Evaluation of the Behavior of The Physical and Mechanical Properties of Green Concrete Exposed to Magnesium Sulfate

Laura Landa-Ruiz, Hilda Ariza-Figueroa, Griselda Santiago-Hurtado, Victor Moreno-Landeros, Raul López Meraz, Rafael Villegas-Apaez, Sabino Márquez-Montero, René Croche, and Miguel Angel Baltazar-Zamora

***Abstract* — In the present research work, four concrete mixtures were designed according to the ACI 211.1 method, the first as a control mixture, with 100% CPC, and the remaining three elaborated with partial replacement of the CPC by combinations of Sugar Cane Bagasse Ash and Silica Fume (SCBA-SF) in 10%, 20% and 30% (Green Concrete). The tests carried out on the four mixtures were physical properties (Slump, Temperature, Density) and mechanical properties as Compressive Strength (F'c) and Modulus of Elasticity, according to the ASTM and ONNCCE standards, the study specimens were exposed in water, as a control medium and a 3.5% solution of $MgSO_4$ as an aggressive medium for a period of 28 days. The results obtained indicate a good performance of the Green Concrete in comparison with the control mixture, in particular the Green Concrete made with 10% and 20% substitution of CPC by SCBA-SF.**

***Index Terms* — Green Concrete, Compressive Strength (F'c), Modulus of Elasticity, SCBA-SF, $MgSO_4$.**

I. Introduction

Hydraulic concrete is the most widely used construction material worldwide, mainly due to its physical, mechanical properties, durability, etc., and that together with reinforcing steel it is possible to build Civil Works indispensable for the development of our societies [1]-[6], as are bridges, buildings, pavements, etc. However, the production of Portland Cement generates between 5% and 8% of carbon dioxide emissions to the environment. For this reason, they have tried to find solutions that delay or reduce the emissions of CO_2 produced by the cement industry in the world. In the present research, Sugar Cane Bagasse Ash (SCBA) and Silica Fume (SF) were used as alternative materials to Portland Cement due to their pozzolanic characteristics [7], [8], in addition It is known that one of the major problems of the integrity of reinforced concrete structures is the corrosion of steel [9]-[14], but it has been reported that the use of this type of pozzolanic materials increases the corrosion resistance of concrete reinforcing steel exposed to aggressive media such as sulfate and chloride ions and contribute to a reduction in CO_2 emissions, concrete that are considered sustainable, ecological or green [15]-[20]. Four concrete mixes were designed in accordance with ACI 211.1, the first being 100% CPC and the remaining three were made with partial substitutions in percentages of 10%, 20% and 30% of the CPC by combinations of CBCA and HS After its performance, they were placed in two different media, control medium (drinking water) and a 3.5% $MgSO_4$ solution, and tests of F´c and Modulus of elasticity performed at 7, 14 and 28 days.

Published on November 21, 2016.
Laura Landa-Ruiz, Universidad Veracruzana, México.
(e-mail: lalanda@uv.mx)
Hilda Ariza-Figueroa, GEOTEST S.A. de C.V., México.
(e-mail: hilda_af@hotmail.com)
Griselda Santiago-Hurtado, Universidad Autónoma de Coahuila, México.
(e-mail: grey.shg@gmail.com)
Victor Moreno-Landeros, Universidad Autónoma de Coahuila, México.
(e-mail: vmmorlan@gmail.com)
Raul Alberto López Meraz, Universidad Veracruzana, México.
(e-mail: raullopez03@uv.mx)
Rafael Villegas-Apaez, Ingenio Mahuixtlán S.A de C.V, Loc., México.
(e-mail: rafaelvillegas23@hotmail.com)
Sabino Márquez-Montero, Universidad Veracruzana, México.
(e-mail: smarquez@uv.mx)
René Croche, Universidad Veracruzana, México.
(e-mail: recroche@uv.mx)
Miguel Angel Baltazar-Zamora, Universidad Veracruzana, México.
(e-mail: mbaltazar@uv.mx)

II. Materials and Methods

A. Materials

1) Characterization of physical properties of aggregates

TABLE I: CHARACTERIZATION OF THE AGGREGATES

Physical properties of materials	Coarse aggregate	Fine aggregate
Specific Mass (MES) g/cm³	2.60	2.20
Bulk Volumetric Mass (BVM) Kg / cm³	1332	-
Absorption (%)	1.7	1.90
Module of Fineness	-	2.90
Maximum Size Nominal (TMN)	¾ "	-

The dosage of the concrete mixtures was according to the ACI 211.1 standards [21], which mainly takes into account the compressive strength (F'c), the slump (workability or consistency), maximum aggregate size, in addition to the characterization of the physical properties of the fine and coarse aggregates. The physical properties of the Coarse Aggregate and Fine Aggregate that were used for the elaboration of the concrete mixtures were determined, the tests were carried out in accordance with the ASTM standards [22]-[25], and the results are shown in Table I.

2) Dosage and proportioning of concrete mixtures

Four hydraulic concrete mixtures were made for a compressive strength of F´c = 300 kg/cm^2 at 28 days. The Portland Cement used was type CPC 30R [26]. The first mixture was called a control mix, which was made with 100% CPC 30R and the remaining three considered GC made with partial substitutions in 10%, 20% and 30% of the CPC 30R by combinations OF SCBA-SF. Table II shows the proportioning that was used for each mixture.

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

Materials	F´c = 300 kg/cm^2 at 28 days			
	100% CPC	10% SCBA-SF	20% SCBA-SF	30% SCBA-SF
Water	197.80	200.60	203.16	206.71
Cement	314.61	284.05	252.51	220.96
SCBA	0	15.78	31.56	47.36
SF	0	15.78	31.56	47.36
Coarse aggregate	886	888	884	881
Fine aggregate	770	771	773	773

B. Method

1) Physical properties of concrete mixtures (Conventional and Green Concrete)

According to the tests of the ONNCCE and ASTM standards, the characteristics of the four concrete mixtures (Conventional Concrete and Green Concrete) were determined in a fresh state. The Slump (NMX-C-156-ONNCCE-2010) [27], Temperature (ASTM C 1064/C1064M–08) [28] and Density (NMX-C-162-ONNCCE-2014) [29], obtaining the results shown in table III.

TABLE III: PHYSICAL PROPERTIES OF GREEN CONCRETE

TEST	100% CPC	10% SCBA-SF	20% SCBA-SF	30% SCBA-SF
Slump (cm)	7.0	6.0	5.5	5.0
Temperature (°C)	24.0	23.5	23.5	22.5
Density (kg/m^3)	2346	2307	2301	2276

2) Mechanical properties of Conventional Concrete and Green Concrete

The tests of that were carried accordance with NMX-C-083-ONNCCE-2014 [30], NMX-C-128-ONNCCE-2013 [31], the name of the test and the specific standard are presented in table IV.

TABLE IV: GREEN CONCRETE TESTS IN HARDENED STATE

TEST	STANDAR
Compressive strength	NMX-C-083-ONNCCE-2014
Modulus of elasticity	NMX-C-128-ONNCCE-2013

3) Characteristics and nomenclature of test specimens

Specimens were made for each concrete mix and placed in two different media, which were denoted by the following nomenclature established in Table V.

TABLE V: SPECIMEN NOMENCLATURE.

Mixture	Exposure environment	
MC	1	2
M10		
M20		
M30		

- MC; Control (100% CPC 30R).
- M10: Green Concrete (5% SCBA-5% SF).
- M20: Green Concrete (10% SCBA-10% SF).
- M30: Green Concrete (10% SCBA-10% SF).
- 1: Control medium (water).
- 2: 3.5% $MgSO_4$ solution.

III. RESULTS AND DISCUSSION

A. Compressive Strength in kg/cm^2

Fig. 1 shows the compressive strength results of the four study mixtures, one of normal concrete (100% CPC 30R) and the remaining three of green concretes based on partial replacement of CPC 30R by combinations of SCBA-SF in 10, 20 and 30%, the tests were at 7, 14 and 28 days as indicated by the NMX-C-083-ONNCCE-2014, in that period the specimens were immersed in the control medium (water) and in the aggressive medium (3.5% $MgSO_4$ solution).

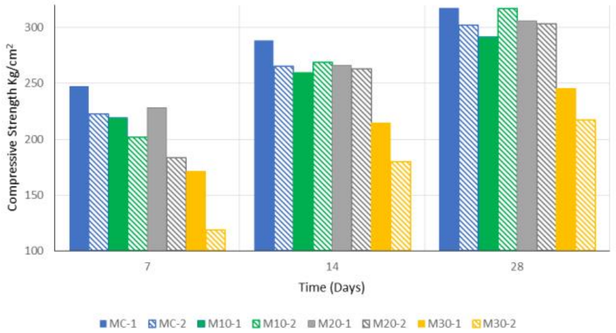

Fig. 1 F'c of the specimens exposed control medium (water) and 3.5% $MgSO_4$ solution.

When carrying out the analysis of the results, we observe that all the mixtures present an increase in compressive strength, F´c, with the passage of time. The MC-1 specimen presents the best performance with the highest values compared to the other mixtures, obtaining 247.50 kg/cm^2 after seven days of curing, increasing to 288.47 kg/cm^2 on day 14, reaching 317.84 kg/cm^2 after 28 days. The specimen MC-2 presents an F'c of 222.53 kg/cm^2 in the first 7 days and subsequently reaches a value of 265.40 kg/cm^2 and ends at 28 days with 302.16 kg/cm^2, reaching a resistance higher than expected of F´c = 300 kg/cm^2 at 28 days. With regard to Green Concrete mixtures, very favorable results are obtained in mixtures M10-1, M10-2, M20-1 and M20-2, with a F'c in 7 days of 219.54 kg/cm^2, 201.57 kg/cm^2, 228.51 kg/cm^2 and 183.39 kg/cm^2 respectively, to report at 28 days, in the same order F´c of 291.84 kg/cm^2, 316.92 kg/cm^2, 305.91 kg/cm^2 and 303.16 kg/cm^2. The Green Concrete identified as M30 presented the lowest performance, with values at 28 days of 245.44 kg/cm^2 and 217.08 kg/cm^2, for control medium (water) and the aggressive medium (3.5% $MgSO_4$ solution). Even so, both meet the resistance to be used in load and support elements such as columns and beams of any civil work, which means that even concrete with 30% replacement of the CPC by agro-industrial and industrial waste (SCBA-SF) is feasible use them taking into account the mechanical resistance obtained in the compression test, F´c, which is the value used in the design of the elements of the works built with reinforced concrete to date, the least in Mexico.

B. Modulus of Elasticity

The Modulus of Elasticity test was carried out on specimens of the 4 concrete mixtures elaborated for the present investigation, one as normal concrete and the remaining three considered ecological concretes due to the substitution of CPC by combinations of SCBA-SF, the test was carried out at an age of 28 days, according to the standard NMX-C-128-ONNCCE-2013, obtaining the results shown in Fig. 2.

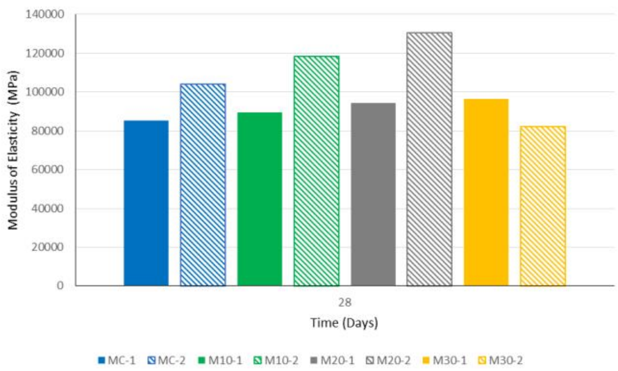

Fig. 2. Modulus of elasticity specimens exposed control medium (water) and 3.5% $MgSO_4$ solution.

The figure shows the results of the different concrete mixtures, tested at the age of 28 days, it is observed how the mixtures MC-2, M10-2, M20-2, exposed to the aggressive environment presented a better performance than the mixtures exposed or control medium (water), and it can be identified that in the control medium there is also a better performance in the Modulus of Elasticity by the three Green Concrete mixtures, M10-1, M20-1, M30-1, having all three values greater than the MC-1 control mix. It is concluded that in the Modulus of Elasticity test the Green Concrete mixtures (10, 20 and 30% of SCBA-SF), present better performance than the conventional or normal concrete, made with 100% CPC.

IV. Conclusions

Regarding the compression resistance test, conventional concrete (100% CPC 30R), presents resistance according to the design of the mixture, F´c = 300 kg/cm^2.

With regard to Green Concrete mixtures, very favorable results are obtained in mixtures M10-1, M10-2, M20-1 and M20-2, with a F'c at 28 days, of 291.84 kg/cm^2, 316.92 kg/cm^2, 305.91 kg/cm^2 and 303.16 kg/cm^2 respectively, being values very close to the control mixture MC-1. With only a difference of 6% of the Green Concrete that obtained the lowest resistance at 28 days M10-1, with respect to the Conventional Concrete mix that obtained the highest resistance MC-1.

In the Modulus of Elasticity test of Green Concrete mixtures (10, 20 and 30% of SCBA-SF), all present better performance than the conventional or normal concrete, made with 100% CPC.

According to the results obtained, all the Green Concrete mixtures M10, M20 and M30 analyzed in this study, comply with the mechanical properties F´c and Modulus of Elasticity to be used in load and support elements as columns and beams of any great civil works, which means that even concrete with 30% replacement of the CPC by agro-industrial and industrial waste (SCBA-SF) is feasible to use them for civil infrastructure. It is recommended, despite the favorable mechanical results obtained, to carry out Durability evaluations in the case of aggressive media where such civil works could be built.

Acknowledgment

MA Baltazar-Zamora, et. al., thank PRODEP for the support granted by the SEP, the Academicians UV-CA-458 "Sustainability and Durability of Materials for Civil Infrastructure" under the Call 2018 for Strengthening Academic Bodies with IDCA 28593.

References

[1] O. Troconis de Rincón et. al., (2016). Reinforced Concrete Durability in Marine Environments DURACON Project: Long-Term Exposure. Corrosion, 72:6, pp. 824-833.

[2] Miguel Angel Baltazar-Zamora, Laura Landa-Ruiz, Yazmin Rivera, René Croche. (2020). Electrochemical Evaluation of Galvanized Steel and AISI 1018 as Reinforcement in a Soil Type MH. European Journal of Engineering Research and Science, 5:3, pp. 259-263.

[3] M. Criado, D.M. Bastidas, S. Fajardo, A. Fernández-Jiménez, J.M. Bastidas. (2011). Corrosion behaviour of a new low-nickel stainless steel embedded in activated fly ash mortars. Cement and Concrete Composites, 33, pp. 644-652.

[4] A. Landa-Gómez et.al., (2018). Correlation of Compression Resistance and Rupture Module of a Concrete of Ratio w/c= 0.50 with the Corrosion Potential, Electrical Resistivity and Ultrasonic Pulse Speed. ECS Transactions. 84, 217-227.

[5] D.M. Bastidas, M. Criado, S. Fajardo, A. La Iglesia, J.M. Bastidas. (2015). Corrosion inhibition mechanism of phosphates for early-age reinforced mortar in the presence of chlorides. Cement and Concrete Composites, 61, pp. 1-6.

[6] G. Santiago-Hurtado, M.A. Baltazar-Zamora, A. Galindo D, J.A. Cabral M, F.H. Estupiñán L., P. Zambrano Robledo, C. Gaona-Tiburcio. (2013). Anticorrosive Efficiency of Primer Applied in Carbon Steel AISI 1018 as Reinforcement in a Soil Type MH. International Journal of Electrochemical Science, 8:6, pp. 8490-8501.

[7] M.K. Yashwanth, B.G. Naresh Kumar, D.S. Sandeep Kumar. (2019). Potential of Bagasse Ash as Alternative Cementitious Material in Recycled Aggregate Concrete. International Journal of Innovative Technology and Exploring Engineering, 8:11, pp. 271-275.

[8] O. Ojeda-Farías, J.M. Mendoza-Rangel, M.A. Baltazar-Zamora. (2018). Influence of sugar cane bagasse ash inclusion on compacting, CBR and unconfined compressive strength of a subgrade granular material. Revista ALCONPAT, 8:2, pp. 194-208.

[9] M.A. Baltazar-Zamora, G. Santiago-Hurtado, V.M. Moreno L, R. Croche B, M. de la Garza, F. Estupiñan L, P. Zambrano R., C. Gaona-Tiburcio. (2016). Electrochemical Behaviour of Galvanized Steel Embedded in Concrete Exposed to Sand Contaminated with NaCl. International Journal of Electrochemical Science, 11:12, pp. 10306-10319.

[10] M.A. Baltazar-Zamora, G. Santiago-Hurtado, C. Gaona-Tiburcio et. al. (2012). Evaluation of the corrosion at early age in reinforced concrete exposed to sulfates. International Journal of Electrochemical Science, 7:1, pp. 588-600.

[11] Miguel Angel Baltazar-Zamora, Sabino Márquez-Montero, Laura Landa-Ruiz, René Croche, Oscar López-Yza. (2020). Effect of the type of curing on the corrosion behavior of concrete exposed to urban and marine environment. European Journal of Engineering Research and Science, 5:1, pp. 91-95.

[12] G. Santiago-Hurtado et. al. (2016). Electrochemical Evaluation of Reinforcement Concrete Exposed to Soil Type SP Contaminated with Sulphates. International Journal of Electrochemical Science, 11:6, pp. 4850-4864.
[13] M.A. Baltazar-Zamora et. al. (2012). Efficiency of Galvanized Steel Embedded in Concrete Previously Contaminated with 2, 3 and 4% of NaCl. International Journal of Electrochemical Science, 7:4, pp. 2997-3007.
[14] Miguel Angel Baltazar-Zamora, José Manuel Mendoza-Rangel, René Croche, Citlalli Gaona-Tiburcio, Cindy Hernández, Luis López, Francisco Olguín, Facundo Almeraya-Calderón. (2019). Corrosion Behavior of Galvanized Steel Embedded in Concrete Exposed to Soil Type MH Contaminated with Chlorides. Frontiers in Materials, 6, pp. 1-12.
[15] A. Landa-Gómez et.al., (2018). Corrosion Behavior 304 and 316 Stainless Steel as Reinforcement in Sustainable Concrete Based on Sugar Cane Bagasse Ash Exposed to Na_2SO_4. ECS Transactions. 84, pp. 179-188.
[16] M.A. Baltazar-Zamora, D.M. Bastidas, G. Santiago-Hurtado, J.M. Mendoza-Rangel, C. Gaona-Tiburcio, J.M. Bastidas, F. Almeraya-Calderón. (2019). 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), 12:23, pp. 1-13.
[17] G. Santiago-Hurtado et. al. (2016). Electrochemical Evaluation of a Stainless Steel as Reinforcement in Sustainable Concrete Exposed to Chlorides. International Journal of Electrochemical Science, 11:4, pp. 2994-3006.
[18] Miguel Angel Baltazar-Zamora, Hilda Ariza-Figueroa, Laura Landa-Ruiz, and René Croche. (2020). 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, 5:3, pp. 353-357.
[19] Hilda A. Ariza-Figueroa et. al. (2020). Corrosion Behavior of AISI 304 Stainless Steel Reinforcements in SCBA-SF Ternary Ecological Concrete Exposed to $MgSO_4$. Materials (Basel), 13:10, pp. 1-16.
[20] Abigail Landa-Sánchez et. al. (2020). Corrosion Behavior of Steel-Reinforced Green Concrete Containing Recycled Coarse Aggregate Additions in Sulfate Media. Materials (Basel), 13:19, pp. 1-22
[21] ACI. Provision of mixtures, normal concrete, heavy and massive ACI 211.1, p. 29. Ed. IMCYC, México (2004).
[22] ASTM C29 / C29M–07–Standard Test Method for Bulk Density ("Unit Weight") and Voids in 412 Aggregate; ASTM International, West Conshohocken, PA, 2007, www.astm.org.
[23] ASTM C33/C33M–16e1–Standard Specification for Concrete Aggregates; ASTM International, 414 West Conshohocken, PA, 2016, www.astm.org.
[24] ASTM C127–15–Standard Test Method for Relative Density (Specific Gravity) and Absorption of 416 Coarse Aggregate; ASTM International, West Conshohocken, PA, 2015, www.astm.org.
[25] ASTM C128–15–Standard Test Method for Relative Density (Specific Gravity) and Absorption of 418 Fine Aggregate; ASTM International, West Conshohocken, PA, 2015, www.astm.org.
[26] NMX-C-414-ONNCCE 2014: Cementantes Hidráulicos. ONNCCE, S.C.; Mexico 2014.
[27] NMX-C-156-ONNCCE-2010: Determinación del revenimiento en el concreto fresco. ONNCCE S.C., México, (2010).
[28] ASTM C 1064/C1064M–08–Standard Test Method for Temperature of Freshly Mixed Hydraulic-426 Cement Concrete; ASTM International, West Conshohocken, PA, 2008, www.astm.org.
[29] 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).
[30] NMX-C-083-ONNCCE-2014: Determinación de la resistencia a la compresión de especímenes – Método de prueba, ONNCCE S.C., México, (2014).
[31] NMX-C-128-ONNCCE-2013: Determinación del Modulo de Elasticidad Estático y Relación de Poisson, ONNCCE S.C., México, (2013).