Electrical-mechanical analysis of a cement paste electrically conductive by the addition of carbon fiber

ABSTRACT: A paste of concrete with conductive capabilities becomes a multifunctional materials and would replace the technical applications that have been developed to solve problems of durability and repair in the structures. The carbon fiber (FC) have characteristics of electrical conductivity (EC) that the adicionarla into a paste of Portland cement (CP) conventional modifies the EC in the paste. The main goal of our work was to develop a conductive cement paste (PCC) for the protection and repair of reinforced concrete structures, for which produced two types of cubical specimens with dimensions 50x50x50 mm for testing of paste to compression and prismatic specimens of 40x40x160 mm to determine the EC by the method of Wenner. Different proportions were made by varying the size and proportions of the FC to identify the metering that provides more EC without negatively affecting the resistance to compression. The percolation threshold for a PCC of electricity with the addition of FC is presented for a percentage of 0.9% with respect to the volumetric fraction of the specimen and in a size of 5 mm in length with a resistance to compression of 25 MPa, this threshold has not altered the mechanical resistance of a conventional paste.

Keywords: carbon fiber, durability, threshold-percolation, carbonaceous material, resistance.

Colaboratión
E.D. Perez-Diaz, Universidad Veracruzana; Luis Carlos Sandoval Herazo, Instituto Tecnológico Superior de Misantla, Emma Garcés Velázquez; Erick Edgar Maldonado Bandala; Sergio Aurelio Zamora Castro, Universidad Veracruzana; Luis Carlos Sandoval Herazo, Colegio de Veracruz

INTRODUCTION

The durability of concrete is an important property and fundamental, it is essential that the concrete structure is able to withstand the conditions for which it has been designed throughout its useful life. The short durability may be caused by external agents derived of the environment or by internal agents in the middle of the concrete [1].

When a structure of reinforced concrete (CA) is in an aggressive atmosphere being attacked by external agents or is in a critical state of deterioration, causing structural failures, it is necessary to establish an appropriate solution to neutralize the attack and prolong the life of the structure. The development of new types of anodes for the protection and repair of structures of CA is a topic of great technological interest [2]. The natural protection against the corrosion of steel reinforcement on concrete (layer of passivity) is usually lost due to the entry of chloride ions or by the carbonation of concrete. The electrochemical removal of chlorides (EEC) and electrochemical realkalisation are techniques used in the repair of concrete structures due to the above problems [3].

Currently we have developed new rehabilitation techniques with the objective to implement actions more efficient and economical. The electrochemical method of removal of chlorides (EEC) with mortars drivers is an example, has been used in the rehabilitation of structures CA, replacing the titanium mesh in the technique of EEC [4]. This technique is based on the use of the electrolysis system for the removal of the chlorides present in the concrete. The Chlorides (Cl-) are negatively charged ions. Through the continuous flow of current between the frame, which acts as a cathode (connects to the negative pole of the power supply), and a provision external, serving as the anode (connects to the positive pole of the power supply), force the chlorides to move outward through the porous structure of concrete by the action of the electric field created. So it is not necessary to replace the contaminated concrete and once removed a sufficient amount of chlorides, increases the durability of the structure [5].

Despite the existence of different studies with the purpose of improving the conductive property of a paste or mortar adding carbonaceous material; in Mexico there are few studies focusing on the proportions and optimal sizes of FC as part of added, generating a better behavior of EC and together with this while maintaining the properties of resistance to compression.

The carbon fiber has properties of EC, the addition of this material in a paste of CP intensifies considerably the EC in the paste, without negatively affecting the resistance to the axial compression with an optimal size and dosage determined in FC.

The objective of this research is to study the mechanical and electrical behavior of a cementitious paste with the addition of conductive material carbonaceous, (which in the development of this research project is to select for FC), through testing and pilot tests standardized to provide effective results and information and sufficient to characterize and analyze the new conductive properties and mechanical pulp to incorporate the fibers.

MATERIAL AND METHODS

The methodology consists of experimental test, following a phased and orderly planning in order to obtain a characterization truthful. The tests that are presented here are governed by international standards ASTM (American Society for Testing Material). In the Table 1 sets out the main materials used for the realization of this research.

Table 1. Main materials used in this investigation.

Equipment or material	Specifications
Portland cement	(CPC 30R), cement of rapid forged, obtaining their f'c to 14 days of age.
Carbon fiber	Crossweave in the form of fabric, high resistance. Fiber diameter 7.2 μm, carbon content of 95%, density 1.81 g/cm^3.
Balance	Digital scale with accuracy of 0.01 g
Mold for compression	Metal mold for cubes with dimensions of 50x50x50 mm.
Mold for EC	Metal mold for beams with dimensions of 40x40x160 mm
Mixing machine	Blender mark Hobart model N50.
Copper	Sheets of 40 mm long and wires 40 mm long
Universal machine	Equipment for performing the test to axial compression. Control brand, model pilot 4.
GECOR 10	Special equipment to obtain and evaluate measures to determine the corrosion as well as electrical resistivity in concrete.

Researchers have concluded that the most important variable for a specific high resistance is the water/cement ratio (A/C). The respective proporcionamientos aggregates in the paste is made with respect to the weight of cement and established a A/C relation of 0.5 following the rule set:

$$\text{A/C ratio} = \frac{\text{Litres of water}}{\text{Kilograms of cement}} 0.5 \qquad \text{Ec. (1)}$$

a) Dosage of the Mixtures

To determine the proportions of water, cement and FC you must know the volume of the two types of specimens, therefore, is divided into two parts, to determine the EC will require specimens in the form of beam with the dimensions set out above (see Table 1); on the other hand, the specimens that correspond to the test of resistance to the axial compression (f'c), where specimens are established in the form of cubes with dimensions mentioned above (Table 1).

Proportion water and cement for beams of 40x40x160 mm:

Total volume of the specimen (v) = 256 cm^3
Water/cement ratio A/C= 0.5
Weight of Water (unknown) = Wh_2O
Weight of cement (unknown) = W_C
ℓh_2O=specific weight of water = 1
ℓc = specific weight of cement = 3.15

Therefore, $$V = \frac{Wh_2\,O}{\ell h_2\,O} + \frac{W_c}{\ell_c} \qquad \text{Ec. (2)}$$

Where, $$\frac{Wh_2\,O}{W_c} = 0.5 \qquad \text{Ec. (3)}$$

Then replacing Ec. (3) in Ec. (2):

$$v = \frac{0.5\,W_c}{\ell h_2 O} + \frac{W_c}{\ell c}$$

$$v = \frac{0.5\,Wc\,\ell c + Wc\,\ell h_2 O}{\ell h_2 O\,\ell c}$$

$$v = \frac{Wc}{\ell_c}(0.5+1)\ell c$$

Knowing all the data then,

$$256\ \text{cm}^3 = \frac{Wc\,(2.575)}{3.15}$$

Clearing the weight of cement,

$$Wc = \frac{256 \; x \; 3.15}{2.575}$$

$$\text{Wc} = 313.1650 \text{ g} + 10\% \text{ (waste)}$$

$$\text{Wc} = 313.1650 * 1.10$$

$$\text{Wc} = 344.487 \text{ g}$$

$$\text{Wh}_2\text{O} = 156.5830 \text{ g} + 10\% \text{ (waste)}$$

$$\text{Wh}_2\text{O} = 156.5830 * 1.10$$

$$\text{Wh}_2\text{O} = 172.2435 \text{ g}$$

The data previously calculated, correspond to the proportion of water and cement, in a relationship 0.5, which is required to make the pouring of the specimens in the form of beam. The specimens of control does not carry the addition of FC, i.e. that the specimens shall be of conventional paste with the purpose of comparing the results of EC and resistance to the axial compression with the altered with FC.

Proportion of FC for beams:

For a characterization of the electrical behavior of the beams with FC, account should be taken of the threshold of percolation, i.e. to study and compare the EC with different sizes and quantities of FC, so as to establish the optimal dosage that best conductive behavior has without affecting the mechanical resistance of the paste.

Are chosen sizes from 5, 10 and 20 mm in length, in addition for each size of FC have different amounts in percentage with respect to the volumetric fraction. These percentages are 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0.

The dosages of cement (WC) and water (Wh_2O) for the paste with the incorporation of FC remain the same that previously were calculated, for each mix concrete. Table 2 summarizes the different proportions.

Example for calculating the quantities of FC:
Input data:

Percentage of FC (%FC) = 0.5%
Volume of the beam (V) = 256 cm^3
Density FC (DF)= 1.81 g/cm^3

Unknown:

Weight of FC (WFC) = Wc*(%FC)*DF

Then,

$$\text{WFC} = 256 \text{ g} * 0.005 * 1.81$$
$$\text{WFC} = 2.3168 \text{ g}$$

For the sizes of FC 10 and 20 mm, shall be the same dosages, therefore, is not displayed and obvious demonstration of calculations.

Three specimens were made by each mixture, i.e. three specimens for each percentage of FC, with the objective of having repeatability and average the results of the tests.

Nomenclature

F 0.5-1'

FC orden of the specimen

% 0.5 FC

Size of FC

Proportion water and cement cubes 50x50x50 mm:

The procedure for calculating the different proportions of water and cement, both for specimens of control as to be modified with the addition of FC is similar to that used in the beams.

Total volume of the specimen (v) = 125 cm^3
You use the Ec. (2) and Ec. (3)

$$\text{Wc} = 168.201 \text{ g}$$
$$\text{Wh}_2\text{O} = 84{,}1005 \text{ g}$$

Table 2. Proportion of FC For the different specimens in the form of beam.

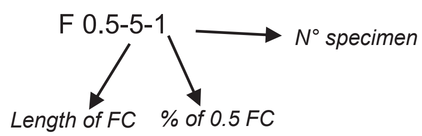
Proportionbeams with FC of 5 mm

Specimens	% FC	WFC
F0.5-1'	0.5	2.32
F0.5-1"	0.5	2.32
F0.5-1"'	0.5	2.32
Total		**6.95**
F0.5-2'	0.6	2.78
F0.5-2"	0.6	2.78
F0.5-2"'	0.6	2.78
Total		**8.34**
F0,5-3'	0.7	3.24
F0.5-3"	0.7	3.24
F0.5-3"'	0.7	3.24
Total		**9.73**
F0.5-4'	0.8	3.71
F0.5-4"	0.8	3.71
F0.5-4"'	0.8	3.71
Total		**11.12**
F0.5-5'	0.9	4.17
F0.5-5"	0.9	4.17
F0.5-5"'	0.9	4.17
Total		**12.51**
F0.5-6'	1.0	4.63
F0.5-6"	1.0	4.63
F0.5-6"'	1.0	4.63

The amount of water and cement is kept constant for all specimens in the form of a cube.

Proportion of FC for hubs:

We used the same dosages (size and percentages of FC) as those used in the beams, therefore, the procedure to determine the weight of FC should be added in each specimen is similar to the previous calculation, Table 3 presents the different dosages of FC. x
Nomenclature:



b) Elaboration of the pastes conductive cement
The development of the different mixtures and the conduct of the trials was conducted in the laboratory of materials of postgraduate courses of the Universidad Veracruzana. The mixing for the creation of the specimens of control was produced on the basis of the ASTM C-305-10 [6].

This same rule was used to develop the paste with the addition of FC, highlighting the following steps, standardized by the authors, before the mixed with CP:

The dosage of FC must be pour in the water and wait 30 s to absorb a certain amount of water.

At the end of the 30 s, with the industrial mixing is shaken by 60 s.

It originates in the established in the ASTM C-305-10.

c) Casting and creation of specimens
To create the specimens, were added the mixture to a maximum height of 30 to 55 mm in the molds. First adds a layer of pulp up to half the height of the mold with the goal of migrating the air bubbles compacting this layer. The compaction consists in 80 strokes per layer on the entire mixture, was carried out with a rubber ram as advised in the rules.

Table 3. Proportion of FC for the different specimens in the form of cubes

Proportion FC hubs of 0.5 mm

Specimens	%FC	WFC
F0.5-10-1	1.0	2.26
F0.5-10-2	1.0	2.26
F0.5-10-3	1.0	2.26
F0.5-10-4	1.0	2.26
F0.5-10-5	1.0	2.26
F0.5-10-6	1.0	2.26
Total		**13.58**

Finished the previous process, proceeded to the second layer of paste followed by the corresponding compaction in the same manner as the first.

The design of the specimens to the test of mechanical resistance to axial compression was produced on the basis of the American standard in force ASTM C-109-99 [7], which indicates the procedure the preparation of specimens for mortars.

Proportion FC hubs of 0.5 mm

Specimens	% FC	WFC
F0.5-5-1	0.5	1.131
F0.5-5-2	0.5	1.131
F0.5-5-3	0.5	1.131
F0.5-5-4	0.5	1.131
F0.5-5-5	0.5	1.131
F0.5-5-6	0.5	1.131
Total		**6.789**
F0.5-6-1	0.6	1.36
F0.5-6-2	0.6	1.36
F0.5-6-3	0.6	1.36
F0.5-6-4	0.6	1.36
F0.5-6-5	0.6	1.36
F0.5-6-6	0.6	1.36
Total		**8.15**
F0.5-7-1	0.7	1.59
F0.5-7-2	0.7	1.59
F0.5-7-3	0.7	1.59
F0.5-7-4	0.7	1.59
F0.5-7-5	0.7	1.59
F0.5-7-6	0.7	1.59
Total		**9.50**
F0.5-8-1	0.8	1.81
F0.5-8-2	0.8	1.81
F0.5-8-3	0.8	1.81
F0.5-8-4	0.8	1.81
F0.5-8-5	0.8	1.81
F0.5-8-6	0.8	1.81
Total		**10.86**
F0.5-9-1	0.9	2.04
F0.5-9-2	0.9	2.04
F0.5-9-3	0.9	2.04
F0.5-9-4	0.9	2.04
F0.5-9-5	0.9	2.04
F0.5-9-6	0.9	2.04
Total		**12.22**

The design of the beams (see Figure 1) consists in the embedding of four tips current sourcing (cathodes), for this research copper, located on the top face of the beam, separated to certain distances along the length of the beam. The method for determining the EC in specimens requires that they be two sheets of equal size located each to 20 mm from each end and two wires located every one to 40 mm of the blades toward the interior of the beam.

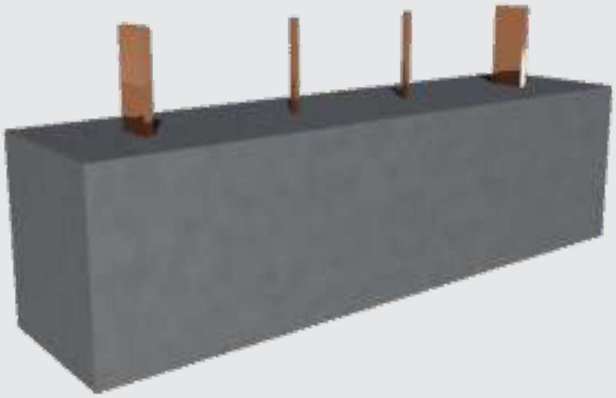


Figure 1. Design of beam 40x40x160 mm to be tested by the method of Wenner

Desencofrado and curing specimens

This item is governed by the ASTM -C-511-98 [8]. Is desmolda metal the centering after 24 hrs of having cast specimens in order to submit them to the curing (Figure 2).

Figure 2. Cured of specimens

The curing method that was used, consists of a solution of calcium oxide with 25% concentration for each 1000 liters of water.

Electrical conductivity

To calculate the EC in paste, used the GECOR 10 (Figure 3), is a high precision electronic device, capable of measuring the voltage and the intensity of a material by the method of Wenner or the four tips [9].

Figure 3. GECOR 10.

Calculations:

With the voltage and current in the readings taken with the GECOR 10 determines the resistance.

$$R = \frac{voltage\ (volts)}{Intensity\ (ampere)} \qquad \text{Ec. (4)}$$

Where,

R= resistance of the specimen.

Voltage reading taken from the device = in the measurement in volts.

Intensity = reading taken from the device in the measurement in amperes.

Determines the resistivity of the specimen with the data previously calculated.

$$\rho\ (\Omega) = \frac{R * A}{L} \qquad \text{Ec. (5)}$$

Where,

P = resistivity (Ω)
A = cross sectional area of the specimen in meters
L= Length between the wires in meters

Now determines the conductivity with the inverse of the resistivity:

$$C = \frac{1}{P} \qquad \text{Ec. (6)}$$

Where,

C = Conductivity in S/mm
P = resistivity, ohm-m

At an age of 4 days in the beams, readings are taken with the GECOR 10 in a wet state (recently removed of the curing process), subsequently captured the readings, are subjected to drying at 60°C for a time of 24 hours. Again take new readings with the GECOR 10, now in a dry state.

The EC will be the average of three specimens of the same dosage for each state.

Resistance to the axial compression

For this pilot test were performed by each dosage specified a number of six specimens, which allowed to try axial compression to the 7 and 14 days of age each mix concrete. The cement used (CPC 30R) allows a cement paste of resistance, acquiring the quick end resistance to 14 days of age.

The value of f'c is obtained from the average of three specimens tested with the same dosage and under the same conditions [7].

RESULTS

The following graphs represent the results of EC of the specimens in their different dosages torque even wet state.

The threshold of percolation defined above, is summarized in the optimal level of concentration of a component, in this case the component in the study is the FC.

The following graphic show the behavior of the specimens wet with their different proportions of FC, where you can admire the variations of EC for each percentage and size of FC.

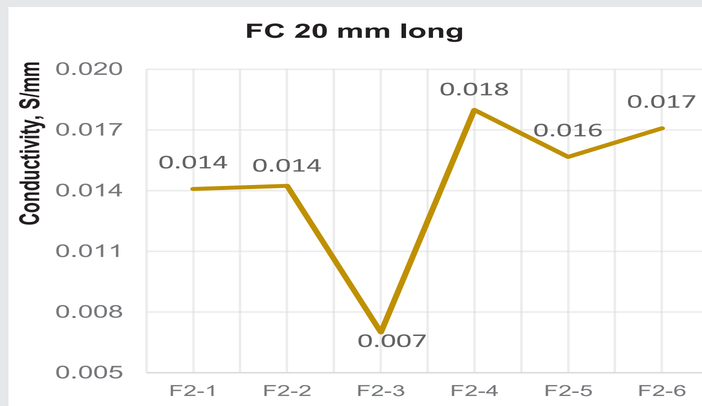
For specimens with FC 20 mm of length (Graph 1), the behavior of the curve is proportional to the percentage relationship FC-conductivity, this refers to the increase of the EC in the specimen as it is lifted the percentage or amount of FC.

The critical points of this curve, i.e. the values of EC more low and high, observed for the FC of 20 mm with a percentage of 0.8% for the greater conductivity with a value of 0.018 S/mm. The lower conductivity was obtained with a value of 0.007 S/mm that corresponds to the percentage of 0.7% of FC.

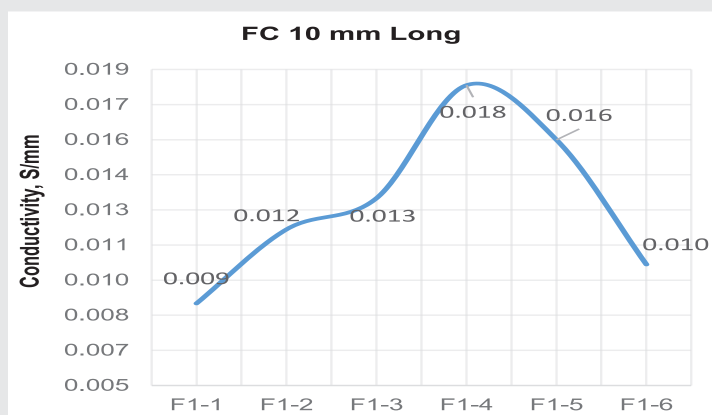
The behavior that acquire the specimens with sizes of 10 mm FC (Graph 2) has a parabolic trend concave side down. This trend indicates that the curve sets a maximum conductivity value, being the point of inflection where it passes from one side growing to a decreasing side, therefore, the value that corresponds to the point of inflection is the optimal value of percentage of FC. The optimum value of EC is given by the 0.8% of FC with a value of 0.01783 S/mm in EC (specimens F2-4). The minimum value of EC is obtained of the percentage corresponding to the 0.5% (specimens F2-1).

The conductive behavior of the specimens with FC sizes of 5 mm in length (Graph 3) has a growing trend on the left side to the point of inflection and decreases the EC to the right side of this point, therefore, has a behavior similar to the earlier curve, highlighting that the optimal value of FC was obtained with a percentage of 0.9% of FC with a conductivity of 0.028 S/mm; the minimum value obtained in conductivity is 0.002667 S/mm corresponding to the specimens with 0.5% of FC.

Already analyzed each trend in the curves of the different sizes of FC is a joint analysis. The specimens with sizes from 5 mm FC in a percentage of 0.5% presented the lowest behavior of conductivity, this can be appearing for two conditions, the percolation existing in these specimens can occur in such a way that the fibers are swarming into groups, these groups are dispersed among themselves along the length of the specimens, therefore the EC may be largely due to the contribution of the cement paste and part of the FC, therefore presents more resistivity to the EC in the compound.

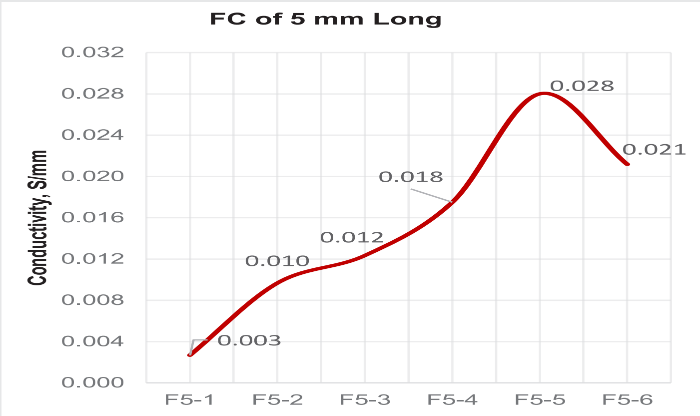


Graph 1. Conductivity of specimen humid with FC 20 mm long

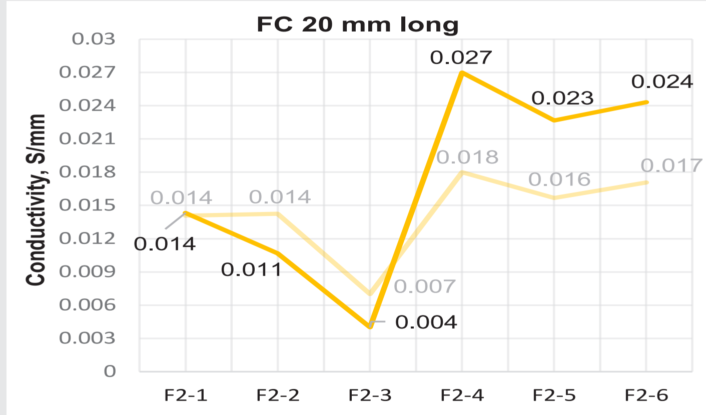


Graph 2. Conductivity of specimen humid with FC 10 mm long

The other condition that may be occurring is the size of the FC, its length can be so short that for a percentage of 0.5% do not reach to be in perfect contact between yes to cause a better electrical behavior.



Graph 3. Conductivity of specimen humid with FC 5 mm long



Graph 4. Conductivity of dry specimen with FC 20 mm long

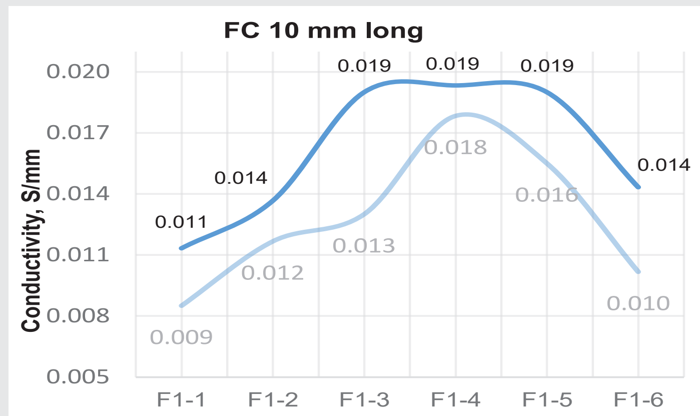
In the sizes from 5 and 10 mm the percentage of 0.5 per cent is the lowest point to the EC. For curves of the sizes of 10 and 20 mm approximately coincide with the same peak of 0.0175 to 0.01783 and S/mm respectively with the same percentage of FC 0.8%.

The threshold of percolation in a qualitative form is found by knowing the curve that greater EC submits, the graphics are notes the threshold of percolation optimo in specimens of size of 5 mm FC with a percentage of 0.9% since it is the most EC provides to the pasta. This is a result of the trend toward a better accommodation of carbon filaments in the specimen causing under vacuum spaces and a better connection of these FC causing greater EC. For a better characterization of this type are required to analyze the behavior of the specimens in a dry state, since its implementation in the engineering would be submitted to a reference state very similar.

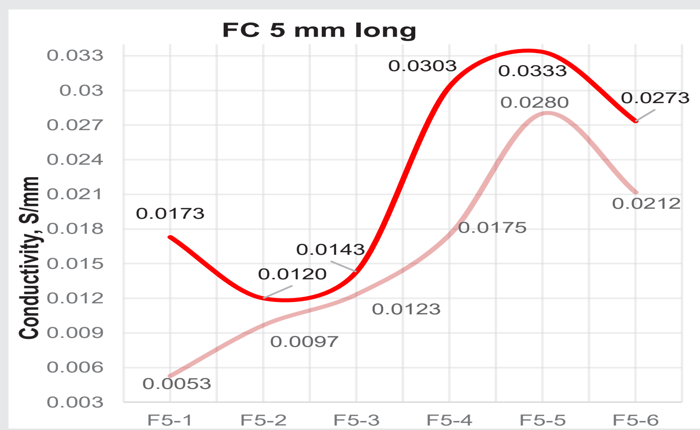
The Graphs 4, 5 and 6, there are two curves, the curve of strong color represents the conductive behavior of the dried specimens and the curve more tenuous specimens wet. The trend of the new curve must be equal since they are subject to the same conditions varying only its moisture content, inducing a single movement ascending or descending in the orderly, i.e. in the axis of the conductivity.

The Graph 4 shows the trend described previously, with an increase in the conductivity with reference to the maximum value of the specimens wet. For a percentage of FC 0.8% are wet and dry values of 0.018 and 0.027 S/mm respectively, therefore, in a state totally dry paste cementante with addition of FC from a proportion of 0.8% onwards leads a higher value of EC that a wet state.

In the Graph 5, the threshold of percolation is presented in the condition of dry and humid with values of 0.01933 and 0.01783 S/mm respectively with a percentage of FC of 0.8%.



Graph 5. Conductivity of specimen dry with FC 20 mm long



Graph 6. Conductivity of dry specimen with FC of 5 mm long

In Graph 6, each curve has a parabolic behavior concave down giving as greater EC the inflection point of the curve, same trend described in Graph 3. The threshold of percolation is presented in the condition of dry and humid with values of 0.028 and 0.03333 S/mm respectively with a percentage of FC 0.9%.

In general the EC in all specimens in their different proportions were higher in dried specimens. As the trend is very similar to the wet specimens the proportions for a EC greater do not vary, i.e. that remains the same size of 5 mm of length of FC with a percentage of 0.9% which presents the threshold of percolation with a value in the EC of 0.03333 S/mm.

Identified the size and optimal percentage of FC that greater leads electricity may be compare these values of EC with those generated by the specimens of control, with the goal of being able to characterize that so much changes in conductivity specimens without the addition of FC and with the addition of this.

Table 4. Specimens of control

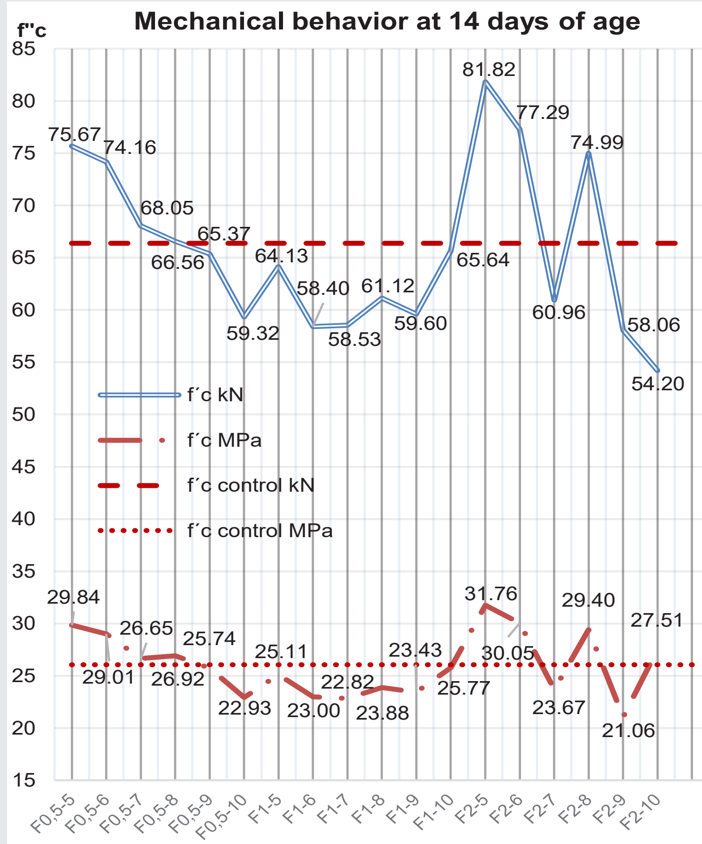
Specimen	Conductivity, S/mm
C_{dry}	0.0001129
C_{humedi}	0.0009860

The values of EC that are shown in the table 4, are the average of the EC taken under the same conditions that the specimens with FC both in the wet condition as the dry.

The conductivity in specimens of wet control has a greater EC that in the dry condition. To compare these values with the conductivity of the conductive cement paste with the addition of FC identifies the paste CP provides less conductivity that with which brings with it the addition of FC. The value of the EC that greatest contribution was in dry conditions for specimens with FC is 70333 S/mm while the control is 0.00011129 S/mm, therefore, a paste of CP when adding this carbonaceous material is converted to a greater extent a compound more conductor of electricity.

Graph 7 represents the mechanical behavior that the cementitious specimens with addition of FC to tested to axial compression, the values of f'c are presented in MPa and kN. Obtained the threshold of percolation of optimum FC for the conductivity analyzes its mechanical behavior. The threshold of percolation was presented in the size of 5 mm of length of FC with an optimal percentage of 0.9%, therefore in mechanical resistance is due to the specimens F0.5-9, for this type of dosage is obtained a value very close to f'c obtained in specimens of control (dashed line horizontal), the value of f'c to F0.5-9 is 25.74 MPa, this value even though it is a little lower than that of control can be inferred that a paste with these doses produces a compression resistance equal to that of a conventional cement paste but with an extra feature of EC Achieved with the addition of FC with a size of 5 mm long and a percentage of 0.9% with respect to its volumetric fraction.

The Graph this is evident in more detail the maximum value of mechanical resistance, which corresponds to the specimens of F2-5, that is to say the specimens with FC size of 20 mm in length and a percentage of 0.5% of FC.



Graph 7. Axial resistance to compression.

CONCLUSIONS

The addition of carbonaceous materials as the FC increment in the paste its electrical conductivity, without losing its resistance to compression, accordingly, makes this paste in a multifunctional material.

The percolation threshold for a cement paste electrically conductive with the addition of carbon fiber is presented for a percentage of 0.9 per cent in a size of 5 mm in length.

This threshold produces in the paste a mechanical behavior similar to that of a conventional pulp, generating a variation below 0.3 MPa to 14 days of age. While the FC with a size of 20 mm of length produces an increase in the mechanical resistance to the 14 days of age up to 4.1 MPa.

REFERENCES

[1] Sánchez, D. (1997). Concrete Technology: technology and properties. ASOCRETO. 2Nd Ed. Pp. 120-200.

[2] Bertolinia, L., Bolzonia, F., Pastore, T. & Pedeferria, P. (2004). Cem. And Concr. Res., 34, 681.

[3] Cobo, A., Prieto, M. I., Gonzalez M. N. (2008). The electrochemical removal of chlorides as a technique of rehabilitation of reinforced concrete structures. XI International Congress of Rehabilita-

tion of architectural heritage and building. Madrid, Spain.

[4] World Road Association, Use Of Innovating Materials For bridge construction and repair, PIARC Technical Committee on road bridges and other structures (C11). vol 11.09.B. 2002. 55.

[5] Del Moral, B. Galao Ó, Antón, C....& Garcés, P. (March, 2013). Usability of cement paste containing carbon nanofibres as an anode in electrochemical chloride extraction from concrete. Vol. 63, 309, 39-48. ISSN: 0465-2746.

[6] American Association State Highway and Transportation Officials Standard AASHTO No.: T162.Standard Practice for Mechanical Mixing of Hydraulic cement pastes and mortars of plastic consistency. ASTM C-305-10.

[7] American Association State Highway and Transportation Officials Standard AASHTO No.: T162 Standard Test Method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] Cube Specimens).ASTMC-109 - 99.

[8] American Association State Highway and Transportation Officials Standard AASHTO No.: T162. Standard Specification for Moist Cabinets, Moist rooms, and Water Storage Tanks used in the Testing of Hydraulic Cements Co. and concretes. ASTM-C511-98.

[9] ASTM G57. Standard Test Method for the measurement in the field of resistivity ground using the method of wenner of 4 points.