AN EXPERIMENTAL INVESTIGATION OF ELECTRICALLY CONDUCTIVE CONCRETE USING ACTIVATED CARBON

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ABSTRACT

Electrically Conductive Concrete (ECC) is a an emerging term across the modern field of structural engineering due to its inherent capability for self-sensing and health monitoring. Th production of ECC involves the application of a variety of costly conductive fillers. Even though activated carbon is an intense conductor and a low-cost substance, it is not well known as an ECC filler that conducts electricity. This study summarizes the findings of an experimental research into the impact of adding activated carbon to structural concrete as the replacement of fine aggregate (at weight percentages of 0%, 8% and 12%) in ECC. Various research done by researchers showed that use of direct current (DC) in ECC showed less accurate results. The estimation of conductivity was performed relying on a two-point uniaxial technique with alternating current (AC). An ammeter to measure electric flow through the specimens and a variac to regulate voltage were also used. The voltage was kept almost constant for all specimens and electric current was noted which later lead to electric conductivity. Results revealed that concrete, alongside sufficient electrical conductivity, could be developed for various uses by adding the right amount of activated carbon. As the percentage of replacement increased from 0% to 12%, so did the electrical conductivity. The gauge length between the measuring nodes were also changed to depict the changes in electric conductivity. In this study changes in electrical flow caused by changes of activated carbon dosage indicates that it can be beneficial for further development of ECC research.

Keywords: *Electrically conductive concrete, activated carbon, smart concrete, electric conductivity, two-point uniaxial method.*

1. INTRODUCTION

Concrete, formerly thought of as a simple and inflexible material, is now a cloak of versatility and intelligence that promises to alter the way people construct and engage with our environment. The fundamental ingredients of concrete are the starting point for this technological transformation. The electric resistivity of normal-weight concrete typically falls within the range of 6.54 to 11 kΩ (Whittington et al., 1981). Incorporating intelligent chemicals, sensitive fibers, and self-healing microorganisms into the concrete mix gives the material surprising new properties. Electrically Conductive Concrete (ECC) is on the rise as a game-changing answer precisely because of how it combines structural functionality and electrical conductivity. This extraordinary material promises smarter, more resilient infrastructure and represents an enormous leap in the construction industry. Nevertheless, the limited strength and high expenses associated with this approach have hampered its extensive use (Yehia & Tuan, 2000).

In this study, activated carbon was used as a conductive filler in ECC. Concrete The manufacture of ECC is costly because of the use of high-cost conductive materials. Implementing activated carbon, a cost-effective material, is an appealing strategy for achieving affordable production of ECC. The electric flow was measured using a two-point uniaxial approach, and the effect of varied amounts of activated carbon dosage was examined. Finally, the fluctuation in electric flow was observed with varying gauge lengths between measuring nodes.

1.1 Electrically Conductive Concrete (ECC)

Electrically Conductive Concrete (ECC) is a futuristic product that unites conventional concrete's characteristics with the scientific wonder of electrical conductivity. Electrically Conductive Concrete is a specialized form of concrete infused with conductive materials such as carbon fibers or nanotube, enabling it to carry electrical currents while retaining its structural integrity. Conductive materials contribute to boost the electrical conductivity of ECC by establishing passageways for the transmission of electrical current throughout the concrete. The conduction of electricity through concrete can occur through two distinct mechanisms: electronic conduction and electrolytic conduction. Electronic conduction is facilitated by the movement of unbound electrons within the conductive medium, while electrolytic conduction is enabled by the movement of ions within the pore solution (Yehia & Tuan, 2000). One way to make a concrete mix better at conducting electricity is to use conductive aggregates like iron ore and slag, and another is adding conductive materials to the cement paste, such as steel shavings, coke breeze, steel, carbon fibers, etc., which makes the paste more conductive (Yehia & Tuan, 2000).

1.2 Objectives of the Study

The primary aim of this study is to investigate the impact of utilizing activated carbon as a conductive substance in Electrically Conductive Concrete. The key objectives of this study can be summed up in the following sentences:

i. To improve the electrical conductivity of structural concrete using Activated Carbon.
ii. To evaluate the effect of different dosages of Activated Carbon in producing ECC.

2. METHODOLOGY

A structural component's prerequisites provide a list of environmental risk standards that a material must fulfil to be suitable for utilization in current real-world scenarios. Concrete is a frequently used construction material comprising a mixture of cement, fine aggregates (such as sand), and coarse aggregates, all combined with water. Eventually, this mixture undergoes a process of hardening in the current research, a substance that conducts electricity was incorporated into the concrete mixture as a partial replacement for the natural fine aggregate up to a specific weight percentage.

2.1 Materials Used

The materials required for this project are enumerated as follows:

a) Cement
b) Aggregate
   - Coarse aggregate - stone chips of maximum size 20 mm
   - Fine aggregate - FM 2.44
c) Electrically conductive material (Activated Carbon)
d) Superplasticizer
e) Water

Table 2.1 Constant parameters of the study

Parameter	Description
Type of cement	Ordinary Portland Cement (OPC)
Water cement ratio	0.5
Cement: sand: coarse aggregate	1:0.75:1.5(M30 Nominal Mix)
Sample type	Cubic, Rectangular Prism
Curing day	28 Days

In this study, fine aggregate was replaced with Activated Carbon:

- Fine aggregate replacement - 0%, 8%, 12% by Activated Carbon.

2.2 Experimental Program

A total of three mixes were prepared, each of which had different amounts of Activated Carbon by replacing fine aggregate but the same quantity of cement and coarse aggregates and water.

Table 2.2 Specimen used for electric conductivity test

<table>
<tr><th>Test Name</th><th colspan="2">Specimen Type</th><th>Denoted As</th><th>Specimen Size</th></tr>
<tr><td rowspan="13">Electrical Conductivity Test</td><td rowspan="9">Cube</td><td>C with 0% activated carbon dry condition</td><td>C-0%-D</td><td rowspan="9">6"x6"x6"</td></tr>
<tr><td>C with 8% activated carbon in dry condition</td><td>C-8%-D</td></tr>
<tr><td>C with 12% activated carbon in dry condition</td><td>C-12%-D</td></tr>
<tr><td>C with 0% activated carbon in SSD condition</td><td>C-0%-SSD</td></tr>
<tr><td>C with 8% activated carbon in SSD condition</td><td>C-8%-SSD</td></tr>
<tr><td>C with 12% activated carbon in SSD condition</td><td>C-12%-SSD</td></tr>
<tr><td>C with 0% activated carbon in SSD condition</td><td>C-0%-S</td></tr>
<tr><td>C with 8% activated carbon in SSD condition</td><td>C-8%-S</td></tr>
<tr><td>C with 12% activated carbon in SSD condition</td><td>C-12%-S</td></tr>
<tr><td rowspan="4">Prism</td><td>Prism with 0% activated carbon in dry condition</td><td>P-0%-D</td><td rowspan="4">18"x6"x6"</td></tr>
<tr><td>Prism with 12% activated carbon in dry condition</td><td>P-12%-D</td></tr>
<tr><td>Prism with 0% activated carbon in saturated condition</td><td>P-0%-S</td></tr>
<tr><td>Prism with 12% activated carbon in saturated condition</td><td>P-12%-S</td></tr>
</table>

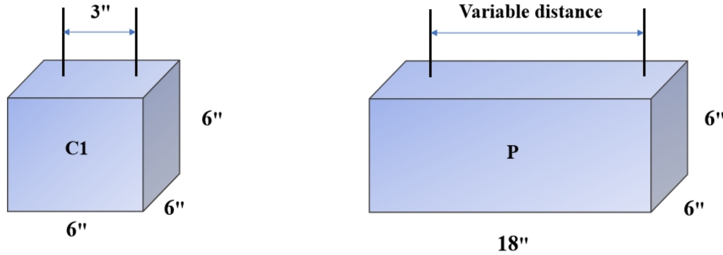

Figure 2.1: Schematic diagram of cube and prism type specimens

2.3 Concrete Mix Proportion

The electrical conductivity of Electrically Conductive Concrete (ECC) is influenced by various parameters, including the kind and amount of electrically conductive materials (ECMs), the quantities of the conductive material, the type of aggregate used, the dispersion of ECMs, and the ionizing ambient. The conductivity can be manipulated through the use of various admixtures.Ordinary Portland cement (ASTM Type I) was used in the study. The M30 grade concrete mix was made with a ratio of 1:0.75:1.5. The study maintained a constant water-to-cement ratio of 0.5. Superplasticizer was used at 1% of cement content (Aboutaleb et al., 2018). ASTM provisions for concrete mixing were strictly followed. The mixture was intended to have a slump of 70mm to 100 mm and a compressive strength of 30 MPa over 28 days, which reflects a standard structural concrete grade (El-Dieb et al., 2018). The characteristics of the aggregates used are depicted in Figure 2.3.

Table 2.3 Characteristics of aggregates used

Material	Attribute
Coarse Aggregate	specific gravity 2.52
	water absorption rate 2.04
Fine Aggregate (Domar Sand)	fineness modulus of 2.44
	specific gravity of 2.77

2.4 Electrical Conductivity Test (ECT)

The purpose of conducting the electrical conductivity test (ECT) was to ascertain the electrical resistivity and, consequently, the conductivity of the various mixtures. This test lacks a standard frame of reference (Aboutaleb et al., 2018). Hence, the dimensions of the specimen and the configuration of the trial were picked based on empirical evidence. The test was conducted after 28 days of curing for saturated samples and dried for seven days in case of dry specimens. C and B type specimens were used. Figure 2.2 depicts a schematic diagram of experimental setup.

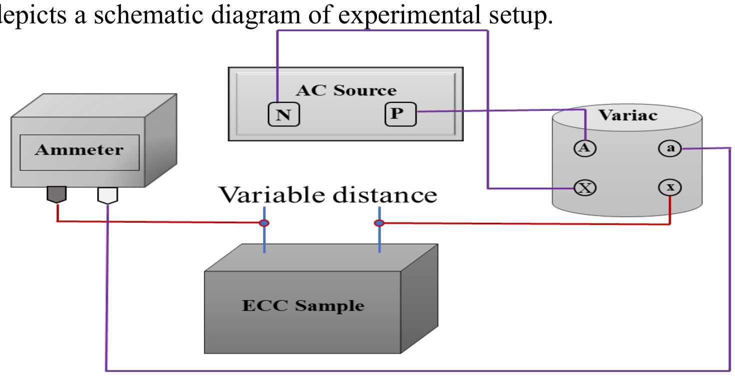

Figure 2.2: Schematic diagram of electric conductivity test setup

Over time, ECC's resistance fluctuates according to the relative humidity and type of additive applied (Sassani et al., 2017). The resistivity was established utilizing the two-point uniaxial strategy. The

two-point uniaxial strategy has been selected due to its basic geometry and quick testing time. With this approach, the resistance value is obtained by applying a voltage across the specimen's two nodes to measure the generated current. The voltage is kept almost constant throughout the study.
The electrical conductivity was calculated using following relationships

$$R = VI \tag{1}$$

$$\rho = R\left(\frac{Wt}{d}\right) \tag{2}$$

$$\sigma = 1/\rho \tag{3}$$

Here, V is voltage (volt), I is current (A), R is resistance (Ω), ρ is resistivity (Ω.cm), W is Width of specimen (cm), t is Thickness of specimen (cm), d is Distance between two nodes (cm), ρ is Electrical resistivity (ohm-cm), σ is Electrical conductivity (1/ohm-cm).
The target of the research was to make ECC using activated carbon. The fine aggregates within the concrete mixture were substituted with activated carbon at varying proportions of 0%, 8% and 12% by weight. For conventional concrete (0% replacement), electric conductivity was measured for dry, SSD and saturated conditions. The same approach was applied for 8% ECC and 12% ECC. The test results were compared to ensure that activated carbon is suitable to be used as a conductive filler in ECC for further study. Wires were inserted at a 3inch gauge length between measuring nodes. C type specimens were used. Then, for P-0% and P-12% specimens, the gauge length between nodes was varied from 3icnhes to 15 inches and the variation of conductivity was measured.

3. EXPERIMENTAL RESULTS

3.1 Effect of Saturation Condition on the Conductivity

Table 3.2 illustrates the differences in electric conductivity between saturated and dry C specimens containing varying percentages of activated carbon designated as C-0%, C-8% and C-12%. The specimens underwent testing adopting weirs as nodes.

Table 3.1: Specimen size for C-type specimens

Specimen type	Length, L (m)	Width, B (m)	Thickness, t (m)
C	0.1524	0.1524	0.1524

Table 3.2: ECT for different saturation condition

Saturation Condition	Specimen Type	Distance Between Two Nodes d (m)	Voltage V (Volt)	Current I (mA)	Resistance R =V/I (Kohm)	Resistivity ρ=V/I * (Bt/d) (Kohm-m)	Conductivity σ = 1/ρ (1/ohm-m) x 10^{-4}
Saturated	C-12%-S	0.0762	269	0.24	1,120.83	341.63	29.27
Saturated	C-8%-S	0.0762	276.5	0.16	1,728.13	526.73	18.98
Saturated	C-0%-S	0.0762	272.2	0.09	3,024.44	921.85	10.85
SSD	C-12%-SSD	0.0762	278.8	0.19	1,467.37	447.25	22.36
SSD	C-8%-SSD	0.0762	268	0.14	1,914.29	583.47	17.14
SSD	C-0%-SSD	0.0762	278.7	0.10	2,787.00	849.48	11.77
Dry	C-12%-D	0.0762	273.6	0.11	2,487.27	758.12	13.19

Dry	C-8%-D	0.0762	274.6	0.08	3,432.50	1,046.23	9.56
Dry	C-0%-D	0.0762	277.3	0.05	5,546.00	1,690.42	5.92

The results of Table 3.2 confirmed that elevating the percentage of the conductive substance, activated carbon, in the mixture increased the conductivity of ECC for saturated, SSD and dry condition. It is further demonstrated in Figure 3.1 that the electric conductivity of the specimen increases proportionally with improvement in the amount of moisture and is maximum for saturated condition.

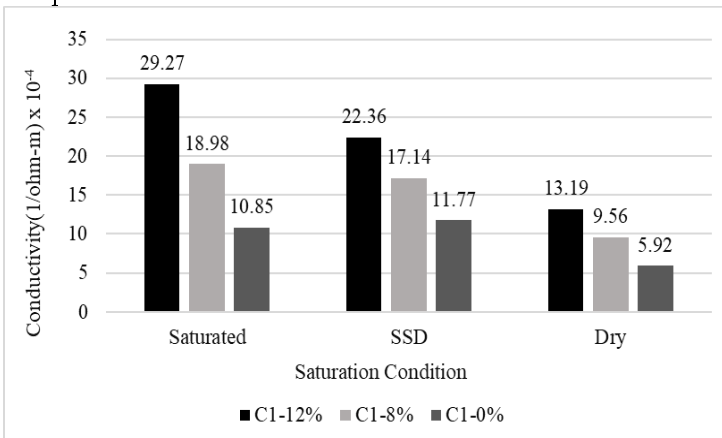

Figure 3.1: Comparison of electric conductivity for various dosage of activated carbon along with different saturation

3.2 Effect of Gauge Length on the Conductivity

The variations in electric conductivity were determined by manipulating the spacing between the nodes. Distance between the nodes is termed as the gauge length. The gauge length between nodes was raised by 3 inches each time up to 15 inches. The test was done for ECC P type specimens with 0% and 12% activated carbon dosage and were respectively denoted by P-0% and P-12%. Both saturated and dry conditions were considered. Obtained results are presented in Table 3.4.

Table 3.3: Specimen size for P-type specimens

Specimen	Specimen Size	Length, L (m)	Width, B (m)	Thickness, t (m)
P	18" x 6" x 6"	0.4572	0.1524	0.1524

Table 3.4: ECT for varying gauge length between nodes for ECC with 0% and 12% activated carbon at saturated condition

Saturation Condition	Specimen Type	Distance Between Two Nodes d (m)	Voltage V (Volt)	Current I (mA)	Resistance R =V/I (Kohm)	Resistivity ρ=V/I * (Bt/d) (Kohm-m)	Conductivity σ = 1/ρ (1/ohm-m) x 10^{-4}
Saturated	P-0%-S	0.0782	279.7	0.030	9323.33	2769.07	3.61
Saturated	P-0%-S	0.1524	283	0.020	14150.00	2156.46	4.64
Saturated	P-0% S	0.2286	283	0.018	15722.22	1597.38	6.26
Saturated	P-0% S	0.3058	280	0.017	16470.59	1250.96	7.99
Saturated	P-0% S	0.3810	281	0.017	16529.41	1007.63	9.92
Saturated	P-12%-S	0.0782	278	0.092	3021.74	897.47	11.14
Saturated	P-12%-S	0.1524	279	0.086	3244.19	494.41	20.23
Saturated	P-12%-S	0.2286	278	0.074	3756.76	381.69	26.20

Saturated	P-12%-S	0.3058	278	0.064	4343.75	329.91	30.31
Saturated	P-12%-S	0.3810	278	0.052	5346.15	325.90	30.68

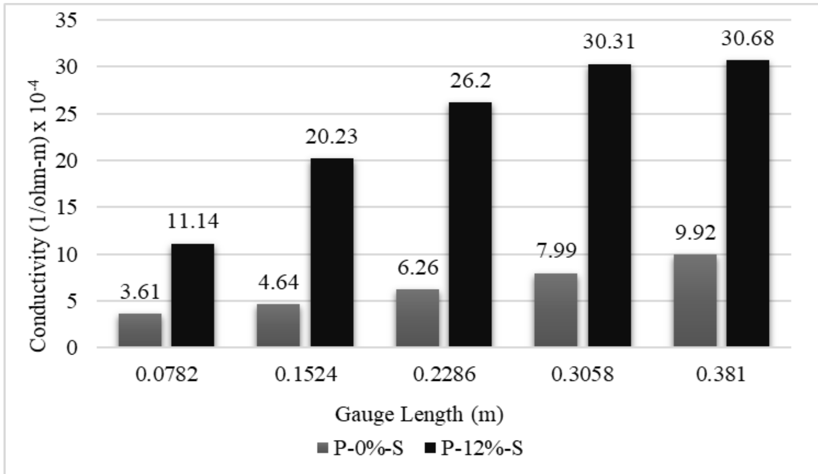

Figure 3.2: Comparison of electric conductivity for varying gauge length between nodes at saturated condition

In saturated condition, Table 3.4 results showed that ECC with 12% activated carbon had much smaller resistance in comparison with conventional concrete and much higher electric conductivity. Figure 3.2 illustrated, as the gauge length between two nodes increased, the conductivity showed a gradual increase for both samples, but the changes were more prominent and higher for P-12%.

Table 3.5: ECT for varying gauge length between nodes for ECC with 0% and 12% activated carbon at dry condition

Saturation Condition	**Specimen Type**	**Distance Between Two Nodes d (m)**	**Voltage V (Volt)**	**Current I (mA)**	**Resistance R =V/I (Kohm)**	**Resistivity ρ=V/I * (Bt/d) (Kohm-m)**	**Conductivity σ = 1/ρ (1/ohm-m) x 10^{-4}**
Dry	P-0%-D	0.0782	284	0.028	10142.86	3012.48	3.32
Dry	P-0%-D	0.1524	284	0.025	11360.00	1731.26	5.78
Dry	P-0%-D	0.2286	284	0.021	13523.81	1374.02	7.28
Dry	P-0%-D	0.3058	283	0.017	16647.06	1264.36	7.91
Dry	P-0%-D	0.3810	284	0.014	20285.71	1236.62	8.09
Dry	P-12%-D	0.0782	283	0.050	5660.00	1681.05	5.95
Dry	P-12%-D	0.1524	284	0.036	7888.89	1202.27	8.32
Dry	P-12%-D	0.2286	285	0.028	10178.57	1034.14	9.67
Dry	P-12%-D	0.3058	284	0.023	12347.83	937.83	10.66
Dry	P-12%-D	0.3810	284	0.020	14200.00	865.63	11.55

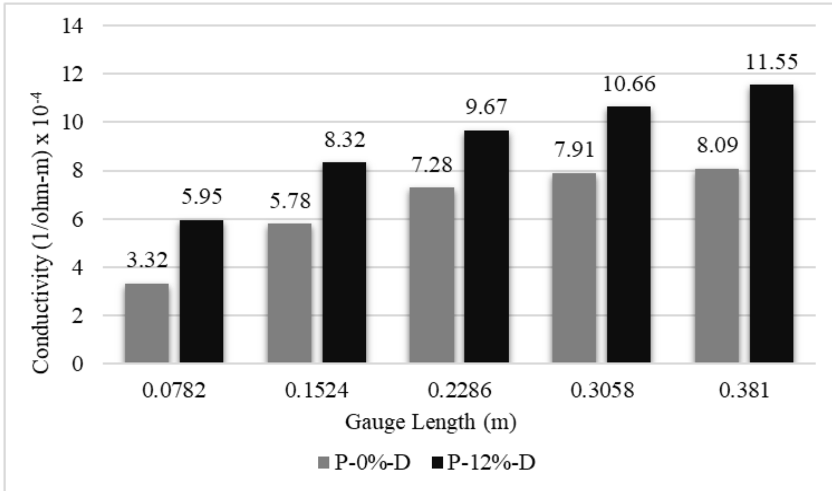

Figure 3.3: Comparison of electric conductivity for varying gauge length between nodes at dry condition

In dry condition, Table 3.5 results showed that ECC with 12% activated carbon had much smaller resistance in comparison with conventional concrete and much higher electric conductivity. As the distance between two nodes increased, the conductivity showed a gradual increase for both samples. Figure 3.3 illustrated, as the gauge length between two nodes increased, the conductivity showed a gradual increase for both samples, but the changes were more prominent and higher for P-12%.

From Figure 3.1, in general it was observed that all examined ratios of activated carbon exhibited remarkable electrical conductivity outcomes in comparison to traditional concrete and indicated steady rise in electric conductivity with the rise of activated carbon percentage. The highest level of conductivity was observed in the saturated ECC sample containing a 12% activated carbon dose. Figure 3.2 and Figure 3.3 showed, as the gauge length between measuring nodes increased, the conductivity showed a gradual increase for both saturated and dry conditions. This was due to the gradual decrease in heat generation as the distance between two nodes is inversely proportional to heat production. Heat hampers the molecular stability and increased resistivity.

4. CONCLUSIONS

The primary conclusions drawn from the test findings acquired in this study are as follows:

- The mixtures having varying concentrations of activated carbon exhibit remarkable electric conductivity that rises with increasing dosage.
- For ECC samples, as the gauge length between measuring nodes grew, the conductivity went up gradually because heat production decreased with increasing spacing, which made the resistance decline.

REFERENCES

Aboutaleb, D., Gohar, R., Ibrahim, K., Mahran, M., Zaghloul, Y., Ghaly, A., Hamza, A., Hussam, A., El Nahas, E., & Abou-Zeid, M. (2018). Electrically Conductive Concrete. *Canadian Society for Civil Engineering.*

El-Dieb, A. S., El-Ghareeb, M. A., Abdel-Rahman, M. A. H., & Nasr, E. S. (2018). Multifunctional electrically conductive concrete using different fillers. *Journal of Building Engineering*, 15, 61–69. https://doi.org/10.1016/j.jobe.2017.10.012

Whittington, H. W., McCarter, J., & Forde, M. C. (1981). The conduction of electricity through concrete. *Magazine of Concrete Research*, 33(114), 48–60. https://doi.org/10.1680/macr.1981.33.114.48

Yehia, S. A., & Tuan, C. Y. (2000). Thin conductive concrete overlay for bridge deck deicing and anti-icing. *Transportation Research Record: Journal of the Transportation Research Board,* 1698(1), 45–53. https://doi.org/10.3141/1698-07