Electrochemical Corrosion in Bars of AISI 304 Embedded in Concrete Immersed in Marine-Sulfated Environment

Brenda Paola Baltazar-García, Daniel Francisco Baltazar-Zamora, Laura Landa-Ruiz, Ce Tochtli Méndez, Griselda Santiago-Hurtado, Victor Moreno-Landeros, René Croche and Miguel Angel Baltazar-Zamora

***Abstract* — The electrochemical behavior of the corrosion resistance of AISI 304 embedded in concrete manufactured as indicated by the ACI 211.1 method was evaluated. The specimens were exposed for more than 150 days to highly aggressive marine-sulfated environment, solution with a concentration of 5% NaCl and 5% Na_2SO_4. The electrochemical technique of Resistance to Linear Polarization (Rp) was used for to determine the corrosion rate (I_{corr}) and monitoring of corrosion potential (E_{corr}). The E_{corr} and I_{corr} results indicate a high level of corrosion for AISI 1018 steel, on the contrary, the electrochemical behaviour of AISI 304 steel according to the values of E_{corr} and I_{corr}, indicate a corrosion resistance of up to 10 times higher when exposed to an environment with a high concentration of chlorides and sulfates.**

***Keywords* — AISI 304, Corrosion, Concrete, Electrochemical Behavior, Marine-Sulfated Environment.**

I. Introduction

Worldwide, concrete is the most widely used material in the construction industry, due to its versatility for the manufacture of different structural elements of Civil Infrastructure such as bridges, roads, buildings, industrial warehouses, airports, tunnels, dams, canals, sewage treatment plants, houses, etc. [1]-[4].

However, if at first it was thought that reinforced concrete had unlimited durability, over time it was determined that one of the main causes of premature damage in civil works built with reinforced concrete was the corrosion of reinforcing steel, causing expenses for billions of dollars in the world [5]-[9], in 1986, it was estimated that more than 244,000 bridges in the USA had significant deterioration, the main cause being corrosion of the reinforcing bars of concrete structures [10]-[12].

Initially, reinforcing steel embedded in concrete is naturally protected from corrosion by the high alkalinity of the surrounding medium, pH=12.2 or higher. However, due to the behavior of concrete as a semi-permeable membrane, aggressive substances or ions enter, the most important being chlorides present in marine environments. [13]-[22], and sulfates that may be present in soils contaminated with agrochemicals, wastewater, etc. [23]-[34].

Unlike corrective or secondary actions, such as the use of corrosion inhibitors, galvanized steel, austenitic stainless steels, epoxy coating of the rods, electrochemical removal of chlorides, the production of more durable concrete based on industrial or agro-industrial residues [35]-[41], also pozzolanic materials when used in the construction industry have a beneficial environmental impact because the manufacturing process of Portland Cement is responsible for emitting 6 and 8% of CO_2 in the world [42]-[45].

Therefore, the present research evaluated the corrosion resistance of bars of AISI 304 and AISI 1018 embedded in concrete immersed in a marine-sulfated environment.

II. Materials and Methods

A. Materials

1) Dosage and Proportioning of Concrete Mixtures

The ACI 211.1 method was used to determine the amount of materials for the preparation of the concrete mix. [46].

TABLE I: Physical characteristics of the aggregates

Physical properties of materials	Coarse Aggregate	Fine Aggregate
Specific Mass, gr/cm³	2.32	2.84
Bulk Volumetric Mass, Kg /m³	1380	-
Absorption (%)	2.45	3.26
Module of Fineness	-	2.70
Maximum Size Nominal	¾ "	-

ASTM standards were used to determine the physical characteristics of the fine and coarse aggregates [47]-[50], see Table I.

A water/cement ratio = 0.65 was used for the design of the concrete mix. Table II shows the dosage for 1 m^3 of concrete.

Submitted on November 26, 2022.
Published on January 04, 2023.
B. P. Baltazar-García, Universidad Veracruzana, Mexico.
(e-mail: pao.baltazar.08@gmail.com)
D. F. Baltazar-Zamora, Universidad Veracruzana, Mexico.
(email: danielfbz8917@gmail.com)
L. Landa-Ruíz, Universidad Veracruzana, Mexico.
(email: lalanda@uv.mx)
C.T. Méndez, Universidad Veracruzana, Mexico.
(email: cmendez@uv.mx)
G. Santiago Hurtado, Universidad Autónoma de Coahuila, Mexico.
(e-mail: grey.shg@gmail.com)
V. Moreno-Landeros, Universidad Autónoma de Coahuila, Mexico.
(e-mail: vmmorlan@gmail.com)
R. Croche, Universidad Veracruzana, Mexico.
(e-mail: rcroche@uv.mx)
M. A. Baltazar-Zamora. Universidad Veracruzana, Mexico.
(e-mail: mbaltazar@uv.mx)

TABLE II: DOSAGE OF CONCRETE MIXTURES IN KG FOR 1 M^3

Materials	Concrete Mixture
Water	205
CPC 30R	315
Coarse Aggregate	869
Fine Aggregate	824

B. Method

1) Quality control test of concrete mixture

The ASTM and ONNCCE standards were used to carry out the control tests of fresh and hardened concrete [51]-[54], the results obtained are within the specifications for conventional concrete, see Table III.

TABLE III: PROPERTIES OF CONCRETE MIXTURE (FRESH AND HARDENED STATE)

TEST	Concrete Mixture
Slump, cm	8
Temperature, °C	18
Density, kg/m³	2164
F´c, Kg/cm²	226

2) Characteristics of reinforcing steel

In each specimen, two bars of AISI 304 and AISI 1018 were embedded, both to be used as working electrodes (WE) and auxiliary electrode (AE), and a third AISI 304 steel bar was embedded, but with a diameter of 1/8" as an auxiliary electrode. In the three bars was placed 5 cm strip of fluorocarbon tape on the upper part, to avoid differential aeration zones, the concentration of salts or crevice corrosion and an area susceptible to corrosion is delimited as indicated in the literature [55], see Fig. 1.

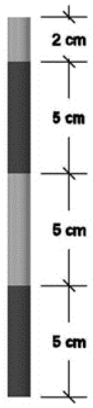

Fig. 1. Reinforcing steel -Characteristics-.

3) Nomenclature of the specimens

For the evaluation of corrosion, the nomenclature was assigned to the study specimens according to the type of steel and the exposure medium. Specimens exposed medium control (Water) and Marine-Sulfated environment (solution at 5% NaCl and 5% Na_2SO_4), see Table IV.

TABLE IV: NOMENCLATURE TEST SPECIMENS

SPECIMEN
304-C
1018-C
304-MS
1018-MS

- 304 =AISI 304.
- 1018 =AISI 1018.
- C = Control medium (water).
- MS= Marine-Sulfated environment (solution at 5% NaCl and 5% Na_2SO_4).

4) Experimental arrangement

The ASTM G59 standard was used to determine the corrosion rate [56], using a potentiostat/galvanostat with a three-electrode arrangement, according to what was reported in the literature [57]-[58]. The characteristics of the concrete specimens that were used to evaluate the corrosion rate are detailed in Fig. 2, two WE (bars AISI 304 and AISI 1018 steel) and one auxiliary electrode (AE) of AISI 304.

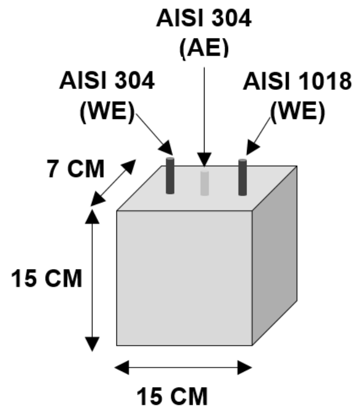

Fig. 2. Study specimens to determine the rate of corrosion.

The three-electrode arrangement is also used in other electrochemical techniques but is used to a lesser extent in the steel-concrete system and more used in other industrial areas [59]-[60].

III. RESULTS AND DISCUSSION

A. Corrosion Potential (E_{corr})

The interpretation of the E_{corr} results was carried out according to what is indicated in the ASTM C-876-15 standard [61] and in the literature [62], Table V shows the parameters for the analysis of the corrosion potentials of the present study.

TABLE V: CORROSION POTENTIAL IN REINFORCED CONCRETE (E_{CORR}).

Corrosion potentials mV vs Cu/CuSO4	
<- 500	Severe corrosion
<-350	90% Corrosion Risk
-350 to -200	Uncertainty of Corrosion Risk
> -200	10% Corrosion Risk

Fig. 3 shows the behavior of corrosion potentials (E_{corr}) of the specimens 304-C and 1018-C. The specimen 304-C reports values of corrosion potentials in the first 28 days from -170 mV to -192 mV, to maintain a stable behavior throughout the evaluation period with more positive values at -200 mV, which indicates a risk of corrosion of 10%. In the case of the specimen 1018-C has E_{corr} values of -358 mV in in the same period, which would indicate a risk of corrosion of 90% to pass to more positive values, presented on day 28 a more noble corrosion potential of -292 mV, behavior associated with the formation of the passive layer, so there is a behavior with a tendency to passivation with the passage of time, remaining in an E_{corr} range between -190 mV to -230 mV, behavior reported in literature because it is the non-aggressive control medium [63].

The results of the corrosion potentials of the specimens 304-MS and 1018-MS are presented in Fig. 4, when exposed to a sulfated marine environment (solution at 5% NaCl and 5% Na_2SO_4). The corrosion potential monitoring period was for more than 150 days, where the 304-MS specimen presented potentials of -174 mV to -162 mV from day 14 to 28, to maintain E_{corr} more positive during the time of the electrochemical tests, with E_{corr} values from -145 mV to -160 mV, indicates a 10% of corrosion risk. The specimen 1018-MS presents E_{corr} from -430 mV to -390 mV in the first 28 days, with an E_{corr} of -332 mV for day 112, reporting E_{corr} greater than -350 mV, which is associated with a 90% risk of corrosion at the end of the exposure time, initiating the activation of the reinforcing steel when exposed to a marine-sulfated environment, the results coincide with investigations in similar media in exposure media with a high concentration of chlorides and sulfates [64]-[65].

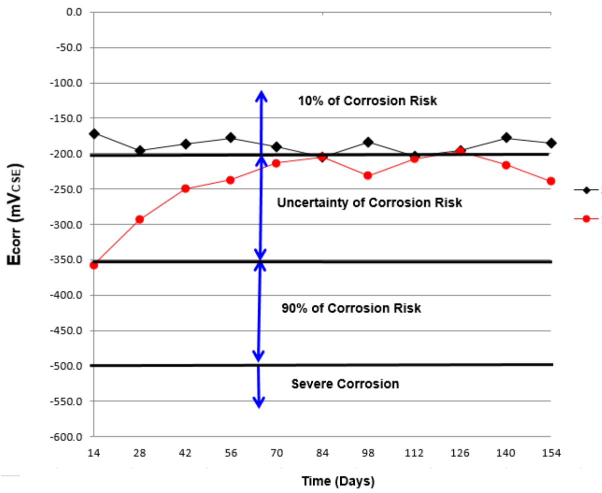

Fig. 3. E_{corr} of AISI 304 vs AISI 1018 concrete exposed to control environment.

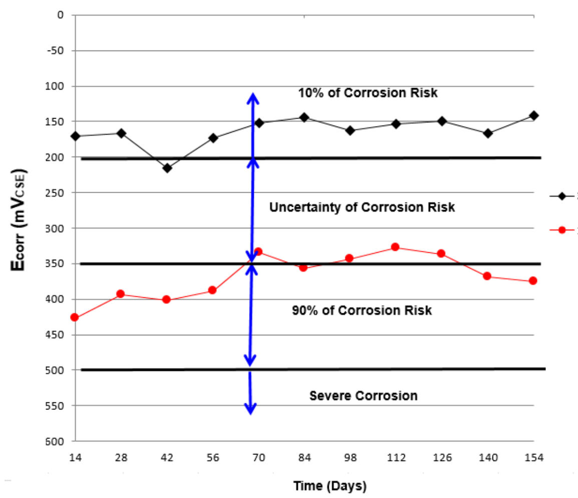

Fig. 4. E_{corr} of AISI 304 vs AISI 1018 concrete exposed to marine-sulfated environment.

B. *Corrosion Current Density (Icorr)*

To determine the level of corrosion present in the study specimens, DURAR NETWORK Manual criteria were used, see Table VI [66].

TABLE VI: Level of Corrosion According to I_{corr}

Corrosion rate (I_{corr}) µA / cm^2	Level of Corrosion
<0.1	Despicable
0.1- 0.5	Moderate
0.5 to 1	High
> 1	Very High

Fig. 3 presents the behavior of monitoring of intensity corrosion current I_{corr} of specimen 304-C and the specimen reinforced with 1018-C. It is found that specimen 304-C reports an I_{corr} of 0.038 µA/cm^2 for day 14, decreasing to 0.029 µA/cm^2 on day 28, normal behavior in the first four weeks of exposure to the control medium, to reach an I_{corr} of of 0.011 µA/cm2 in the day 56, and remain stable until the last monitoring in an I_{corr} range of 0.009 to 0.01 µA/cm^2, values 10 times less than 0.1 µA/cm^2, which represents the absence of corrosion in the evaluated system, according to what is indicated in Table VI.

For specimen 1018-C, a similar behavior is observed, with relatively high values of I_{corr} beginning to reach values that indicate a negligible corrosion level over time, however, the influence of the type of steel is observed in the I_{corr} ranges obtained, given that in the curing stage the values reported by specimen 1018-C are 10 times higher than specimen 304-C, with an I_{corr} from 0.30 µA/cm^2 to 0.20 in the first 28 days, ending with a value of 0.07 µA/cm^2 until the end of the exposure period. This behavior that coincides with what has been reported by some research [67]- [68].

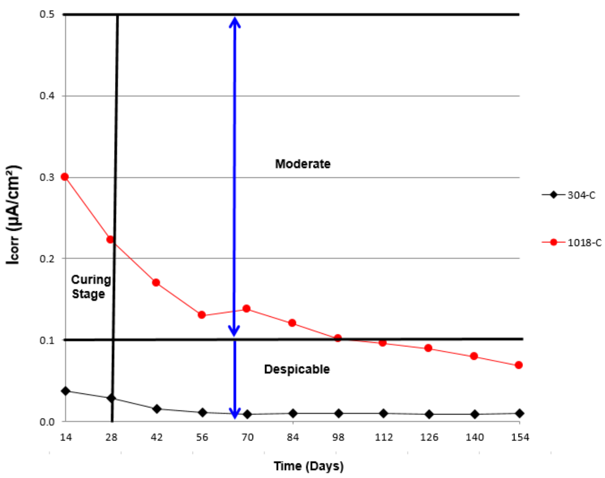

Fig. 5. Icorr of AISI 304 vs AISI 1018 concrete exposed to control environment.

Fig. 6 presents the results of 304-MS and 1018-MS specimens, when exposed to a sulfated marine environment (solution at 5% NaCl and 5% Na_2SO_4) for more than 150 days. The specimen 304-MS reports in the curing stage values of I_{corr} from 0.034 to 0.026 µA/cm^2, to decrease to 0.014 µA/cm^2 in the day 56, to present until the last day of the electrochemical test, I_{corr} values of 0.011 to 0.013 µA/cm^2, with a variation of only 0.001 to 0.003 µA/cm^2 compared to specimen 304-C exposed to the non-aggressive medium (water), it is found that the 304-MS specimen exposed to the highly aggressive marine-sulfated environment offers great resistance to corrosion, behaving as if the exposure medium were not aggressive, this has been reported in various investigations worldwide, however, the number of studies on concrete durability in media with such a high concentration of NaCl and Na_2SO_4, are significantly less [69]-[70].

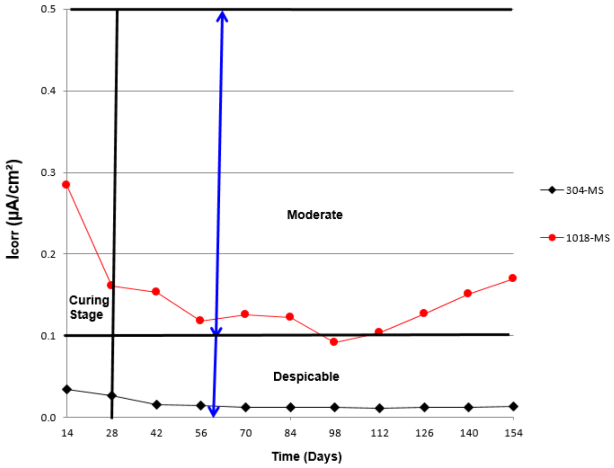

Fig. 6. I_{corr} of AISI 304 vs AISI 1018 concrete exposed to marine-sulfated environment.

On the contrary to the great anticorrosive efficiency to the aggressive medium reported by the specimen with AISI 304 Stainless Steel, 304-MS, the specimen 1018-MS presented a good behavior in the curing stage, with I_{corr} of 0.28 to 0.16 µA/cm^2, with a tendency to lower values of I_{corr} reporting on day 98 I_{corr} of 0.09 µA/cm^2, to later report constant increases in I_{corr} until reaching at the end of the corrosion tests, day 150, an I_{corr} of 0.17 µA/cm^2, but with an upward trend, behavior that indicates a much lower resistance when the this specimen is exposed to a highly aggressive environment (solution at 5% NaCl and 5% Na_2SO_4). Due to the results obtained in the present investigation, the intelligent use of AISI 304 stainless steel is justified for the construction of durable concrete structures, which would allow significant and sustainable savings to increase up to two times the useful life.

IV. Conclusions

The behavior in the control medium of both AISI 304 and AISI 1018 steels, is of a tendency to E_{corr} values that indicate 10% risk of corrosion and I_{corr} values that confirm the level of negligible corrosion, with I_{corr} values below of 0.1 µA/cm^2, with AISI 304 steel presenting the lowest values in all the monitoring.

The specimens with AISI 304 steel presented a great resistance to corrosion of more than 10 times when exposed to the marine-sulfated environment of the present study, reporting similar values of I_{corr} a of the specimens exposed to the control medium with only a difference of between 0.001 to 0.003 µA/cm^2.

The use of AISI 304 stainless steel is recommended as reinforcement in concrete structures that will be exposed to environments with high concentrations of chlorides and sulfates, using it intelligently in critical areas of each structure.

Acknowledgment

MA Baltazar-Zamora thanks to the National System of Researchers (CONACYT) for the support.

References

[1] Hassi S, Menu B, Touhami ME. The Use of the Electrochemical Impedance Technique to Predict the Resistance to Chloride Ingress in Silica Fume and Fly Ash-Reinforced Blended Mortars Exposed to Chloride or Chloride–Sulfate Solutions. *Journal of Bio- and Tribo-Corrosion.* 2022;8:13. DOI: 10.1007/s40735-021-00609-1.

[2] Baltazar-Zamora MA, Márquez-Montero S, Landa-Ruiz L, Croche R, López-Yza O. Effect of the type of curing on the corrosion behavior of concrete exposed to the urban and marine environment. *European Journal of Engineering Research and Science*. 2020;5(1):91-95. DOI: 10.24018/ejeng.2020.5.1.1716.

[3] Sagñay S, Bautista A, Donaire J, Torres-Carrasco M, Bastidas DM, Velasco F. Chloride-induced corrosion of steel reinforcement in mortars manufactured with alternative environmentally-friendly binders. *Cement and Concrete Composites.* 2022;130:104557. DOI: 10.1016/j.cemconcomp.2022.104557.

[4] Volpi-León V, López-Léon LD, Hernández-Ávila J, Baltazar-Zamora MA, Olguín-Coca FJ, López-León AL. Corrosion study in reinforced concrete made with mine waste as a mineral additive. *International Journal of Electrochemical Science.* 2017;12(1):22-31. DOI: 10.20964/2017.01.08.

[5] Rabi M, Shamass R, Cashell KA. Structural performance of stainless steel reinforced concrete members: A review. *Construction and Building Materials.* 2022;325:126673. DOI: 10.1016/j.conbuildmat.2022.126673.

[6] Troconis de Rincón O, Montenegro JC, Vera R, Carvajal AM, de Gutiérrez RM, Del Vasto S, Saborio E, *et. al.* Reinforced Concrete Durability in Marine Environments DURACON Project: Long-Term Exposure. *Corrosion.* 2016 ;72(6):824-833. DOI: 10.5006/1893.

[7] Xiao T, Du C, Liu Y. Electrochemical Evaluation on Corrosion Behavior of SAF 2507 Duplex Stainless Steels in Blended Concrete with Metakaolin and ultrafine Slag Admixtures. *International Journal of Electrochemical Science.* 2021;16:210642. DOI: 10.20964/2021.06.15.

[8] Landa-Ruiz L, Croche R, Santiago-Hurtado G, Moreno-Landeros V, Cuevas J, Méndez CT, Jara-Díaz M, *et. al.* Evaluation of the Influence of the Level of Corrosion of the Reinforcing Steel in the Moment-Curvature Diagrams of Rectangular Concrete Columns. *European Journal of Engineering and Technology Research.* 2021;6(3):139-145. DOI: 10.24018/ejeng.2021.6.3.2423.

[9] Raczkiewicz W. Use of polypropylene fibres to increase the resistance of reinforcement to chloride corrosion in concretes. *Science and Engineering of Composite Materials.* 2021;28(1):555–567. DOI: 10.1515/secm-2021-0053

[10] Bautista A, Blanco G, Velasco F. Corrosion behaviour of low-nickel austenitic stainless steels reinforcements: A comparative study in simulated pore solutions. *Cement and Concrete Research*. 2006; 36(10):1922–1930. DOI: 10.1016/j.cemconres.2005.10.009

[11] Rameshkumar M, Malathy R, Chandiran P, Paramasivam S, Chung IM, KimSH, PrabakaranM.Study on Flexural Behaviour of Ferroceme nt Composites Reinforced with Polypropylene Warp Knitted Fabric. *Polymers.* 2022;14(19):4093. DOI: 10.3390/polym14194093

[12] Baltazar-Zamora MA, Santiago-Hurtado G, Gaona-Tiburcio C, Maldonado-Bandala EE, Barrios-Durstewist CP, Núñez-J RE, Pérez-López T, *et. al.* Evaluation of the corrosion at early age in reinforced concrete exposed to sulfates. *International Journal of Electrochemical Science.* 2012;7(1):588-600.

[13] Zhang Q, Li H, Feng H, Jiang T. Effect of Bagasse Ash Admixture on Corrosion Behavior of Low Carbon Steel Reinforced Concrete in Marine Environment. *International Journal of Electrochemical Science.* 2020;15(7): 6135–6142. DOI: 10.20964/2020.07.65

[14] Santiago-Hurtado G, Baltazar-Zamora MA, Galván-Martínez R, López L LD, Zapata G F, Zambrano P, Gaona-Tiburcio C, *et. al.* Electrochemical Evaluation of Reinforcement Concrete Exposed to Soil Type SP Contaminated with Sulphates. *International Journal of Electrochemical Science.* 2016;11(6):4850-4864. DOI: 10.20964/2016.06.31

[15] Pan C, Li X, Mao J. The effect of a corrosion inhibitor on the rehabilitation of reinforced concrete containing sea sand and seawater. *Materials.* 2020; 13:1480. DOI: 10.3390/ma13061480

[16] Landa-Ruiz L, Ariza-Figueroa H, Santiago-Hurtado G, Moreno-Landeros V, López Meraz R, Villegas-Apaez R, Márquez-Montero S, *et. al.* Evaluation of the Behavior of The Physical and Mechanical Properties of Green Concrete Exposed to Magnesium Sulfate. *European Journal of Engineering Research and Science.* 2020;5(11):1353-1356. DOI: 10.24018/ejeng.2020.5.11.2241

[17] Gaona Tiburcio C, Samaniego-Gámez O, Jáquez-Muñoz JM, Baltazar-Zamora MA, Landa-Ruiz L, Lira-Martínez A, Flores-De los Rios JP, *et. al.* Frequency-Time Domain Analysis of Electrochemical Noise of

Passivated AM350 Stainless Steel for Aeronautical Applications. *International Journal of Electrochemical Science.* 2022;17(9):220950. DOI: 10.20964/2022.09.49.

[18] Baltazar-Zamora MA, Mendoza-Rangel JM, Croche R, Gaona-Tiburcio C, Hernández C, López L, Olguín F, *et. al.* Corrosion Behavior of Galvanized Steel Embedded in Concrete Exposed to Soil Type MH Contaminated with Chlorides. *Frontiers in Materials.* 2019;6:1-12. DOI: 10.3389/fmats.2019.00257.

[19] Roventi G, Bellezze T, Giuliani G, Conti C. Corrosion resistance of galvanized steel reinforcements in carbonated concrete: Effect of wet–dry cycles in tap water and in chloride solution on the passivating layer. *Cement and Concrete Research*. 2014;65:76–84. DOI: j.cemconres.2014.07.014

[20] Santiago-Hurtado G, Baltazar-Zamora MA, Olguin-Coca J, López L LD, Galván-Martínez R, Ríos-Juárez A, Gaona-Tiburcio C, *et. al.* Electrochemical Evaluation of a Stainless Steel as Reinforcement in Sustainable Concrete Exposed to Chlorides. *International Journal of Electrochemical Science.* 2016;11(4):2994-3006. DOI: 10.20964/110402994

[21] Yeomans SR. Performance of Black, Galvanized, and Epoxy-Coated Reinforcing Steels in Chloride- Contaminated Concrete. *Corrosion.* 1994;50(1):72–81.

[22] Baltazar-Zamora MA, Santiago-Hurtado G, Moreno L VM, Croche B R, de la Garza M, Estupiñan L F, Zambrano R P, *et. al*, Electrochemical Behaviour of Galvanized Steel Embedded in Concrete Exposed to Sand Contaminated with NaCl. *International Journal of Electrochemical Science.* 2016;11(12):10306-10319. DOI: 10.20964/2016.12.28

[23] Dehwah HAF, Maslehuddin M, Austin SA. Long-term effect of sulfate ions and associated cation type on chloride-induced reinforcement corrosion in Portland cement concretes. *Cement and Concrete Composites.* 2002;24(1):17–25. DOI: 10.1016/S0958-9465(01)00023-3

[24] Baltazar-Zamora MA, Ariza-Figueroa H, Landa-Ruiz L, Croche R. Electrochemical Evaluation of AISI 304 SS and Galvanized Steel in Ternary Ecological Concrete based on Sugar Cane Bagasse Ash and Silica Fume (SCBA-SF) exposed to Na_2SO_4. *European Journal of Engineering Research and Science.* 2020;5(3):353-357. DOI: 10.24018/ejeng.2020.5.3.1852

[25] Wang D, Zhao X, Meng Y, Chen Z. Durability of concrete containing fly ash and silica fume against combined freezing-thawing and sulfate attack. *Construction and Building Materials.* 2017;147: 398–406. DOI: 10.1016/j.conbuildmat.2017.04.172.

[26] Liang MT, Lan JJ. Reliability analysis for the existing reinforced concrete pile corrosion of bridge substructure. *Cement and Concrete Research.* 2005;35(3):540–550. DOI: 10.1016/j.cemconres.2004.05.010.

[27] Baltazar-Zamora MA, Landa-Ruiz L, Rivera Y, Croche R. Electrochemical Evaluation of Galvanized Steel and AISI 1018 as Reinforcement in a Soil Type MH. *European Journal of Engineering Research and Science.* 2020;5(3):259-263. DOI: 10.24018/ejeng.2020.5.3.1789.

[28] Farhangi V, Karakouzian M. Effect of fiber reinforced polymer tubes filled with recycled materials and concrete on structural capacity of pile foundations. *Applied Sciences*. 2020;10:1554. DOI: 10.3390/app10051554.

[29] Castaneda-Robles IE, López-León LD, Moreno-Landeros VM, Baltazar-Zamora MB, Olguín-Coca FJ, Lizárraga-Mendiola LG. Electrochemical behavior of carbon steel under a continuous kerosene flow in two different kind of sections. *International Journal of Electrochemical Science.* 2018;13(9):9039–9050. DOI: 10.20964/2018.09.36.

[30] Cosoli G, Mobili A, Tittarelli F, Revel GM, Chiariotti P. Electrical Resistivity and Electrical Impedance Measurement in Mortar and Concrete Elements: A Systematic Review. *Applied Sciences.* 2020;10: 9152. DOI:doi.org/10.3390/app10249152.

[31] Baltazar-Zamora MA, Bastidas DM, Santiago-Hurtado G, Mendoza-Rangel JM, Gaona-Tiburcio C, Bastidas JM, Almeraya-Calderón F. Effect of Silica Fume and Fly Ash Admixtures on the Corrosion Behavior of AISI 304 Embedded in Concrete Exposed in 3.5% NaCl Solution. *Materials (Basel).* 2019;12(23):1-13. DOI: 10.3390/ma12234007.

[32] Figueira RB. Electrochemical sensors for monitoring the corrosion conditions of reinforced concrete structures: A review. *Applied Sciences.* 2017;7:1157. DOI: 10.3390/app7111157.

[33] Landa-Ruiz L, Landa-Gómez A, Mendoza-Rangel JM, Landa-Sánchez A, Ariza-Figueroa H, Méndez-Ramírez CT, Santiago-Hurtado G, *et. al.* Physical, Mechanical and Durability Properties of Ecofriendly Ternary Concrete Made with Sugar Cane Bagasse Ash and Silica Fume. *Crystals.* 2021;11:1012. DOI: 10.3390/cryst11091012.

[34] Ormellese M, Berra M, Bolzoni F, Pastore T. Corrosion inhibitors for chlorides induced corrosion in reinforced concrete structures. *Cement and Concrete Research.* 2006;36(3):536–547. DOI: j.cemconres.2005.11.007.

[35] M.A. Baltazar-Zamora et. al. Efficiency of Galvanized Steel Embedded in Concrete Previously Contaminated with 2, 3 and 4% of NaCl. *International Journal of Electrochemical Science.* 2012;7(4):2997-3007.

[36] Shaheen F, Pradhan B. Influence of sulfate ion and associated cation type on steel reinforcement corrosion in concrete powder aqueous solution in the presence of chloride ions. *Cement and Concrete Research.* 2017;91:73–86. DOI: j.cemconres.2016.10.008.

[37] Landa-Ruiz L, Baltazar-Zamora MB, Bosch J, Ress J, Santiago-Hurtado G, Moreno-Landeros VM, Márquez-Montero S, *et. al.* Electrochemical Corrosion of Galvanized Steel in Binary Sustainable Concrete Made with Sugar Cane Bagasse Ash (SCBA) and Silica Fume (SF) Exposed to Sulfates. *Applied Sciences*. 2021;11:2133. DOI: 10.3390/app11052133.

[38] Burtuujin G, Son D, Jang I, Yi C, Lee H. Corrosion behavior of pre-rusted rebars in cement mortar exposed to harsh environment. *Applied Sciences*. 2020;10:8705. DOI: 10.3390/app10238705.

[39] Baltazar-Zamora MA, Landa-Sánchez A, Landa-Ruiz L, Ariza-Figueroa H, Gallego-Quintana P, Ramírez-García A, Croche R, *et. al.* Corrosion of AISI 316 Stainless Steel Embedded in Sustainable Concrete made with Sugar Cane Bagasse Ash (SCBA) Exposed to Marine Environment. *European Journal of Engineering Research and Science.* 2020;5(2):127-131. DOI: 10.24018/ejers.2020.5.2.1751

[40] Xu P, Jiang L, Guo M, Zha J, Chen L, Chen C, Xu N. Influence of sulfate salt type on passive film of steel in simulated concrete pore solution. *Construction and Building Materials*. 2019;223:352–359. DOI: j.conbuildmat.2019.06.209

[41] Baltazar-Zamora MA, Landa-Ruiz L, Landa-Gómez AE, Santiago-Hurtado G, Moreno-Landeros V, Méndez Ramírez CT, Fernandez Rosales V, *et. al.* Corrosion of AISI 316 Stainless Steel Embedded in Green Concrete with Low Volume of Sugar Cane Bagasse Ash and Silica Fume exposed in Seawater. *European Journal of Engineering and Technology Research.* 2022;7(1):57-62. DOI: 10.24018/ejeng.2022.7.1.2716

[42] Abdall TA, Koteng DO, Shitote SM, Matallah M. Mechanical and durability properties of concrete incorporating silica fume and a high volume of sugarcane bagasse ash. *Results in Engineering*. 2022;16:1-13. DOI:10.1016/j.rineng.2022.100666

[43] Landa-Ruiz L, Márquez-Montero S, Santiago-Hurtado G, Moreno-Landeros V, Mendoza-Rangel JM, Baltazar-Zamora MA. Effect of the Addition of Sugar Cane Bagasse Ash on the Compaction Properties of a Granular Material Type Hydraulic Base. *European Journal of Engineering and Technology Research*. 2021;6(1):76–79. DOI:10.24018/ejeng.2021.6.1.2335.

[44] Abdall TA, Koteng DO, Shitote SM, Matallah M. Mechanical Properties of Eco-friendly Concrete Made with Sugarcane Bagasse Ash. *Civil Engineering Journal.* 2022; 8(6):1227-1239. DOI: 10.28991/CEJ-2022-08-06-010

[45] Ojeda-Farías O, Mendoza-Rangel JM, Baltazar-Zamora MA. Influence of sugar cane bagasse ash inclusion on compacting, CBR and unconfined compressive strength of a subgrade granular material. *Revista ALCONPAT*. 2018;8(2):194-208. DOI: 10.21041/ra.v8i2.282.

[46] ACI. Provision of mixtures, normal concrete, heavy and massive ACI 211.1, p. 29. Ed. IMCYC, Mexico (2004).

[47] ASTM C29 / C29M–07–Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate; ASTM International, West Conshohocken, PA, 2007, www.astm.org.

[48] ASTM C127–15–Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate; ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[49] ASTM C128–15–Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate; ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[50] ASTM C136 / C136M –14–Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates; ASTM International, West Conshohocken, PA, 2014, www.astm.org.

[51] NMX-C-156-ONNCCE-2010: Determinación del revenimiento en el concreto fresco. ONNCCE S.C., México, (2010).

[52] ASTM C 1064/C1064M - 08 Standard, (2008). Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete. ASTM International, West Conshohocken, PA, 2008, www.astm.org.

[53] NMX-C-162-ONNCCE-2014: Determinación de la masa unitaria, cálculo del rendimiento y contenido de aire del concreto fresco por el método gravimétrico., ONNCCE S.C., México, (2014).

[54] NMX-C-083-ONNCCE-2014: Determinación de la resistencia a la compresión de especímenes – Método de prueba, ONNCCE S.C., México, (2014).

[55] Baltazar-García BP, Baltazar-Zamora DF, Landa-Ruiz L, Méndez CT, Solorzano R, Reyes J, Márquez S, *et. al.* Corrosion Behavior of AISI 1018 Reinforcing Steel in Sustainable Concrete made with Sugar Cane Bagasse Ash and Recycled Aggregates Exposed in Seawater. *European Journal of Engineering and Technology Research.* 2022;7(6):101-107. DOI: 10.24018/ejeng.2022.7.6.2930.

[56] ASTM G 59-97 (2014) – Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements, ASTM International, West Conshohocken, PA, 2014, www.astm.org.

[57] Barrios Durstewitz CP, Baldenebro López FJ, Núñez Jaquez RE, Fajardo G, Almeraya F, Maldonado-Bandala E, Baltazar-Zamora M, *et. al.* Cement Based Anode in the Electrochemical Realkalisation of Carbonated Concrete. *International Journal of Electrochemical Science.* 2012;7(4):3178 – 3190.

[58] Feliu S, González JA, Andrade C, Techniques to Assess the Corrosion Activity of Steel Reinforced Concrete Structures, ASTM STP 1276. ASTM, 1996.

[59] Gaona-Tiburcio C, Montoya-Rangel M, Cabral-Miramontes JA, Estupiñan-López F, Zambrano-Robledo P, Orozco Cruz R , Chacón-Nava JG, *et.al.* Corrosion Resistance of Multilayer Coatings Deposited by PVD on Inconel 718 Using Electrochemical Impedance Spectroscopy Technique. *Coatings.* 2020;10:521. DOI. 10.3390/coatings10060521.

[60] Cabral-Miramontes JA, Bastidas DM, Baltazar MA, Zambrano-Robledo P, Bastidas JM, Almeraya-Calderón FM, Gaona-Tiburcio C. Corrosion behavior of Zn-TiO2 and Zn-ZnO Electrodeposited Coatings in 3.5% NaCl solution. *International Journal of Electrochemical Science.* 2019;14(5): 4226 – 4239. DOI: 10.20964/2019.05.10

[61] ASTM C 876-15, Standard Test Method for Corrosion potentials of uncoated reinforcing steel in concrete, ASTM (2015).

[62] Song HW, Saraswathy V. Corrosion Monitoring of Reinforced Concrete Structures – A Review. *International Journal of Electrochemical Science.* 2007; 2(1):1-28.

[63] Ariza-Figueroa HA, Bosch J, Baltazar-Zamora MA, Croche R, Santiago-Hurtado G, Landa-Ruiz L, Mendoza-Rangel JM, Bastidas JM, *et.al*. Corrosion Behavior of AISI 304 Stainless Steel Reinforcements in SCBA-SF Ternary Ecological Concrete Exposed to $MgSO_4$. *Materials (Basel).* 2020;13(10):1-16. DOI: 10.3390/ma13102412.

[64] Chakraborty S, Mandal R, Chakraborty S, Guadagnini M, Pilakoutas K. Chemical attack and corrosion resistance of concrete prepared with electrolyzed water. *Journal of materials research and technology.* 2021; 11: 1193-1205. DOI: 10.1016/j.jmrt.2021.01.101.

[65] Jee AA, Pradhan B. Long term effect of chloride and sulfates concentration, and cation allied with sulfates on corrosion performance of steel-reinforced in concrete. *Journal of Building Engineering.* 2022; 56: 104813. DOI: 10.1016/ j.jobe.2022.104813.

[66] Troconis De Rincón O, Helene P, Castro P, Andrade C. Manual de Inspección, Evaluación y Diagnóstico de Corrosión en Estructuras de Hormigón Armado, p. 134. *Red DURAR. CYTED.* Venezuela (1997).

[67] Baltazar-García BP, Baltazar-Zamora DF, Landa-Ruiz L, Méndez CT, Solorzano R, Estupiñan López FH, Croche R, *et. al*. Eco-Friendly Concrete Made with System CPC-SCBA-SF As a Protector Against Sulfate Corrosion of Reinforcing Steel AISI 1018. *European Journal of Engineering and Technology Research.* 2022;7(6):14-20. DOI: 10.24018/ejeng.2022.7.6.2911.

[68] Landa-Sánchez A, Bosch J, Baltazar-Zamora MA, Croche R, Landa-Ruiz L, Santiago-Hurtado G, Moreno-Landeros VM, et. al. Corrosion Behavior of Steel-Reinforced Green Concrete Containing Recycled Coarse Aggregate Additions in Sulfate Media. *Materials (Basel).* 2020;13(19):1-22. DOI: 10.3390/ma13194345.

[69] Zhang F, Hu Z, Wei F, Wen X, Li X, Dai L, Liu L. Study on Concrete Deterioration in Different $NaCl-Na_2SO_4$ Solutions and the Mechanism of Cl^- Diffusion. Materials (Basel). 2020;14(17):5054. DOI: 10.3390/ma14175054.

[70] Sun H, Jiang C, Cao K, Yu D, Liu W, Zhang X, Xing F, *et. al.* Monitoring of steel corrosion and cracking in cement paste exposed to combined sulfate–chloride attack with X-ray microtomography. *Construction and Building Materials.* 2021;302:124345. DOI: 10.1016/j.conbuildmat.2021.04.124345.