Carbonation Depth of Sustainable Concrete Made with Agroindustrial and Industrial Waste Exposed to the Urban Environment of the City of Xalapa, Ver; Mexico

Brenda Paola Baltazar-García, Daniel Francisco Baltazar-Zamora, Odilón Sánchez-Sánchez, Patricia Balderas, José Manuel Mendoza-Rangel, Citlalli Gaona-Tiburcio, Laura Landa-Ruiz, José Reyes, David Lozano, Ce Tochtli Méndez, and Miguel Angel Baltazar-Zamora

***Abstract* — In the present investigation the effect of the urban environment of the city of Xalapa, Ver., México in the depth carbonation in Sustainable Concrete made with Agro-Industrial and Industrial Waste Materials like Sugar Cane Bagasse Ash (SCBA) and Silica Fume (SF), was evaluated. The Sustainable Concretes and the Conventional Concrete (Concrete of reference) were designed for a relation water/cement= 0.65 according to the indicated for the ACI 211.1. The Conventional Concrete was elaborated with 100% of Portland cement, and the Sustainable Concretes with partial substitution of Portland cement for the waste of SCBA and SF in percentages of 10, 20, 30, 40, and 50%. The results through the application of phenolphthalein, indicate that the Carbonation depth is proportional to the increase of the substitution of Portland Cement for agro-industrial and industrial waste. The sustainable concrete with 50% of substitution of SCBA-SF presents the worst performance, with a carbonation depth of 1.48 cm, which represents an increment of more of 350% than the conventional concrete at being exposed for one year to the present environment of study.**

***Keywords* — Agroindustrial-Industrial Waste, Carbonation Depth, Sustainable Concretes, Urban Environment.**

I. INTRODUCTION

Hydraulic concrete is the most used material of construction at the global level, due to its big physics-mechanic benefits and the durability intrinsic to the same nature of its components, which allows the constructions of majority of the constructions of the civil infrastructure necessary for the development of our society [1]-[4]. The durability of the concrete, according to the ACI, is the capacity for resisting the action of weathering, chemistry attack, abrasion or every other process or condition of service of the structures.

Traditionally it was associated the durability to the resistance characteristics of concrete and particularly to its compression-resistance, but the practice experience and the advance of the investigation in this area have demonstrated that it is only one of the involving aspects, but not the only one and neither enough for obtaining a durable concrete.

The problem of durability is eminently complex, as far as every situation of exposition and condition of service deserves a particular specification for the materials and design of the mixture and for the additives, the technique of production, and the constructive process.

Carbonation is a natural phenomenon that occurs every day in thousands of concrete structures for over the world. A well-understanding process that has been perfectly investigated and documented. For concrete that does not contain reinforced steel, carbonation is, generally, a process with fewer consequences.

Nevertheless, in reinforced concrete, this chemistry process is apparently innocuous, which advances slowly and progressively from the surface exposed of the concrete, to inside the womb, and when arriving to the deepness of the reinforced steel, begins the corrosion of the same one.

It has that many works of investigation that have demonstrated that the principal aggressive agents responsible of the corrosion of steel are the chlorides presented on the marine environments principally [5]-[14], such as the sulphates that are found like salts in the environment for the regular in the subsoil [15]-[26]. In addition to this, the corrosion of reinforced steel is the principal pathological cause of the big damages into the infrastructure elaborated based on reinforced concrete [27]-[29], with premature costs of reassurances for millions of dollars [30]-[34].

Even though Carbonation is a less important cause for corrosion, in comparison with the originated by the chlorides and sulphates, its study is also important due to the damages that provokes to the structure, economic cost and even human loss. The corrosion due Carbonation generally presents principally in urban environments, with huge concentrations of CO_2 such as the presence of humidity of over the 70%

Despite the fact that many researches have been made

Submitted on April 18, 2023.
Published on May 26, 2023.
B. P. Baltazar-García, Universidad Veracruzana, Mexico.
(e-mail: pao.baltazar.08@gmail.com)
D. F. Baltazar-Zamora, Universidad Veracruzana, Mexico.
(e-mail: danielfbz8917@gmail.com)
O. Sánchez-Sánzhez, Universidad Veracruzana, Mexico.
(e-mail: odsanchez@uv.mx)
P. Balderas, Universidad Autónoma del Estado de México, Mexico.
(e-mail: pbalderash@uaemex.mx)
J. M. Mendoza-Rangel, Universidad Autónoma de Nuevo León, Mexico.
(e-mail: jmmr.rangel@gmail.com)
C. Gaona-Tiburcio, Universidad Autónoma de Nuevo León, Mexico.
(e-mail: citlalli.gaonatbr@uanl.edu.mx)
L. Landa-Ruiz, Universidad Veracruzana, Mexico.
(e-mail: lalanda@uv.mx)
J. Reyes, Universidad Veracruzana, Mexico.
(e-mail: albreyes@uv.mx)
D. Lozano, Universidad Veracruzana, Mexico.
(e-mail: dlozano@uv.mx)
C. T. Méndez, Universidad Veracruzana, Mexico.
(e-mail: cmendez@uv.mx)
M. A. Baltazar-Zamora, Universidad Veracruzana, Mexico.
(e-mail: mbaltazar@uv.mx)

about the topic of corrosion, in relation with conventional concretes with different types of reinforced steel and in recent years of sustainable concretes exposed to aggressive environments with diverse variables [35]-[41]. It does not exist information about the prediction of premature Carbonation in sustainable concretes elaborated at based of Sugar Cane Bagasse Ash and Silica Fume as substitution of Portland cement at being exposed to the environment of the city Xalapa, Ver. Owing to the mentioned before, in this present research it was evaluated the resistance to the carbonation of sustainable concretes, with the purpose of being able to take decisions that allow treating or, in some cases, prevent damages for corrosion due to the carbonation. As well as motivating the use of sustainable concretes that carry out with the requirements of mechanic resistance and durability, thing that would have a positive impact in the industry of construction and into the environment that had incorporated pozzolanic waste on partial substitutions of Portland cement, due that the fabrication of this is responsible for the 6-8% of the total emissions of CO_2 of the world [42]-[46].

II. Materials and Methods

A. Materials

1) Dosage and proportioning of conventional concrete and sustainable concretes

As indicated before, it were elaborated mixtures of conventional concrete and sustainable concretes, designed for a relation w/c= 0.65, based on the method ACI 211.1. [47], this method is based into the physical properties of the stone aggregates, the essays for determining the mentioned properties were realized according to the normative ASTM [48]-[51], Table I shows the obtained results of the physic characterization of the aggregates that were used in the present investigation:

TABLE I: Physical characteristics of the aggregates

Physical properties of materials	Coarse Aggregate	Fine Aggregate
Specific Mass, gr/cm³	2.60	2.20
Bulk Volumetric Mass, Kg /m³	1442	-
Absorption (%)	1.70	1.80
Module of Fineness	-	2.94
Maximum Size Nominal	¾ "	-

The provision of each material used in the mixtures of CC and SC, for the required quality, can be observed in Table II, the dosage was for one cubic meter of concrete. The CC with 100% of CP and the SC with 10, 20, 30, 40 and 50% of combination of SCBA and SF.

TABLE II: Dosage of Mixtures of Conventional Concrete and Sustainable Concrete kg for 1 m^3

Materials	CC	SC10	SC20	SC30	SC40	SC50
Water	205.00	205.00	205.00	205.00	205.00	205.00
Cement	315.00	283.5	252.00	220.50	189.00	157.50
SCBA	0.00	15.75	31.50	47.25	63.00	78.75
SF	0.00	15.75	31.50	47.25	63.00	78.75
Fine Aggregate	746	746	746	746	746	746
Coarse Aggregate	881	881	881	881	881	881

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 [52]-[55], the results obtained are within the specifications for conventional concrete, see Table III.

TABLE III: Properties of Conventional Concrete and Sustainable Concrete (Fresh and Hardened state)

TEST	CC	SC10	SC20	SC30	SC40	SC50
Slump, cm	8	7	6.5	4.5	3	2
Temperature,°C	25	24.5	24.0	23.5	23.0	23.0
Density, kg/m³	2254	2268	2273	2289	2227	2149
F´c, Kg/cm²	337	313	346	358	335	205

2) Characteristics of test specimens

In order to make the essay for determining the carbonation depth of the conventional and sustainable concretes, cylindrical specimens of 15 cm in diameter and 30 cm in height were elaborated, see Fig. 1.

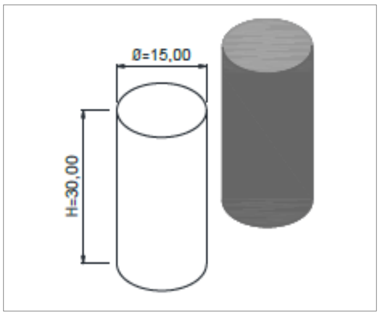


Fig. 1. The specimens' dimensions in cm.

Every specimen of study was placed on the flat-roof of the Laboratory of Materials in the installations of the Faculty of Civil Engineering, located in the City of Xalapa, Ver; Mexico, see Fig. 2.

Fig. 2. Location of the specimens on the flat-roof of the Laboratory of Materials.

3) Nomenclature of the study specimens

For the evaluation of carbonation depth, the used nomenclature was the one that is indicated in the next Table IV.

TABLE IV: Nomenclature Carbonation Test

SPECIMENS	
CC-F	CC-P
SC10-F	SC10-P
SC20-F	SC20-P
SC30-F	SC30-P
SC40-F	SC40-P
SC50-F	SC50-P

- CC = Conventional Concrete,
- SC = Sustainable Concrete,
- 10, 20, 30, 40 y 50 = Percentage of substitution of Portland Cement for combinations of SCBA and SF.

Cuts in the Frontal and Posterior part of each one of the specimens of study were made, taking into account that the front part was on direction to the preferential wind, which is similar to the indicated in the literature [56]-[58]. In order to apply the phenolphthalein and determining the carbonation depth, the frontal and posterior part were determined as:

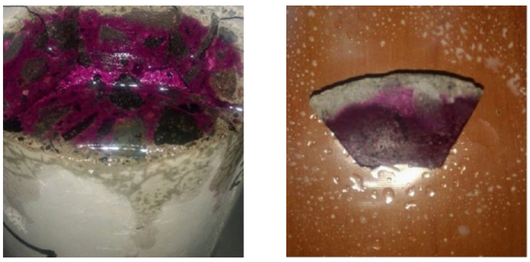
- F= For the Frontal part of the specimen,
- P= For the Posterior part of the specimen.

4) Experimental arrangement for carbonation test

For determining the carbonation depth of the specimens CC and SC, cuts were made on the frontal and posterior parts for every specimen, see Fig. 3.

Fig. 3. Cuts on the frontal and posterior part of the specimens.

The application of the phenolphthalein was realized with spray, in order to measure with a vernier-caliper the distance from the border of the cylinder to the surface that presented the violet color; this color indicates that the ph of the concrete is alkaline o higher than 12. The above was realized in four lectures in order to determine the average of the deepness presented in each cut, this process was repeated for each one of the specimens of study, see Fig. 4.



(a) (b)

Fig. 4. Application of phenolphthalein to determine the carbonation depth: a) On the surface of the specimen; b) In the cut piece made to the specimen.

III. Results and Discussion

A. Carbonation Depth in the Frontal Part

In Fig. 5 are present the results of the Carbonation depth in each one of the specimens of Conventional Concrete (CC) and Sustainable Concretes (SC) according to the percentage of substitution of Portland Cement for the combination of Sugar Cane Bagasse Ash (SCBA) Agro-Industrial waste and the Silica Fume (SF) industrial waste; the percentages of substitution, like it has been mentioned in previous paragraphs, were of the 0,10,20,30,40 and 50%, identifying the specimens as CC, SC10-F, SC20-F, SC30-F, SC40-F y SC50-F.

The analysed results were obtained after have exposed the specimens of study during a year to the environment of the city Xalapa, Ver. México and correspond to the carbonation depth in the front part of the specimen in relation to the preferential winds.

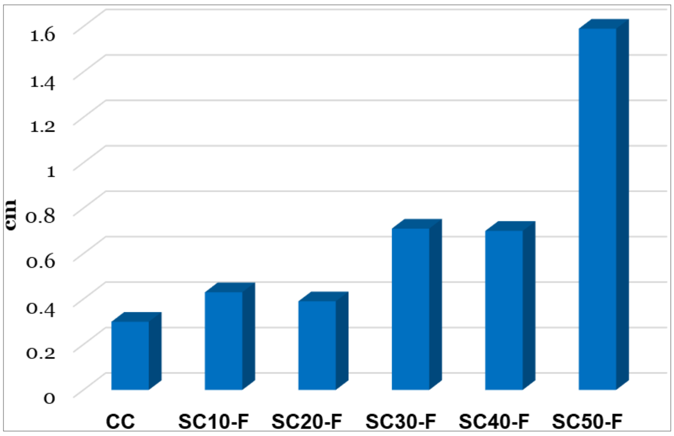


Fig. 5. Carbonation depth for the front part of the conventional and sustainable concretes.

Of Fig. 5, it has that the specimen of CC presented the lowest carbonation deepness, which was 0.30 cm. It is observed that the specimen SC10-F had an increase of 0.13 cm in its deepness with regard to the CC, with a carbonation depth of 0.43 cm, the above makes contrast with the carbonation depth that presented the specimen SC20-F which was of 0.39 cm, which corresponds to an increase of 0.09 cm in comparison with the specimen CC, with a higher resistance than the specimen SC10-F.

According to the specimen SC30-F and SC40-F, these presented a meaningful increase in the carbonation depth of more of the 100% with regard to the CC and of more of the 70% in relation with the specimens CS10-F and CS20-F, reaching a deepness of 0.71 cm and 0.70 cm, respectively. Finally, the specimen that presented the worst behaviour or resistance to the carbonation after a year of exposition to the environment of the city of Xalapa, Ver; Mexico, was the CS50-F, presenting a carbonation deepness of 1.60 cm, four times bigger than the presented in the specimen elaborated with CC.

B. Carbonation Depth on the Posterior Part

In Fig. 6 can be appreciated the results of the carbonation deepness presented in the posterior part of each one of the specimens of this study, conventional concrete and sustainable concretes with the different percentages of substitution of combinations of SCBA and SF for Portland cement.

The specimen CC presents a carbonation depth of 0.35 cm, with an increase of 0.05 cm with regard to its frontal part. For the case of the specimen SC10-P, it has that its deepness presents a huge increase, reaching a value of 0.66 cm, almost two times the obtained value in the CC, with an increase of 0.31 cm.

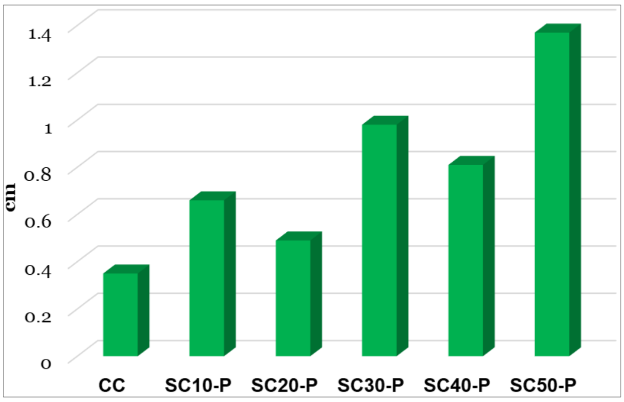


Fig. 6. Carbonation depth of the posterior part of conventional and sustainable concretes.

With respect to the specimen SC20-P, this reported a carbonation depth of 0.49 cm, being lower than the observed in the specimen SC10-P. On the other hand, it has that the specimen SC30-P has a lower resistance to the carbonation than the specimens with a 10 and 20%of substitution of SCBA and SF, with a carbonation deepness, after have been exposed to the environment of Xalapa City for a year, of 0.98 cm.

The specimen SC40-P presented a deepness of 0.81 cm; additionally, it has that the worst performance against the carbonation due to the environment of Xalapa city was presented for the specimen SC50-P with a deepness of 1.37 cm after one year of exposition.

IV. Conclusions

The Conventional Concrete made with 100% Portland Cement presented in the front and posterior section the lowest carbonation deepness and as a result it presented an average, between the two sections, of 0.33 cm of carbonation depth.

The sustainable concretes with 10 and 20% of SCBA and SF, presented an average on its carbonation depth of 0.55 and 0.44 cm, respectively. Which represents an increment of the 67 and 33% in relation to the conventional concrete.

At incrementing the substitution in 30 and 40% of Portland Cement for the agro-industrial and industrial waste (SCBA and SF), the sustainable concretes SC30 and SC40 presented a carbonation depth of 0.85 cm and 0.76 cm, respectively. These values represented an increment of more of the 160% with respect to the conventional concrete.

The sustainable concrete with 50% of substitution of SCBA-SF presents the worst performance, reporting a carbonation depth of 1.48 cm in average of the two sections, frontal and posterior, which represents an increment of more of the 350% than the conventional concrete.

It has that in the sustainable concretes based on agro-industrial and industrial waste (SCBA and SF) which had been exposed to the environment of the City of Xalapa, Ver; Mexico for a year, the resistance to the carbonation decreased in accordance to the percentage of substitution of the Portland cement presented in the mentioned concretes.

Consequently, it is recommended the use of the sustainable concretes based on SCBA and SF as substitutes of the Portland Cement, between a 10 and 20%.

For the use of the sustainable concretes with substitutions of 30, 40 and 50% it is recommended to apply a coating or protection on them, in order to increase its resistance to the attacks of CO_2 and reaching its useful life of design.

Acknowledgment

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

References

[1] Rabi M. Bond prediction of stainless-steel reinforcement using artificial neural networks. *Proceedings of the ICE - Construction Materials.* 2023;176(2):1-11. DOI: 10.1680/jcoma.22.00098.

[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] Zhang C, Zhu M, Xu K, Yuan Y, Guo S, Wei G. Effect of HSO3− and alternating current on corrosion behaviour and mechanism of CoCrFeNi HEA in a simulated marine environment. *Corrosion Engineering, Science and Technology,* 2023;58:2190443. DOI: 10.1080/1478422X.2023.2190443.

[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] 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.

[6] Santiago-Hurtado G, Baltazar-Zamora MA, Galván-Martínez R, López LLD, Zapata GF, 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.

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] Jáquez-Muñoz JM, Gaona-Tiburcio C, Méndez-Ramírez CT, Baltazar-Zamora MA, Estupinán-López F, Bautista-Margulis RG, Cuevas-Rodríguez J, Flores-De los Rios JP, Almeraya-Calderón FM. Corrosion of Titanium Alloys Anodized Using Electrochemical Techniques. *Metals*, 2023;13(3):476. DOI: 10.3390/met13030476.

[12] 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.

[13] 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.

[14] Baltazar-Zamora MA, Santiago-Hurtado G, Moreno LVM, Croche BR, de la Garza M, Estupiñan LF, Zambrano RP, *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.

[15] Sakai T, Inukai S, Inagaki M, Nakano M. Improvement in seismic resistance using replacement/counterweight fill method for existing high embankments on inclined ground constructed with various embankment materials. *Soils and Foundations,* 2023;63(2):1-14. DOI: 10.1016/j.sandf.2023.101284.

[16] 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.

[17] 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.

[18] Zapata-Padilla JR, Juárez-Alvarado CA, Durán-Herrera A, Baltazar-Zamora MA, Terán-Torres BT, Vázquez-Leal FR, Mendoza-Rangel JM. Portland Cement-Based Grouts Enhanced with Basalt Fibers for Post-Tensioned Concrete Duct Filling. *Materials,* 2023;16(7):2842. DOI: 10.3390/ma16072842

[19] 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.

[20] 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.

[21] 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.

[22] 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.

[23] 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.

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

[25] 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.

[26] Raczkiewicz W, Wójcicki A. Temperature impact on the assessment of reinforcement corrosion risk in concrete by galvanostatic pulse method. *Applied Sciences,* 2020;10(3):1-13. DOI: 10.3390/app10031089.

[27] 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.

[28] 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.

[29] 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.

[30] 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.

[31] 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.

[32] 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.

[33] 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.

[34] Raczkiewicz W, Bacharz M, Bacharz K, Teodorczyk M. Reinforcement Corrosion Testing in Concrete and Fiber Reinforced Concrete Specimens Exposed to Aggressive External Factors. *Materials,* 2023;16(3):1174. DOI: 10.3390/ma16031174.

[35] Baltazar-Zamora MA, Maldonado-Bandala E, Loya Tello MU, Santiago-Hurtado G, Olguín Coca FJ, Ortiz-Cedano A, Barrios DCP, *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] Baltazar-García BP, Baltazar-Zamora DF, Landa-Ruiz L, Méndez CT, Santiago-Hurtado G, Moreno-Landeros V, Croche R, Baltazar-Zamora MA. Electrochemical Corrosion in Bars of AISI 304 Embedded in Concrete Immersed in Marine-Sulfated Environment. *European Journal of Engineering and Technology Research,* 2023;8(1):13-18. DOI: 10.24018/ejeng.2023.8.1.2942.

[37] 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.

[38] 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.

[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] Ewa DE, Egbe EA, Ukpata JO, Etika A. Sustainable subgrade improvement using limestone dust and sugarcane bagasse ash. *Sustainable Technology and Entrepreneurship*, 2022;2:1-8. DOI: 10.1016/j.stae.2022.100028.

[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] Nikhade H, Birali RRL, Ansari K, Khan MA, Najm HM, Anas SM, Mursaleen M, *et al.* Behavior of geomaterial composite using sugar cane bagasse ash under compressive and flexural loading. *Frontiers in Materials*, 2023;10:1-17. DOI: 10.3389/fmats.2023.1108717.

[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] 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 MgSO4. *Materials (Basel)*, 2020;13(10):1-16. DOI: 10.3390/ma13102412.

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

[48] 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.

[49] 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.

[50] 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.

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

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

[53] 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.

[54] 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.

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

[56] 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.

[57] 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.

[58] Santiago-Hurtado G, Maldonado-Bandala EE, Olguin Coca FJ, Almeraya-Calderón F, Torres-Acosta A, Baltazar-Zamora MA. Electrochemical Behavior of Reinforced Concrete and Its Relation With the Environment of Xalapa, Veracruz. *International Journal of Electrochemical Science.* 2012;7(10): 9825 - 9834.