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Assessment of Non-destructive Methods for Evaluating the Performance of Surface Treatments on Concrete

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Abstract. Hydrophobic films are frequently applied to concrete structures to reduce water ingress and provide protection against weathering and chemical attacks. However, these waterproof coatings tend to deteriorate with time and require reapplication to maintain their effectiveness. Deciding when the retreatment should be applied and how to assess existing treated surfaces can sometimes be a challenging task for owners of concrete structures. Consequently, this paper presents findings on the assessment of absorption characteristics of surface-treated concrete using several techniques. Three non-destructive test methods were used to evaluate the efficacy of surface treatment under different curing conditions and with varying numbers of treatments. The methods employed were the initial surface absorption test, Karsten tube test and electrical conductivity test (wet method). The results show that the employed methods were all able to distinguish between treated and untreated surfaces. Treated samples exhibited better resistance to water absorption and electrical conductivity than untreated ones, and the absorption characteristics were found to be influenced by the number of treatments and curing regimes. All three test methods were effective in assessing surface treatment quality, with the Karsten tube test being the most practical for in-situ evaluation due to the simplicity of its setup.

Keywords: Hydrophobised concrete, Non-destructive testing, Initial surface absorption test, Karsten tube, Electrical conductivity, Surface treatment.

1. Introduction

It is widely known that the deterioration of concrete is often due to the intrusion of moisture and deleterious substances (Chen et al., 2018; Gilayeneh & Nwaubani, 2022) and can be avoided, provided the ingress of water is prevented (Benson et al., 1998; Zhang et al., 2010; Gardner et al., 2018). Apart from water being a conveyor through which harmful substances are transported or deposited into concrete, its presence is also vital for many deterioration-related chemical processes (Yu et al., 2018; Beushausen et al., 2021; Al-Jabari, 2022). Therefore, if water, together with any chemical it carries in solution such as chlorides and sulphates, is prevented from penetrating through the cover concrete, most durability-related issues can be averted, and the service life of the structure extended. Modern research has shown that one of the most practical and economical means of preserving and enhancing the durability of concrete is by hydrophobisation, which is simply the process of making concrete water-resistant through the application of hydrophobic agents or coatings (Nwaubani & Dumbelton, 2001; Pan et al., 2017).

An improvement in the durability of concrete is also a step towards sustainability as the need for frequent replacement or maintenance is avoided. Being the most widely used construction material, concrete's longevity has positive implications for the environment. Reducing the frequency of repairs or replacements helps minimise the environmental impact associated with Portland cement, whose production process is energy-intensive and releases greenhouse gases (Boesch & Hellweg, 2010; Georgiopoulou & Lyberatos, 2018). Apart from Portland cement production, the construction industry itself is also considered unsustainable and harmful to the environment as it is resource-intensive and generates huge amount of waste (Spence & Mulligan, 1995; Teo & Loosemore, 2001; Ajayi et al., 2015). Therefore, the use of surface treatment on concrete structures as a means of enhancing durability can also be considered a conscious approach to protecting the environment.

It is for the above reasons that many commercial products, ranging from organic to inorganic coatings are now being developed for application as surface treatment and waterproofing of exposed concrete structures. However, these protective coatings often degrade over time, mainly due to exposure to ultraviolet radiation (Büttner & Raupach, 2008; Lucquiaud et al., 2014). Many of these waterproofing or water-repelling agents, particularly silane and siloxane sealers, are colourless and become absorbed into the surface of the concrete. Thus, the presence of these hydrophobised layers may not be visible to the naked eye, and so non-conventional methods may be required for assessing the presence and quality of existing surface treatment (Nwaubani et al., 2000). In practice, deciding which assessment method to employ is also a daunting task for owners of ageing concrete structures. An EU-sponsored project carried out by Nwaubani and other international partners (Nwaubani & Dumbelton, 2001, 1997; Nwaubani, 1999) has proposed the use of a simple but reliable suite of non-destructive test methods for evaluating the efficacy of surface-treated Historic stone faces in European structures. Their research established that the most appropriate site techniques for characterising the performance and conditions of surface treatments on Historic stone structures are the electrical conductivity and Karsten Tube tests (Nwaubani, 2019, 2018).

Although no test has been specifically developed for assessing the quality of concrete's surface treatment, there are well-established non-destructive techniques that could be adopted (Dumbelton, 1996). As a result, numerous efforts including other EU-sponsored projects (Van Hees et al., 1995; Tilly et al., 1996) have been directed towards assessing the applicability of available techniques for in-situ evaluation of surface treatment on concrete. Notwithstanding, there is still a need to ascertain the following:

- How the number of applied treatments affects the absorption characteristics of surface-treated concrete.
- How to determine when the need arises for re-treatment of a previously treated surface that has been exposed to weathering.
- The influence of curing regimes and environmental conditions on the absorption characteristics of surface-treated concrete.
- The influence of assessment methods and procedures on the findings obtained.

2. Research Objectives

This paper presents and discusses the results of an investigation carried out to assess the applicability of three non-destructive methods in evaluating the performance of surface treatments and how the number of applied treatments and curing regimes of treated samples affect the surface absorption characteristics. The applied surface treatment was silane and was chosen because of its ability to outperform other treatments and hence, has become the most preferred treatment in the industry. Initial surface absorption test (ISAT), Karsten tube water absorption test, and electrical conductivity were the three non-destructive techniques employed in this investigation.

3. Experimental Details and Procedures

3.1. Specimen Description, Preparation and Curing Conditions

Two sizes of concrete specimens were used in this investigation: 100-mm cube specimens for the ISAT and Karsten tube test, and 300 x 150 x 60 mm specimens for the electrical conductivity test. The concrete samples were made with a w/b ratio of 0.7, cement content of 340 kg/m^3 and a mix ratio of 1:2:3. The concrete had a 28-day compressive strength of 35.3 MPa. The cement used was Ordinary Portland Cement 32.5N while the fine and coarse aggregates were uncrushed river sand and gravel, respectively. Mixing was done in a rotary mixer for a total duration of five minutes. The aggregates and cement were first mixed before adding water. After mixing, the concrete was poured into the moulds and properly vibrated. The specimens were demoulded after 24 hours and cured in water for two weeks at a temperature of 20 ± 3 ˚C. After the two-week period, the specimens were removed from the curing bath and allowed to dry for a week under ambient conditions of the laboratory (approximately 20 ± 3 ˚C) before the application of the penetrating sealer.

The specimens were coated with monomeric alkyl (isobutyl) tri-alkoxy silane. The treatment was applied by a continuous spray at a coverage rate and nozzle pressure of 300 ml/m^2 and 0.069 N/mm^2, respectively. For samples receiving more than one treatment, the second coating was applied 48 hours after the first treatment. After the application of the penetrating sealer, the specimens were allowed to continue curing for another week either under the ambient laboratory condition or in an oven at 50 degrees Celsius for 48 hours and then at the ambient laboratory condition for the remaining of the curing period. Table 1 presents the scenarios investigated as well as the specimen nomenclatures. All specimens were tested after 28 days of casting and for each scenario, three specimens were investigated.

Table 1. Specimen Nomenclatures and Curing Conditions.

Specimen Label	Number of treatments Applied	Curing Conditions
UT - 20˚C	Untreated (control)	20˚ Celsius
ST - 20˚C	Single Treatment	20˚ Celsius
DT - 20˚C	Double Treatment	20˚ Celsius
ST - 50˚C	Single Treatment	50˚ C for 48 hrs and then at 20˚ C

3.2. Initial Surface Absorption Test (ISAT)

Initial surface absorption test (ISAT) is a British Standard test for measuring water absorption properties of concrete and as such, the test was conducted as prescribed by BS 1881: Part 5 (1970). Figure 1 shows the schematic diagram of the test apparatus and setup. The setup comprised a specimen clamp, a reservoir, a cap, capillary tubes, and a capillary scale. The specimen was secured in the clamp and the cap positioned and tightened. After, the capillary tubes were connected from the reservoir to the inlet of the cap, and from the outlet of the cap to the capillary scale. The reservoir was set up to maintain a water head of 200 ± 20 mm above the specimen's surface. Following this, the reservoir was filled with water and the inlet valve of the cap was opened to allow water to flow in. The water level in the reservoir was regularly replenished to maintain the water head of 200 ± 20 mm. Water was allowed to overflow through the capillary scale to release any trapped air. The valve was then closed, and the stopwatch started when the flow on the capillary scale reached zero. The readings were taken at 10-, 30-, and 60-minute intervals. The presented data is the average of three readings taken from three test specimens.

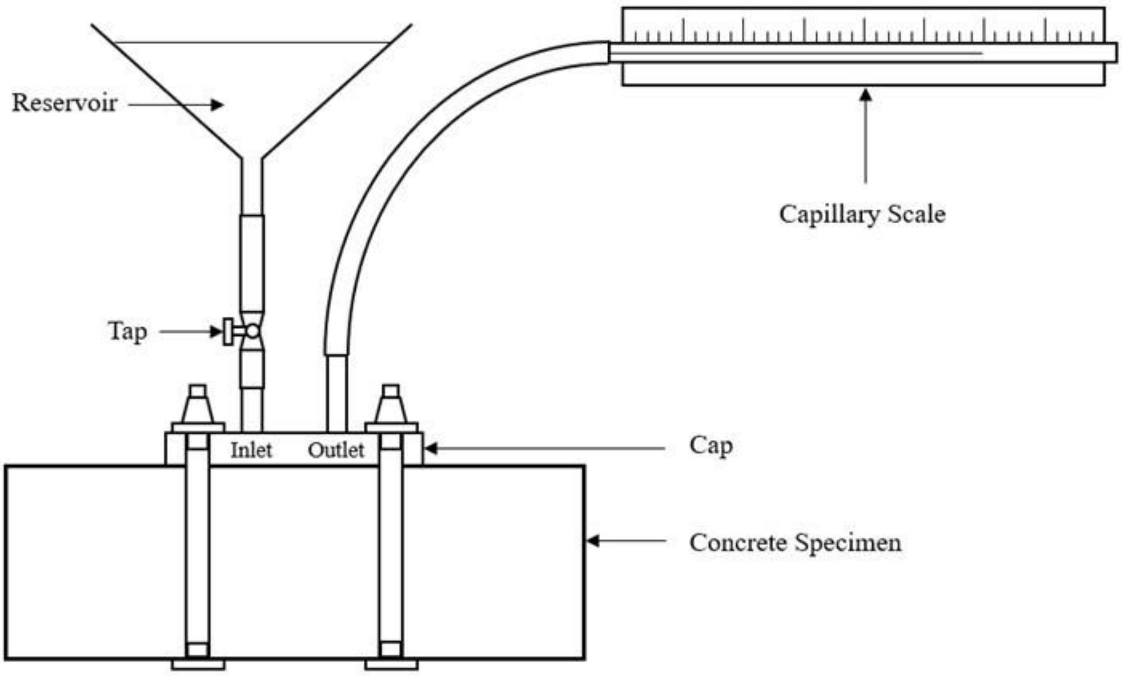


Fig 1. Schematic of the Initial Surface Absorption Test.

3.3. Karsten Tube test

Karsten tube test also measures water absorption of concrete and is similar to the RILEM tube test which has been adopted in the United States for assessing the absorbency of water-repellent treated surfaces. The standard procedure for conducting this test is described in RILEM TC 25-PEM (1980), and the setup consists of a graduated glass tube which has a diameter and capacity of 2.7 mm and 4 ml, respectively. The schematic of the Karsten tube test is illustrated in Figure 2. As shown in Figure 2, the end of the graduated glass tube which has a bowl-like shape was fastened to the sample with commercial modelling clay. The tube was filled with water to the appropriate level (the zero mark) and the stopwatch started. The volume of the absorbed water was recorded at various intervals up to an hour. The presented result is the average of three readings from three test specimens.

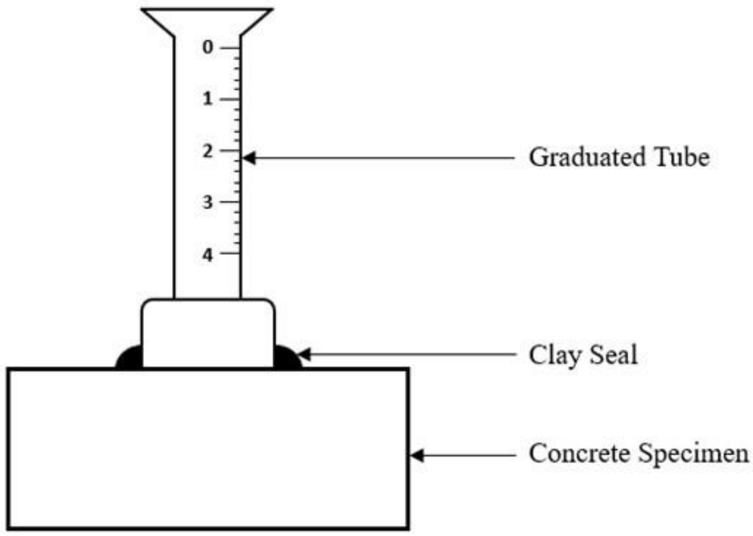


Fig 2. Schematic of the Karsten Tube Test.

3.4. Electrical Conductivity Test

Conductivity, which is the measure of the ability of a substance to conduct electric charges, is the inverse of resistivity. Thus, the measure of a substance's conductivity is also a direct measure of its resistivity. High conductance is an indication of low resistance and vice versa. The method used in this investigation takes advantage of the principle of current flow in an electrolytic solution and, hence, can be called the Wet Method. A constant AC voltage is applied through the electrodes and the electrolyte, which are in contact with the test surface. As the electrolyte penetrates the concrete, the flow of the current increases. Figure 3 shows the setup schematic of the electrical conductivity test. The setup consisted of two Nickel electrodes mounted in a plastic casing, which is connected to a control unit. As shown in the schematic, the ends of the electrodes protruding out of the plastic casing were wrapped with a sponge. Before the testing, all parts of the test kit were cleaned, and the equipment calibrated. The sponge-end of the electrodes was then soaked in sodium hydroxide solution. The test started when the terminals were placed on the test surface and the stopwatch started. Readings of the electrical conductivity test were also taken at various intervals up to an hour and the data presented are the averages of three sets of readings. For this investigation, the Germany ZTV-SIB 90 was adopted as there is currently no relevant standard for measuring the electrical resistivity or conductivity of concrete.

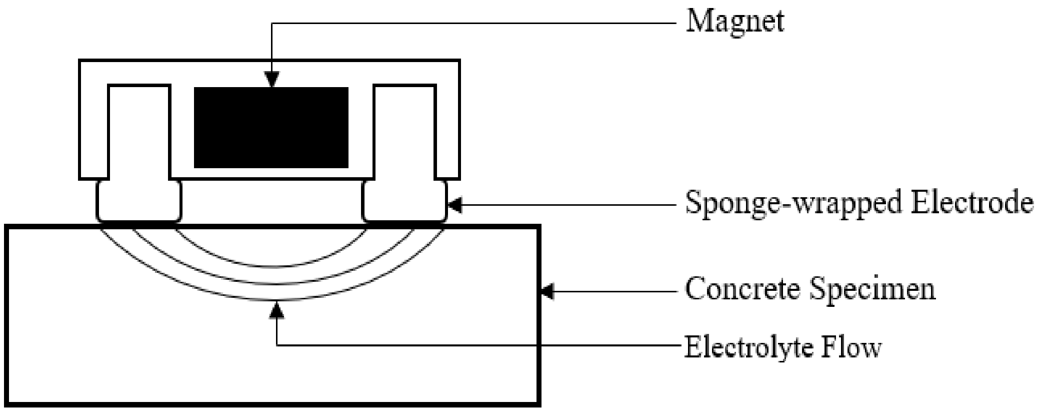
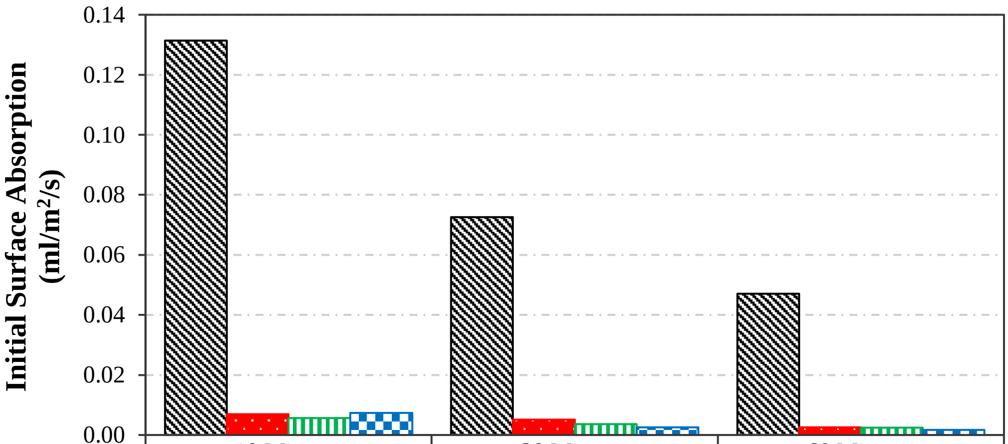


Fig 3. Schematic of the Electrical Conductivity Test.

4. Results and Discussion

4.1. Initial Surface Absorption Test (ISAT) Results

The results of the ISAT test are presented in Figure 4, which shows that there is a clear difference between treated and untreated samples. Untreated samples displayed the highest water absorption. This suggests that ISAT has the potential to distinguish between sections of concrete that have been successfully hydrophobised and those that have not been successfully treated. The 10-minute absorption of the untreated samples was 1800 and 2250% more than the single- and double-treated samples, respectively, which were all subjected to the same curing conditions. The number of applied treatments and curing regimes of the treated samples were also found to influence the absorption characteristics. Samples with double treatment absorbed less water than the single treatment but the difference in absorption seemed negligible at 60 minutes. The single-treated samples (ST - 50˚C), cured at 50 degrees for 48 hours, exhibited the lowest absorption at 30 and 60 minutes.



	10 Minutes	30 Minutes	60 Minutes
UT - 20˚C	0.1314	0.0726	0.0471
ST - 20˚C	0.0069	0.0051	0.0025
DT - 20˚C	0.0056	0.0036	0.0024
ST - 50˚C	0.0074	0.0025	0.0017

Fig 4. Results of the Initial Surface Absorption Test.

4.2. Karsten Tube Test Results

Karsten tube measures the cumulative water absorbed by the specimen with respect to time and the results are presented in Figure 5. The results follow the same order as the initial surface absorption test, with ST - 50˚C samples showing the lowest absorption. Untreated samples were found to experience the highest level of water absorption, and the number of treatments and curing regimes of the treated samples were also found to influence the absorption characteristics of the surface treatment. Similarly, the results also show the suitability of using the Karsten tube test for distinguishing between treated and untreated concrete surfaces. These findings further demonstrate the effectiveness of surface treatment in increasing concrete's resistance to water penetration.

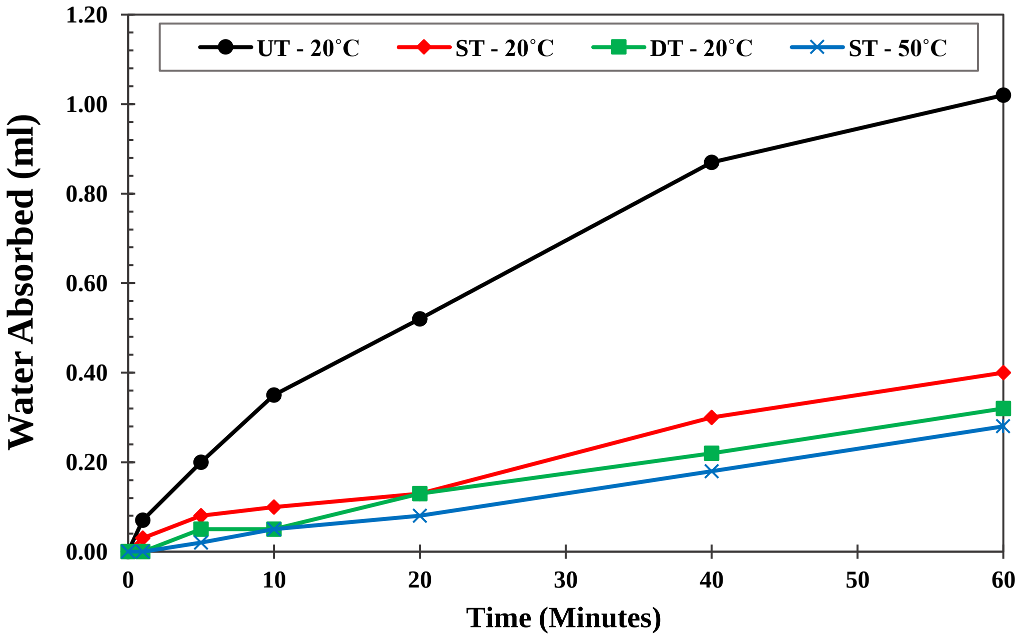


Fig 5. Results of the Karsten Tube Test.

4.3. Electrical Conductivity Test Results

Table 2 presents the results of the electrical conductivity test. As with the water absorption tests, untreated samples exhibited the highest conduction. However, the double-treated samples cured at 20° C displayed the lowest conductivity instead of ST - 50 specimens as displayed in the water absorption tests. This emphasized the effectiveness of silane treatment in blocking the passage of ionic species (Hassan & Cabrera, 1995; Ibrahim et al., 1997; Medeiros & Helene, 2008). The results also show that the ability of silane treatment to block ionic species (sodium and hydroxide ions as in the case of this study) improves with the number of treatments. It is also worth noting that an increase in the current readings with time is observed for all samples and can be attributed to the gradual diffusion of the sodium and hydroxide ions through the silane coating. The untreated samples had extremely high current flowing through as early as 1 minute after being in contact with the electrodes, which can be linked to the rapid penetration of the electrolyte. When compared to the treated samples cured at the same temperature, a reduction of over 3700 and 8200% is observed for the single and double treatment, respectively. This further validates the role of surface treatment in improving concrete's resistivity as well as the potential of electrical conductivity or resistivity testing for hydrophobisation.

Table 2. Results of the Electrical Conductivity Test.

Time (Minutes)	**Measured Current (mA)**							
	1	**5**	**10**	**15**	**20**	**30**	**45**	**60**
UT - 20°C	500	596	688	772	838	940	1033	1082
ST - 20°C	13	19	23	28	34	48	61	70
DT - 20°C	6	7	8	9	9	11	12	14
ST - 50°C	9	15	18	22	24	28	34	38

5. Conclusions

This paper describes the surface absorption characteristics of hydrophobised concrete, which were assessed by the initial surface absorption test, Karsten tube test and electrical conductivity test. The results presented show that all three test methods investigated can reasonably differentiate hydrophobised surfaces from non-hydrophobised surfaces. The findings of this investigation further prove that water absorption and electrical resistivity or conductivity are essential criteria, not only for characterising the performance and quality of the concrete itself but also for assessing the effectiveness of concrete's surface treatments. An effective surface treatment should have low water absorption and high resistance to conduction. Based on the obtained results, the following conclusions can be reached:

1. The application of surface treatment does modify the absorption characteristics of concrete and is effective in improving concrete's resistance to water penetration and electrical conduction.
2. Treated samples displayed better resistance to water absorption and conduction than untreated ones.
3. An increase in the number of treatments correlates with better resistance to water absorption and electrical conduction, although the observed difference between single and double treatment seem marginal for the water absorption tests.
4. Similarly, as the number of treatments increases, the efficacy of silane treatment in blocking ionic species such as sodium and hydroxide ions also improves.

5. The curing of treated samples at a higher temperature did improve the quality of the surface treatment.
6. All three tests were fairly simple and relatively easy to carry out. However, the Karsten tube test seems to be the most practical for in-situ evaluation given the simplicity of its test apparatus.

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