

IV. CONCLUSIONS

The use ofCarbonFiber as anodeintegratedtothe concrete coating in theelectrochemicaltechniqueofcathodicprotection, has advantages in itsperformanceoverthetraditionaltechniqueofusingTitaniummesh, obtaininglowercorrosionrates after theapplicationofthetechnique.FactattributedtotheproximityofCF withthesurfaceofthereinforcingsteel and reflected in a greater performance in thecorrosionprotectionof up to 12% greaterthantheTitaniummesh, evenwhenthevaluesofthecorrosionpotentialswerevery similar.As thesurfaceofthe concrete coatingbecomes a multifunctional material withmechanicalpropertiessuitableforstructural use and electricalpropertiesacceptablefor use as anode in electrochemicaltechniques, it can presentadditionalbenefitstotheprotectionofsteel, reducingthepossibleappearanceoffisures duetothehighestmechanicalresistancetotensionprovidedby CF.

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