Non-destructive testing of concrete treated with penetrating surface sealant using a Karsten-tube.

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Abstract: Surface treatment is increasingly becoming acceptable as a means of ensuring concrete durability by way of controlling or preventing the ingress of various deleterious agents of concrete deterioration. In practice, a combination of non-destructive and semi-destructive evaluation of the concrete surface is often necessary to decide on the need for treatment or re-treatment of previously treated surfaces. The owners of structures and restorers appreciate simple and non-destructive methods in making any interventions on surfaces that have been treated previously. Existing knowledge would suggest that correct interpretation of these test results would depend on an understanding of the effect of factors such as the initial moisture content, quality of the concrete and exposure conditions. This paper presents the result of a study to assess the applicability of the “Karsten-tube” in measuring the water uptake of treated and un-treated concrete surfaces and the effects of the concrete quality, and environmental conditions upon the test results. The results are compared with complementary tests for oxygen permeability and porosity of the concrete specimens studied. 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 indicates that Karsten-tube is a quick non-destructive method for obtaining useful information about the condition of treated and un-treated concrete surfaces and could be used for rapid and reliable assessment of the need for re-treatment of previously treated surfaces. Well-treated surfaces will have low water uptake values, irrespective of the quality of the concrete.

1. 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 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 [1,2,3,4], thus excessive build-up within the concrete is discouraged.

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 [5,6]. Because silanes and siloxanes chemically react with concrete, it is 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.

The unsealed and sealed concrete structures require 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 ions penetration and other aggressive agents. For example, the British Standard [7] for testing silicones suggests immersing freshly prepared and treated concrete in water for 7 days. The increase in weight is obtained by removing cores, as suggested in BS1881, part 122 [8]. These tests are destructive, time consuming, costly and the number of samples that can be taken from a structure are limited. Non-destructive test methods are therefore more desirable and cost effective.

A number of non-destructive test have been developed [9] for concrete. In practice, compressive strength has long been found a convenient measure for assessing concrete quality [10,11,12], largely because of the experience and knowledge that has been accumulated from the use of the cube crushing test as a control for concrete production. The trust vested in 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 as a good indicator of the 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. In some countries the life of the structures can be lengthened by providing

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extra cover to steel, by chamfering the corners or by using circular cross-sections or by using surface coatings which prevent or reduce the ingress of water, carbon dioxide or aggressive chemicals.

Experience has shown that using surface coatings is practical and it makes sense [13]. The consequence of this is that recently, it has become mandatory in many countries for Highway concrete bridges. Other practical methods, for evaluation and assessment of the efficacy of treated concrete and stone surfaces has been suggested [14, 15, 16], but more needs to be done for this to be widely accepted. Thus, this paper presents the results of a study carried out on concrete surfaces, with and without penetrating sealers, using simple, and mostly non-destructive in-situ test methods to evaluate moisture absorption. 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, exposure to laboratory air, leaving outside laboratory and drying in an oven at 100 °C.

2. Materials and experimental details

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

2.1 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.

2.2 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°C to eliminate the effect of variable moisture. The moisture content determination was carried according to BS1881: Part 122. The percentage by weight of water absorption of coarse aggregate and fine aggregate used were 3.6% and 2.4% respectively.

2.3 Water

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

2.4 Admixture and Sealant.

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

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 ₂ O ₃	5.02	27.90
Fe ₂ O 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 ₂ O	0.39	0.80
K ₂ O	0.84	3.70
P ₂ O 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 m ² /g (BET)	1.04	1.29

2.5. Experimental details

2.5.1 Mix proportion

Three concrete mixtures 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. Proportion of the binder: fine aggregate: coarse aggregate was 1:2.06:3.08. The mixes had a cement content of 360 kg/m³.

Superplasticizer was used for Mix B and C to maintain same slump of 50 ± 25mm for all mixtures.

2.5.2 Specimen Preparation and Curing

Three types of specimens were prepared: 400 x 400 x 100 mm slabs for the measurement of surface water absorption; 100 mm diameter and 50 mm thickness cylinders for the determination of the coefficient of oxygen permeability; and 70 x 70 mm cubes for the determination of porosity. A total of 75 specimens was 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 poker vibrator. Specimens were finished with a smooth wood, then covered with plastic to prevent early evaporation. Specimens were stripped from their moulds the day

following casting and placed in a curing room at 20 ± 2 °C and about 99 percent relative humidity for 28 days.

2.5.3 Application of the penetration Sealant

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 treatment of specimens was delayed for minimum of 28 days to allow adequate strength to be attained, and to avoid the possibility of the concrete reacting with penetrating sealer. The rate of application of saline solution was 0.3 liters/m². One side of each slab was treated; selected cubes and cylinders were completely treated, while others were left untreated. Two coats of these sealant materials were applied.

2.5.4 Environmental Conditions

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

- i. Oven dries at 110 °C.
- ii. Inside laboratory at 20 ± 2 °C
- iii. 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 they were 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 can be obtained.

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

2.5.5 Water Absorption Test

Fig. 1 shows details of the “Karsten” tube used for the test on vertical surfaces. The test is similar to the RILEM tube test which was adopted in the United States in the early 1980s by the water repellent manufacturing industry to assess water absorption properties of walls and other substrates, with or without treatment. It consists of a graduated tube with a diameter of 2.7mm and a 4ml capacity. At the bottom there is an opening with an area of water in contact with the test surface as described in RILEM COMMISSION 25-PEM [17] PROCEDURE II.4. The Karsten tube used for the water absorption tests are fixed to the concrete using commercial modelling clay. Water is poured into the tube and the volume of water absorbed over 60 minutes duration is measured. The amount of water absorbed by the concrete is measured at intervals. Tests are repeated three times in selected areas of the slab specimen and the volume of water plotted against the time.

Fig.1. Karsten Tube Kit

2.5.6 Oxygen permeability

Specimens 100 mm diameter and 50 mm thickness were used. Fig.2 show the setup of the apparatus used. Specimens were carefully placed 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/m²) with the top valve of the cell apparatus closed. When equilibrium was reached the valve was opened and the flow of oxygen bubbles through the burette was determined.

Fig. 2 Gas Permeability Apparatus

2.5.7 Porosity

The specimens used for this test were 70 x 70 mm cubes. The specimens were put in a glass vessel (Fig. 3) and air was expelled for about one hour using vacuum saturation pump at a pressure of about 760 mm Hg. The vacuum pump was stopped and the glass vessel was filled with distilled water through an open valve. The vacuum pump was started again for another one hour, to be sure that the specimens were fully saturated. Fig.3 shows the setup of the vacuum saturation apparatus used for porosity determination.

Fig.3 Vacuum saturation apparatus

3. Results and discussion

The results of the water absorption for different mixes and different environmental conditions of concrete, treated and untreated are presented in figures 4a to 4e. In all the tests carried out for surface water absorption, the concrete treated with penetrating sealant shows significant reduction in water uptake than the untreated concrete. Fig. 4a to 4e show that, irrespective of water-cement ratio and environmental conditions, the maximum value of water absorption is 0.28 ml for the treated concrete and maximum value of 1.35 ml for untreated concretes. The significant reduction in water absorption of treated concrete compared with the untreated concrete indicates that if adequate treatment can be provided, water absorption would be limited.

3.1 Influence of water-cement ratio

It was observed from Fig. 4a and 4e that the rate of water absorption decreases as water-cement ratio decreases. The decrease in water absorption is about 40 percent for the untreated oven dry specimen, while for others that are partially saturated, the decrease was between 10 – 20 percent, as water-cement ratio decreased from 0.5 to 0.35. The treated concrete show between 5 – 20 percent decreases in water absorption as water-cement ratio decreases from 0.5 to 0.35. Comparing the results of treated and untreated concrete with ISAT [18] typical value of rate of water absorption at 60 minutes of test, it was observed that all the treated and untreated concrete performed satisfactorily except for untreated oven dry concrete water absorption greater than 0.17 ml/m²/s for typical low water absorption value. However, the untreated oven dry concrete at water-cement ratio of 0.35 are within the range of 0.17 – 0.35 ml/m²/s typical value of ISAT for average water absorption compared to untreated oven dry concrete at water-cement ratio of 0.5. Actually, the high rate of water absorption for oven dry concrete at water-cement of 0.5 may not be expected on site, as complete removal of water from concrete is not possible under normal condition.

3.2 Influence of PFA

The results show the influence of pulverized Fuel Ash (PFA) in reducing water absorption of concrete. Reduction of 15 – 20% in the water absorption of untreated PFA concrete was observed when compared with OPC only concrete mix of the same water-cement ratio. The treated concrete also shows a significant reduction in water absorption due to presence of PFA. The reduction is due to the fact that PFA is instrumental in causing pozzolanic reaction and the resulting deposition of the extra hydration products leads to pore refinement or transformation of large pores into fine pores. Figure 4a to 4e shows that for treated and untreated concrete, the rate of water absorption is significantly reduced in the presence of PFA.

3.3 Influence of environment

The environmental conditions of test specimens, as can be seen in Figure 4a to 4e, show that water absorption decreases with increase in the moisture content of concrete. The oven dry concrete absorbs water steadily at high rate compared to fairly saturated concrete, as noted above. The concrete left outside laboratory shows lower water absorption than the one left inside the laboratory, because the outside one must have absorbed moisture from the atmosphere, though this may not always be the case. There is a decrease of 70 – 80% in water absorption when treated concrete is oven dry, and a decrease of 50 – 70% for other irrespective of water-cement ratio used. The water absorption is greater in concrete soaked in salinated water than the concrete soaked in deionized water. The reason for this is not very clear.

Legend

Figure 4a: Initial Surface Absorption of Oven Dry Concrete Specimens

Figure 4d: Initial Surface Absorption of Concrete Soaked in Salinated water

Figure 4b: Initial Surface Absorption of Concrete inside Lab

Figure 4c: Initial Surface Absorption of Specimens Left inside Lab

Figure 4e: Initial Surface Absorption of Specimens Soaked in Salinated water

3.4 Porosity

Fig. 5 shows the result for the porosity experiments. The treatment of concrete reduces porosity but not significantly. Decreasing the water-cement ratio also led to a very significant reduction in porosity since there is less water which evaporates during drying of the specimen to leave pores in the concrete matrix. The results clearly show that the presence of PFA reduces the porosity of the concrete (treated or untreated). The concrete soaked in salinated water show a higher porosity than the concrete treat in deionized.

3.5 Oxygen Permeability

The results for oxygen permeability test results are shown in Fig.6. They show similar pattern to that of the porosity. The penetrating treatment reduces the measured oxygen permeability for the entire concrete specimen. Permeability decreases as the water-cement ratio of the specimens

5. Porosity Test Results

Fig. 6. Oxygen Permeability Test Results

decreased. The presence of the PFA further reduced the oxygen permeability of treated and untreated specimens. The measurable permeability to oxygen of the specimens was clearly influenced by the environmental exposure condition

Conclusions

From the results of the experiment carried out, the following conclusions are made regarding the performance of treated and untreated concretes.

1. The effects of penetrating sealants on various types of concrete are different. The moisture condition of the concrete matrix affects the amount of water uptake and must be taken into account when assessing the performance of penetrating sealants on concrete.
2. The application of penetrating sealants to concrete incorporating PFA further enhances the overall performance with respect to water absorption and oxygen permeability when compared with the untreated concrete of the same water-cement ratio.
3. Treatment of the concrete surface with penetrating sealant does not cause a large difference in porosity between treated and untreated concrete but the observed difference in the water absorption is significantly high.
4. Lower water-cement ratio and addition of PFA reduces water absorption of concrete, but treatment of the concrete surface with penetrating sealer further improves the water absorption performance of the concrete albeit, marginally.
5. The Karsten-Tube is a quick and effective non-destructive apparatus for determining the moisture absorption of treated and untreated concrete surfaces.
6. Further works should include establishing a relationship between the moisture content of treated and untreated concrete based on the time of application of penetrating sealant, the quality of the concrete and different exposure conditions.

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