Fifth International Conference on Sustainable Construction Materials and Technologies. http://www.claisse.info/Proceedings.htm

EVALUATION OF ELECTRICAL CONDUCTIVITY AS A TECHNIQUE FOR ASSESSING THE EFFICACY OF SURFACE-TREATED CONCRETE.

Sunday Onyebuchi Nwaubani[1]
[1]University of the Witwatersrand, Johannesburg, South Africa
Sunday.nwaubani@wits.ac.za

ABSTRACT

Various types of protective treatments have been developed over the years, varying from natural materials such as lime washes, used on heritage structures, to sophisticated polymers and protective coatings currently used to counter degradations due to natural weathering or to prevent premature corrosion of steel reinforcement in highway concrete bridges. However, these new materials have finite lives and may need to be renewed after a few years due mostly to degradation caused by the effect of the ultra-violet radiation. A few standard methods exist for non-destructive site assessment of surface treated structures but these are not well known.

This paper presents the results of an investigation to verify the applicability of the electrical conductivity method for field or in-situ conditions. Three concrete mixes and five different exposure conditions were investigated. Some specimens were soaked in 3% Sodium Chloride solution to study the effects of aggressive agents. The results indicate that concrete treated with penetrating sealants exhibited significant reduction in electrical conductivity compared with the untreated concrete.

Keywords: Electrical conductivity, Surface-Treated Concrete, Penetrating sealers, Silane, Non-destructive test.

INTRODUCTION

Penetrating sealers are used for the treatment of concrete surfaces to prevent the deterioration of embedded steel in concrete. They are widely applied on bridge decks. This is due to the fact that bridge deck deterioration is a common problem in most countries. The function of penetrating sealers is not only to act as physical barrier by preventing the entry of harmful substances such as chloride ions, carbon dioxide, water oxygen, etc, through making the pores hydrophobic and repellent to liquid. It also discourages excessive build-up of these deleterious species within the concrete [CIRIA (1987), Swamy and Tanikawa (1990), Nwaubani and Dumbelton (2001)].

The unsealed and sealed concrete structure requires regular maintenance, as there is no material that is maintenance free. Various field tests of penetrating sealers have used cored or drilled samples to determine the extent of severity of chloride ion penetration and other aggressive agents. These tests are destructive, time consuming, costly and the numbers of samples that can be taken from a structure are limited. Non-destructive test methods are therefore more desirable and cost effective.

In recent years, there has been interest in the use of silane and siloxane sealers that are silicone-based molecules with alkyl groups linked to silicone atom. When applied to concrete, a chemical reaction occurs and creates a hydrophobic layer that has been found to be effective in hindering the ingress of chloride laden water while allowing water vapour to escape upon drying [Hewlett (1990), Bashear et al (1990), Nwaubani (2018)]. Because silanes and siloxanes chemically react with concrete, it's often thought that re-treatment is not required. However, if sealers are to be used on bridge decks and concrete pavements, the service life of a sealer becomes dependent on its effectiveness under abrasive conditions.

A number of non-destructive tests have been developed for concrete [Bashear, P.A.M. (1992)]. In practice compressive strength has been found a convenient measure for concrete quality [BS 1881(1970)], largely because of the great deal of knowledge that has been accumulated from the use of the cube crushing tests as a control for concrete production. The prestige that has accrued to strength as a measure of concrete quality has in turn encouraged the use of non-destructive test to provide an estimate of the strength of in-situ concrete, since this is related to durability of concrete. Nevertheless, it has long been recognized that strength can only be an indirect measure of durability and that other parameters governing the ease of movement of liquids and gases through concrete would provide a better assessment.

This paper presents the results of durability tests carried out on concrete surfaces with and without penetrating sealers, using simple, and mostly non-destructive in-situ test methods to evaluate moisture absorption and electrical conductivity. Complementary laboratory (destructive) test methods were used to evaluate porosity and permeability. The results are compared for specimens subjected to different environments which include; soaking in deionized water, soaking in salinated water, leaving in laboratory air, leaving outside laboratory and drying in oven at 100 ˚C.

MATERIAL AND EXPERIMENTAL PROCEDURE

The materials used, mix proportions, specimen preparation, method of application of penetrating sealer and environmental curing conditions are discussed briefly in the following sub-sections.

Materials

The cement used was Ordinary Portland Cement (OPC). Pulverized Fuel Ash (PFA), a pozzolanic material, was used as cement replacement. The physical and chemical properties of the materials are given in Table.1 below.

Table.1: Physical and Chemical Properties of OPC and PFA

Properties	Ordinary Portland Cement (OPC)	Pulverised Fuel Ash (Pfa)
Oxide Composition (%)		
SiO_2	20.40	52.80
Al_2O_3	5.02	27.90
Fe_2O_3	2.92	11.70
MnO	0.60	-
TiO_2	0.21	1.00
CaO	64.25	1.20
MgO	2.83	1.50
Na_2O	0.39	0.80
K_2O	0.84	3.70
P_2O_5	0.08	-
SO_3	2.63	0.70
L.O.I	0.70	2.10
Physical Characteristics		
Specific Gravity (cc/g)	3.12	2.24
Specific Surface m2/g (BET)	1.04	1.29

Aggregates

Fine aggregates of maximum size of 10 mm and coarse aggregates of maximum size of 20 mm were used. Both the coarse and fine aggregates were oven dried to constant weight at 110^{o}C.to eliminate the effect of variable moisture content and moisture content determination was carried out according to BS1881: Part 122. Percentage by weight of water absorption of course aggregate and fine aggregate used were 3.6% and 2.4% respectively.

Admixture

Superplasticizer was used as chemical admixture to improve the workability of concrete mix. The penetrating sealer used was alkyl trialkoxy-silane, a Nicote SN 511 brand.

Water

Tap water was used for concrete mix and distilled water for tests carried out on the cast specimens.

Experimental Details

Mix proportion

The three concrete mixes were used in this study:

Mix A: 100% OPC and water-cement ratio of 0.5

Mix B: 100% OPC and water-cement ratio of 0.35

Mix C: 75% OPC, 25% PFA and water-binder ratio of 0.35

The mix proportions for the three concrete mixtures were the same. The proportion of the binder: fine aggregate: coarse aggregate was 1:2.06:3.08. The mixes had a cement content of 360 kg/m^3.

The slump value for the control mix was established and a super-plasticizing admixture was used for Mix B and C to maintain same slump of 50 ± 25mm for all mixtures.

Specimen Preparation and Curing

Three types of specimens were prepared: 400 x 400 x 100 mm slabs - for the measurement of electrical conductivity; 100 mm diameter and 50 mm thick cylinders - for the determination of coefficient of oxygen permeability; and 70 x 70 mm cubes - for the determination of porosity. A total of 75 specimens were made: 15 slabs, 30 cylinders and 30 cubes. Steel moulds were used for casting of specimens, except for slab specimens where wood moulds were used in addition to available steel moulds. Vibrating table was used to compact cubes and cylinder specimens. The compaction of slab was carried out in three layers using a porker vibrator. Specimens were finished with a smooth wood, and then covered with plastic to prevent early evaporation. Specimens were stripped from their moulds the day following casting and placed in the curing room at 20 ± 2 ˚C and about 99% relative humidity for 28 days.

Application of Penetration Sealer

Specimens were brought out of the curing room after 28 days and left to dry for 3 days before the application of treatment on the required surfaces. The reason for applying the treatment of the specimens after 28days curing was to allow sufficient strength to be attained, and to avoid the possibility of the concrete reacting with the penetrating sealer. The rate of application of saline solution was 0.3 liters/m^2. One side of each slab was treated; selected cubes and cylinders were completely treated, while others were left untreated. Two treatment coatings were applied.

Environmental Conditioning of Test Specimens

The treated and untreated specimens were placed in different environments as follows:

i. Oven dried at 110 ˚C.
ii. Placed inside laboratory at 20 ± 2 ˚C
iii. Placed outside laboratory at 20 ± 10 ˚C
iv. Soaked in deionized water at 20 ˚C
v. Soaked in salinated water at 20 ˚C

The oven dry specimens were allowed to cool to room temperature before being tested. The specimens soaked in 3% solution of sodium chloride at least 3 days and those soaked in deionized water, were allowed to dry for 3 days so that reasonable results could be obtained.

The tests used to evaluate the performance of the treated and untreated concrete, when subjected to different environments were:

- **Electrical Conductivity**

Conductivity measures the ability of a solution to conduct an electric current between two electrodes. In solution, the current flows by ion transport, consequently, with an increasing amount of ions present in the liquid, the liquid will have a higher conductivity. If the number of ions in the liquid is very small, the solution will be "resistive" to current flow. AC current is used to prevent complete ion migration to the two electrodes.

Figures 1 and 2, shows the setup of the equipment and the schematic diagram of the sensor used for the measurement. Wet method was used for electrical conductivity test, since depth of penetration of treatment is just few millimeters below the concrete surface. The equipment has nickel electrodes and calcium hydroxide solution (lime) was used as electrolyte. A constant AC voltage was applied to the contact surface through the electrode and the electrolyte. If a surface has been treated with a water repelling agent, when the electrode is placed upon it, none of the electrolyte is absorbed by the substrate, the circuit remains open and zero voltage flows between the two electrodes. However, if the surface has not been treated, or a treatment is no longer effective, then the electrolyte will be absorbed and electrical circuit will be closed and voltage will flow.

Figure 1: Setup of the Electrical Conductivity Equipment

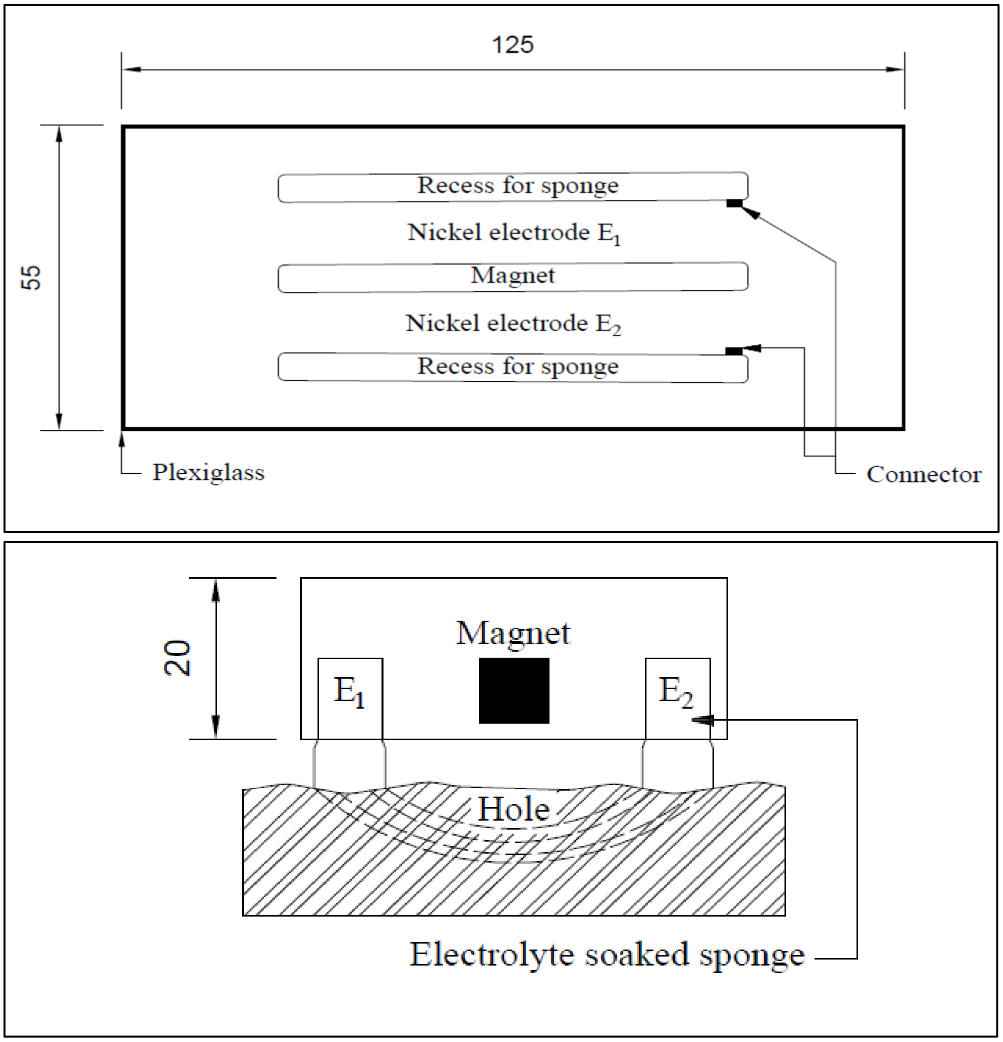

Figure 2: Schematic diagram of the Sensor used for the measurement

The size of the measured value (in arbitrary units) is dependent upon the cross sectional area of the connecting electrolyte, and therefore depends, solely on the number of ineffective areas in the hydrophobic treatment in the area under test and on time. It follows that the profile of the resulting measured value-time plot is synonymous with the condition of any treatment present.

Initial preparation includes cleaning of the terminals and calibration test plate, making a saturated sodium hydroxide solution and application of a coating to the area surrounding the test zone. Once the initial preparation has been completed, testing on a horizontal surface involves use of sponges soaked in saturated $Na(OH)_2$ solution which are positioned in the terminals, and then connected to the control box. The terminals are 100mm long by 50mm wide; the test area thus has to be greater than these dimensions. The test starts when the terminals are placed on the test sample surface and the operation of the equipment is simple. Measurements are made at intervals, until the end of the test at 90 minutes. Four readings were taken at a specific time with the aid of switch and transmitter sockets on the measuring instrument. Average of the readings was taken and used in the analysis of the results.

It would appear that the term "conductivity" is a misnomer. The equipment does not measure conductivity, but in fact measures a surfaces' inability to absorb moisture. The more repellent the surface is to moisture absorption, the lower the readings.

Oxygen Permeability

Specimens 100 mm diameter and 50 mm thickness were used. Figure 3 shows the setup of apparatus used. Specimens were properly placed in the cylindrical cells and sealed to avoid oxygen leakage. The oxygen was allowed to flow into the test specimen at a pressure of 1 bar (10^5 N/m^2) with the top valve of the cell apparatus closed. When equilibrium was reached the valve was opened and the flow of bubbles through the burette was determined.

Figure 3: Gas Permeability Apparatus

Porosity

Specimens used for this test were 70 x 70 mm cubes. The specimens were put in a glass vessel (Figure 4) and air was expelled for about one hour using vacuum saturation pump at a pressure of about 760mm Hg. The vacuum pump was stopped and the glass vessel was filled with distilled water through an open valve. The vacuum pump was switched on again for another one hour to be sure that the specimens were fully saturated. The saturated specimen is then weighed in air and in water and then dried to constant weight in the oven, at 105^{o}C. The total porosity of the sample is then calculated using the following equation:

Porosity = $\frac{M3-M1}{M3-M2}$ x100 [1]

where;

M_3 = mass of sample saturated with water, weighed in air,

M_1 = mass of the dried sample, weighed in air.

M_2 = mass of sample saturated with water, weighed in water.

The result is expressed as a percentage of the bulk volume.

Figure 4: Vacuum Saturation Apparatus

RESULTS AND DISCUSSION

The results of the tests and studies carried out are reported in the following subsections. It should be noted that the test carried out do not exactly reflect what happens on site, but provide understandings of what should be expected when carrying out site tests.

Electrical Conductivity

The results of the electrical conductivity are presented in Figure 5a to 5e.

Influence on Treatment

In all cases of concrete treated with penetrating sealer, the electrical conductivity result was significantly reduced when compared with that of the untreated concrete. Electrical conductivity depends on the moisture content of concrete and the presence of penetrating sealer reduces the ingress of moisture, consequently, the treated concrete surface was observed to have a lower value of electrical conductivity compared to the untreated concrete. The initial current values indicate the degree of saturation of the concrete, or the amount of conductive solution other than water present. It is also important to observe that the initial value of current passed differ for the treated and untreated concrete surfaces. The values give an indication of the wetness or saturation of the concrete. As can be seen from the figures, a dry concrete shows initial zero reading. It was also noticed that the shape of the curves for treated concrete is almost flat, starting from the beginning of each curve, while that of untreated concrete shows a rapid increase in the first ten minutes and then tends to be flat depending on degree of saturation of the concrete. This shows that penetrating sealers cause the concrete to portray a good electrical resistance. The cumulative current passed shown in Figure 5b to 5e indicates that under normal condition of fairly saturated treated concretes, the cumulative current passed is not more than 450 mA, while nearly saturated treated concretes do have cumulative current passed of not more than 800 mA even when salt is present. In general, concrete treated with penetrating sealer reduces the amount and rate at which moisture can penetrate the concrete, and consequently, reduced the electrical conductivity.

Influence on Water-Cement Ratio

The results shown in Figures 5a and 5e shows a general increase in the electrical conductivity of concrete when water-cement ratio is reduced from 0.5 to 0.35. Unlike the case of water absorption that increases as the water content of the concrete decreases, electrical conductivity increases with increase in water content. However, it should be remembered that the presence of ions other than water may increase or decrease the electrical conductivity of concrete.

Influence of PFA

The presence of PFA was observed to greatly reduce the electrical conductivity of treated and untreated concrete. The reduced presence of lime in the PFA mix, as a result of pozzolanic reaction, makes it effective in reducing the electric conductivity of concrete. Reduction of 20–70% for untreated concrete is observed. The treated concrete containing PFA exhibits a greater reduction of 45–80% electrical conductivity compared to concrete containing 100% OPC of the same water-cement ratio. The treated concretes containing PFA experienced a maximum value of 319 mA of current passing in the absence of salt. The treated concrete containing PFA and the presence of salt, gave a value of 569 mA of current passed which is not bad compared with the untreated concrete. It can be seen that PFA generally reduced the electrical conductivity of concrete.

Influence of Environmental Conditions

Figures 5a shows that the treated and untreated concrete dried in oven exhibits lower value of electrical conductivity than the concretes subjected to low temperature. This is expected since the water content determines the electrical conductivity of concrete, the greater the water content the greater electrical resistivity. However, when all the water have been removed, the test results still show some values for untreated concrete, and the reason being that electrolyte used in performing the experiment is absorbed by the concrete and hence provide contact for current flow. The electrical conductivity of treated and untreated concretes soaked in salinated exhibits higher value than that soaked in water and as known salt is a better conductor of electricity than water. Figure 5a to 5e show the electrical resistivity of concrete subjected to different environments. It can be seen clearly that the value of current passed depends on the amount of moisture presence and the conductive ions other than water.

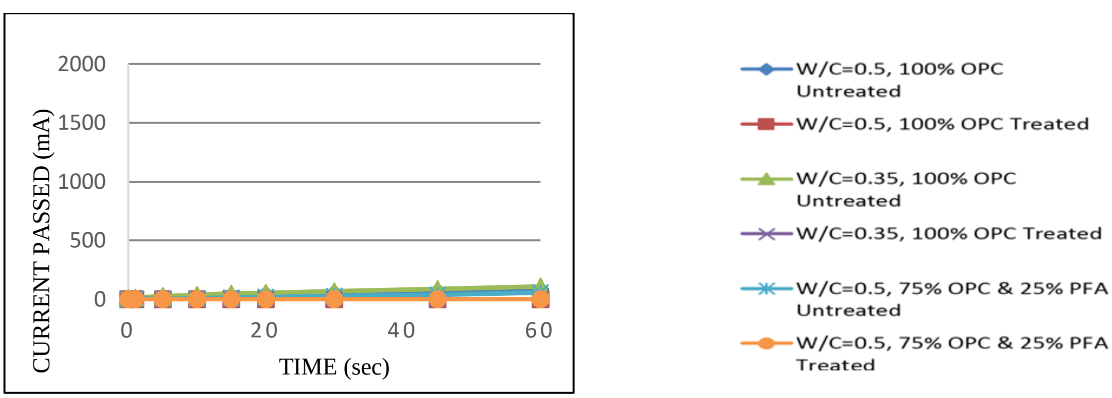

Figure 5.a: Electrical Conductivity of Oven

Key

Dry Concrete Specimens

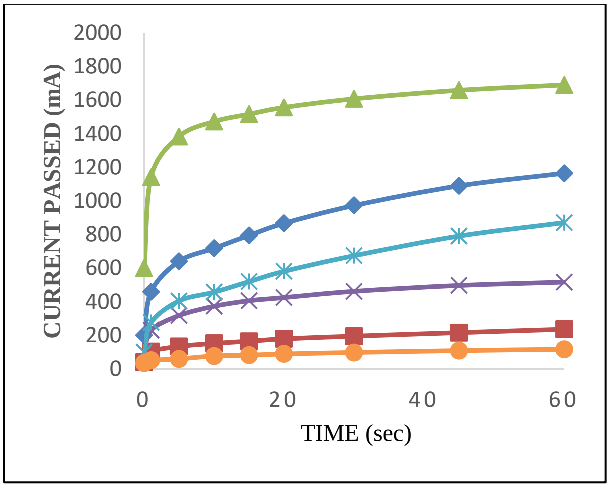

Figure 5.b: Electrical conductivity of Concrete Specimens Left inside Lab

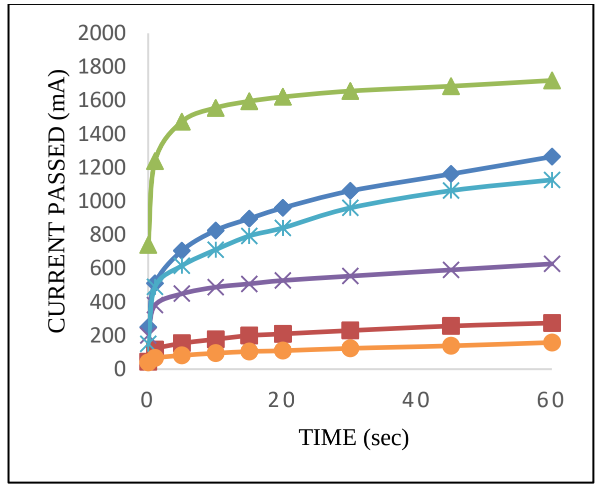

Figure 5.c: Electrical Conductivity of Specimens Stored outside Lab

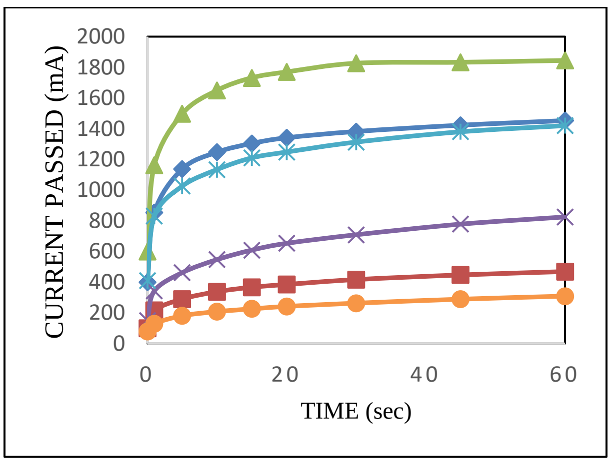

Figure 5.d: Electrical Conductivity of Concrete Specimens Soaked in Deionized Water

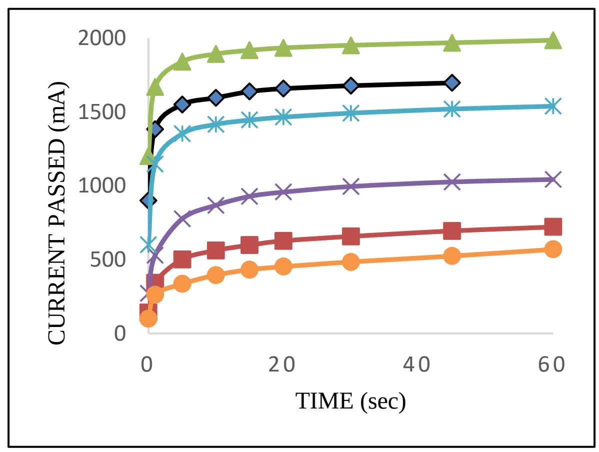

Figure 5.e: Electrical Conductivity of Concrete Specimens Soaked in Salinated Water

Porosity

Figure 6, shows the results of porosity. It was observed that treatment of concrete reduces porosity but not as significant as generally observed in initial surface absorption and electrical resistivity. However, decreasing water-cement ratio resulted in significant reduction in porosity. The presence of PFA reduces the porosity of treated and untreated concrete. The concrete soaked in salinated water show a higher porosity than the concrete treated in deionized.

Oxygen Permeability

The results of oxygen permeability are similar in pattern to porosity. The treatment reduces the oxygen permeability of concrete. Permeability decreases as water-cement ratio decreases. The presence of PFA further reduced the oxygen permeability of treated and untreated concretes. For results of oxygen permeability at each water-cement ratio showing the influence of the environment on treated and untreated concrete, see Figure 7 below.

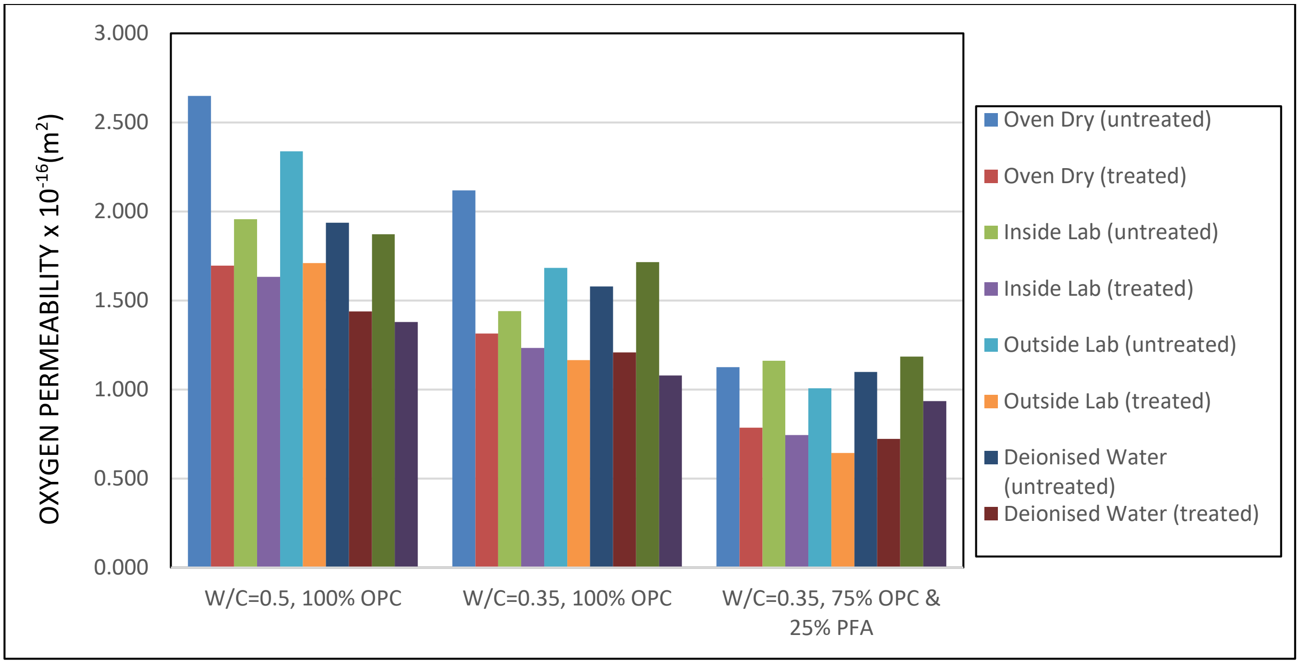

Figure 7: Oxygen Permeability Test Results

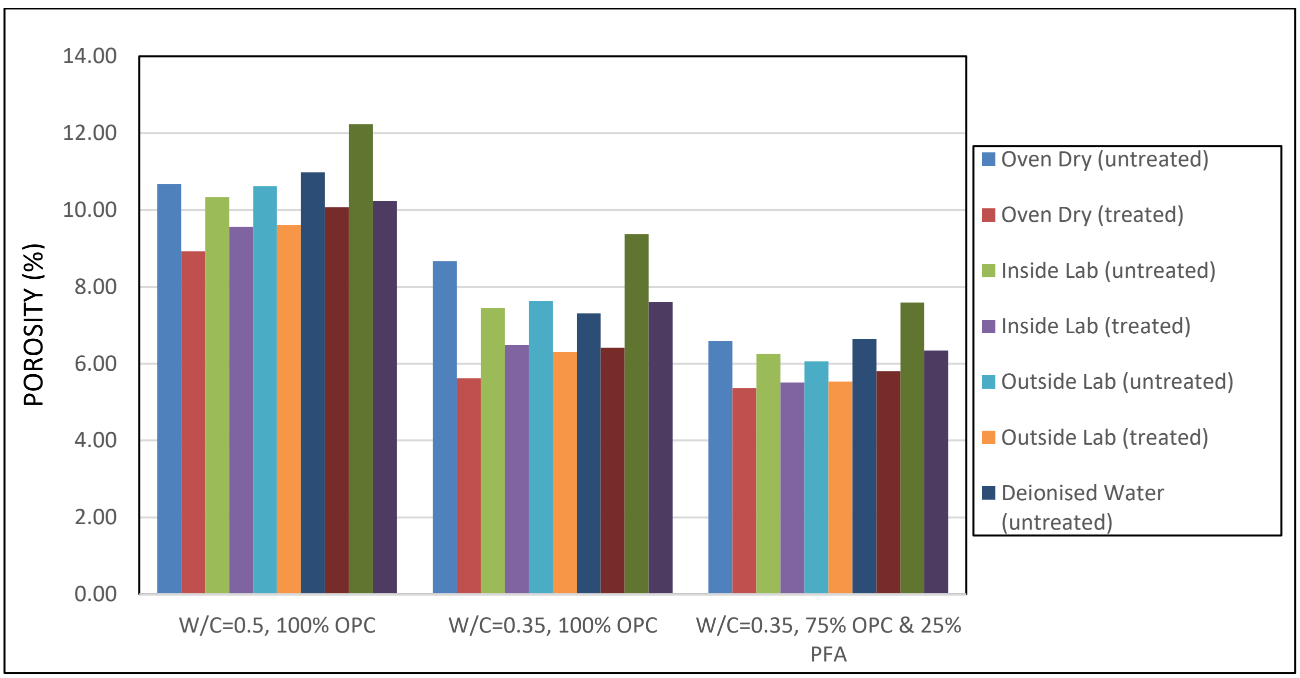

Figure 6: Porosity Test Results

CONCLUSIONS

From the results of the experiments carried out, the following conclusions could be made regarding the performance of treated and untreated concretes.

1. Electrical conductivity technique is suitable for non-destructive assessment of the efficacy of surface-treated concrete**.**
2. The effects of penetrating sealers on various types of concrete are different. The moisture condition affects the durability test performance and this effect must be taken into account when assessing the performance of penetrating sealer on concrete.
3. The electrical conductivity results were sensitive to the water content of the concrete mix and was found to be increasing as water-cement ratio decreases.
4. The presence of pozzolanic materials further enhances the durability performance of the concrete. A greater reduction in electrical conductivity of treated and untreated concretes was observed when pulverized Fuel Ash (PFA) was used as cement replacement.
5. The difference in porosity between treated and untreated concrete is small compared to that observed for electrical conductivity.

REFERENCE

Bashear, L., Cleland, D.L, Bashear, P.A.M., Long, A.E, (1992). "Assessment of the performance of surface treated concrete", Proceeding protective coatings.

Bashear, P.A.M.,(1992), "A brief review of methods for measuring the permeation properties of concrete in-situ". Proceedings Structures and Buildings, Institution of Civil Engineers(feruary 1992), pp. 74-83.

Bashear, P.A.M., Montgomery, F.R., Long, A.E., Batayneh, M.(1990). "Durability of Surface Treated Concrete". R.K. Dhir, J.W. Green, E. spon,(Eds.), Protection of concrete , pp. 212-221.

British Standard Institution, BS1881(1970). "Methods of testing concrete Part 5: Methods of testing hardened concrete for other than strength".

CIRIA (1987), "Protection of Reinforced Concrete by Surface Treatments", Technical Note 130, Construction Industry Research and Information Association, Esslingen.

Hewlett P.C.(1990). "Methods of Protecting Concrete-Coatings and Linings", J.W.Green, E. Spon, R.K. Dhir (Eds.), Protection of Concrete (1990), pp. 105-134.

Nwaubani, S.O and Dumbelton, J. (2001). "Practical approach to in-situ evaluation of surface-treated structures", Construction and building materials, 15(4), pp. 199-212.

Nwaubani, S.O. (2018), "Non-destructive testing of concrete treated with penetrating surface sealant using a Karsten-tube". International Conference on Concrete Repairs, Rehabilitation and Retrofitting (ICCRRR 2018). MATEC Web of Conferences 199, 07010.