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Research Paper

INTERPRETATION OF HYDROPHOBICITY IN CONCRETE BY IMPREGNATION

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The durability of reinforced concrete structures is greatly affected by corrosion of steel reinforcement through chloride attack. The use of impregnates is the most widely employed method to tackle chloride attack for structures in the UK. Impregnate manufacturers and DMRB standards stresses the use of impregnates on dry surfaces, achieving a dry surface is easy however moisture below the surface exists and this can affect the performance of the impregnates. The Concrete cubes were cast and cured, before being submerged in a water bath to determine their moisture content at various times. The cubes were surface dried, water and silane based impregnates were applied and then submerged in salt solution. The cubes were dry drilled at various depths of 5-20 mm for dust samples, which were used to obtain chloride concentrations by the method of Volhards titration. The performance of impregnates is dependent on the quality of concrete, as it directly influences the pore structure which in turn determines the rate of chloride ingress. Impregnate application on dry surface showed a chloride concentration of 0.029% at 20 mm. However impregnates applied to a dry surface, but with a moisture content of 1.88% showed a chloride concentration of 0.053%. This indicates the performance of impregnates is effected by moisture. Although solvent based impregnate performed better than the water based in dry condition, their performance are similar when applied in the moist concrete.

Keywords: Deterioration, Durability, Impregnate, Sorption test, Initial Surface Absorption Test (ISAT)

INTRODUCTION

It has been estimated that the value of the infrastructure built environment represents approximately 50% of the national wealth of most countries within Europe. Because of this the degree and rate of degradation of the built environment in Europe is of enormous economic and technical importance. When it is borne in mind that approximately 50% of the expenditure in the construction industry in Europe is spent on repair, maintenance and remediation then it is evident that even

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marginal savings could result in the release of substantial funds for new developments. One specific area which is assuming an increasing proportion of the costs in most countries is the premature deterioration of concrete structures. It has now been recognized that this lack of durability, relative to that anticipated, needs to be addressed as a matter of urgency. A similar situation exists in countries where much of their development has taken place in this century. However, the proportion of concrete structures is relatively higher than in Europe. For example in the United States, conservative estimates of the current cost to rehabilitate deteriorating concrete structures are in the 100 billion dollar range. It is evident, therefore, that the deterioration of concrete structures is a major problem in almost all parts of the world.

The mechanisms of deterioration and their rate are controlled by the environment, the paste microstructure and the fracture strength of the concrete. Environmental factors such as seasonal temperature variations, cyclical freezing and thawing, rainfall and relative humidity changes, and concentration of deleterious chemicals in the atmosphere water in contact with the concrete are the main causes of degradation. However, the single most important parameter that leads to premature deterioration is the ingress of moisture into the concrete (Basheer, 1996 and Mehta, 1994). Permeability of concrete to the macro-environment during its service life therefore can be used as a measure of its durability. Moisture is continuously transported in the form of liquid and vapor from either the surrounding environment or the internal body of the concrete if the surface is relatively dry. The rate of water and ion ingress through the concrete depends on the physical structure of the paste. Precise characterization of this physical structure is, however, extremely difficult, if not impossible. Therefore average values of permeability, porosity, diffusivity and sorptivity have to be used to model the transport mechanisms through the complex pore structure. The durability of concrete subjected to aggressive environments depends largely on the penetrability of the pore system (Sabir *et al.,* 1998). The main transport processes which describe the movement of aggressive substances through concrete can be categorized as follows such as Absorption, where concrete takes in liquid by capillary suction to fill the pore space available (McCurrich, 1985 and Nevile, 1995). Permeability, where a fluid passes into concrete under the action of a pressure gradient (Perraton, 1992). Diffusion, where a liquid, gas or ion migrates through concrete, due to a concentration gradient (Perraton, 1992).

The concrete is a well-known construction material in civil engineering practice used in many forms and applications. However concrete suffers from being a porous material, allowing moisture to penetrate the surface and enter through its surface pores. This is an undesired characteristic which could lead to deteriorating outcomes, affecting its physical functionality, aesthetics and durability in service life. In fact application of impregnate materials treatment have been developed to protect building materials such as masonry and concrete from water ingression which in turn will prolong service life and durability. The hydrophobic impregnate materials is the one which lines the surface pores providing protection from water ingress, but allows the substrate to breathe, moisture to diffuse out and not become trapped internally. Thus in the present research work an attempt was made to investigation, the effect of Hydrophobicity by considering two different Grades of concrete and hydrophobic impregnates in case of Sorption test and ISAT to procure rate of flow of water with differential time duration without hydrophobic impregnate material.

LITERATURE REVIEW

The enhancement of durability of reinforced concrete is typically associated with a dense concrete matrix, i.e., a very compact microstructure expected to lower permeability and reduce transport of corrosive agents to the steel (Beeldens, 2001). This can be achieved with a well graded particle size distribution (Hwang *et al.,* 1996), supplementary cementitious materials such as fly ash and silica fume (Chang *et al.,* 2001), or low W/C ratios (Mehtam, 1996). These concepts, however, rely upon the concrete to remain uncracked within a structure throughout its expected service life and resist the transport of water, chloride ions, oxygen, etc. In this presumed uncracked state, numerous concrete materials have shown promising durability in laboratory tests (Weiss, 2002). In reality, however, reinforced concrete members crack due to both applied structural loading, shrinkage, chemical attack and thermal deformations, which are practically inevitable and often anticipated in restrained conditions (Mihashi, 2004). The durability of concrete structures is intimately related to the rate at which water is able to penetrate the concrete. This is because concrete is susceptible to degradation through leaching, sulfate attack, freezing-and-thawing damage, and other mechanisms such as steel corrosion in reinforced concrete structures that depend on the ingress of water. Because cracks significantly modify the transport properties of concrete, their presence greatly accelerates the deterioration process.

Similarly in Initial surface absorption test, the rate of penetration of water into a defined area of concrete (5000 mm^2) after intervals of 10, 30 and 60 min at a constant water head (200 mm height) and temperature (20^{0}C) is measured. There are specifications for preparing the test area, initial moisture condition, surface area to be in contact with water and the time at which measurements have to be taken. The guidelines on the test method, calibration and sample preparation are available in BS 1881: Part 208 (1996). The main advantage of this test is, that it is a quick and simple non-destructive in situ test for measuring the water penetration into a concrete surface. This test method provides reasonably consistent results on oven dried samples. The limitations of this test include the difficulty of ensuring a water tight seal in site conditions, the influence of the moisture condition of concrete on measured property and insufficient water head. The initial surface absorption is defined as the rate of flow of water at a constant applied head and temperature into the concrete surface per unit area at a stated interval from the start of the test (Bungey, 1989). The first version of this test [16] was further developed into a commercial test and incorporated into the British Standards. By monitoring the movement of the water in the capillary tube the initial surface absorption value can be calculated in units of ml/m^2/s. The main advantage of the ISAT is that it is a quick and simple non-destructive in situ test method which can be used to measure the water penetration of a normal cast concrete surface. It can also be used on exposed aggregate and profiled surfaces provided a water-tight seal is achieved. The practical difficulty of ensuring a water-tight seal is probably one of the test's greatest limitations but another limitation is that the measured property is greatly affected by the moisture condition of the concrete. This, however, applies to nearly all near-surface absorption and air permeability tests and is best summarized by a quote from Neville (1995). The lower value of initial surface absorption may be due either to the inherent low absorption characteristics of the concrete tested or else to the fact that the pores in poor-quality concrete are already full of water. Thus the main application of the ISAT is as a quality control test for precast concrete units which can be tested whenever they are dry. A new method for testing concrete using the initial Surface Absorption Test (ISAT) has been developed for site use which was conducted by Dhir (1993). It is based on applying a vacuum to an ISAT cap placed on the concrete surface until drying is achieved. The progress of the drying is monitored by placing indicating silica gel desiccant in the ISAT cap and observing the color change. The method is quick, simple and practical for in situ applications. Results of comparisons with the existing in situ method in BS 1881 show that the new method is potentially more capable of producing reliable and reproducible measurements and therefore will allow better comparison of in situ and laboratory-obtained data.

Another research work carried out by [19] discusses the current approach for specifying concrete durability in structures. The shortcomings of the use of bulk parameters such as strength, water-binder ratio, and binder content to specify durability are discussed. Studies carried out over the last 10 years at Dundee University, using simple permeation tests, which are sensitive to curing, cement type, and concrete grade, have shown close association between permeation properties and concrete durability. Paper deals with the measurement of concrete durability by the Dundee-modified Initial Surface Absorption Test (ISAT). A wide range of concrete mixes made with ordinary Portland cement and blends with Pulverized Fuel Ash (PFA) and ground granulated blast furnace slag were designed. The duration of moist-curing was varied from 0 to 28 days, and the maximum aggregate size ranged from 5 to 40 mm. All mixes were tested for absorptivity and durability, including freeze-thaw resistance, carbonation, chloride ingress, and mechanical wear. Results show that the absorptivity of concrete, measured with the ISAT, can be used as an accurate specification for concrete durability, irrespective of curing, grade, or mix constituents. A tentative surface absorptivity classification for durability has been proposed. The investigation carried out by [20] inferred that water absorption of mortar modified with combinations of polymer and pozzolan by using initial surface water absorption test. Since surface of mortar or concrete serves as medium that will be most easily penetrated by moisture that can cause corrosion of reinforcement that leads to durability problem, it's imperative to make it durable. Polymer additive and pozzolanic cement replacement used in this study was Styrene Butadiene Rubber (SBR) and Fly Ash (FA) respectively. Mixes were prepared with two w/c ratio of 0.3 and 0.4 with different combinations of 5%, 7%, and 10% SBR additive and 10%, 20%, and 30% FA cement replacement. Results showed that modified mortar with combinations of higher percentages of polymer additive and low percentages of pozzolanic cement replacement have the lowest initial surface absorption rate compared to unmodified mortar. It can concluded based on this study that high percentage of polymer addition and low percentages of pozzolanic cement replacement in mortar can increase its resistance to water absorption. The effect of curing conditions and silica fume replacement on the compressive strength and the initial surface absorption of high performance concrete is reported by Al-Oraimi (2007). The silica fume contents were 5, 10, 15 and 20%, by weight of cement. Four different curing conditions were used: air curing, control curing and two other curing conditions recommended by BS8110 and ACI308-81. The cementitious material (binder) content was constant (400 kg/m^3); the water/cement (w/c) ratio was also maintained at a constant value of 0.35; while the water/binder (w/b) ratio ranged from 0.35 to 0.28. The addition of silica fume enhanced the compressive strength significantly up to 30%.

The 28-day compressive strength was found to be 69.9 MPa without silica fume and it was determined to be 89.9 MPa with silica fume under the standard curing condition. The 28-day compressive strength results under the control curing condition were found to be higher than the compressive strength for specimens cured under other curing conditions. The surface absorption (ml/m^2/s) was found to decrease as the percentage replacement of silica fume was increased. Control curing also decreases the surface absorption of water compared with air curing. Concrete with silica fume was less sensitive to drying than that without silica fume. The deterioration of concrete structures is a major problem in many countries throughout the world. This has prompted the search for methods of predicting the service life of both existing and new structures. Current prediction methods are still in their infancy and, before they can be used with confidence, more reliable information on the properties of the concrete in these structures will be required. The different range of test methods for determining the strength and transport properties and the extent of corrosion are critically reviewed by Long (2001). Whilst all provide useful information the ability to measure the transport properties has been shown by many researchers to give the most reliable indication of the likely durability. In spite of this it is recommended that an holistic overview is adopted as no single test is sufficiently reliable at present. Using such an approach, durability-based design criteria can be developed for concrete and the remaining life of existing structures estimated. Furthermore research conducted by investigator presents the results of an experimental data on the water absorption and sorptivity properties of mechanically loaded Engineered Cementitious Composites (ECC). It is a newly developed high performance fibre reinforced cementitious composite with substantial benefit in both high ductility and improved durability due to tight crack width. By employing micromechanics-based material design, ductility in excess of 3% under uniaxial tensile loading can be attained with only 2% fibre content by volume, and the typical single crack brittle fracture behavior commonly observed in normal concrete or mortar is converted to multiple micro cracking ductile response in ECC as noted by Mustafa (2009).

Thus in the present research work an attempt was made to investigation the effect of Hydrophobicity by considering two different Grades of concrete and hydrophobic impregnates in case of Sorption test and ISAT to procure rate of flow of water with differential time duration without hydrophobic impregnate material. The permeability, which is a measure of the flow of water or various gases under pressure gradient, is generally used to examine durability characteristics of concrete. It is of significance where concrete is exposed to water pressure such as water retaining structures. However, in structures located above ground level, measurement of capillary water absorption (sorptivity) characteristics of concrete would be more appropriate. Capillary water absorption of concrete is measured by allowing all face of a concrete specimen to be in contact with water and to determine the rate of absorption of water through substrates by inspection of changes in mass

EXPERIMENTAL WORK

In order to achieve the objectives, a series of tests such as Sorption could be carried out to evaluate the effectiveness of impregnation in case of case of impregnated as well as control concrete cube and also ISAT could be conducted on concrete cube without impregnation. In fact both tests were to be conducted within laboratory conditions on concrete cubes of size 100 mm^3. In which considered two Grades of concrete (C30 and C40) and produced total number of 24 concrete cubes, where in which split up into two groups of 12 for each Grade of concrete. Also selected two types of impregnate material such as Solvent Based (SB) as well as Water Based (WB) impregnant material for this investigations. To determine the effectiveness of these two impregnants, these concrete cubes will be divided into three groups such as solvent based impregnation, water based impregnation and a control variable. These cubes will undergo a series of experiments to produce comparative data to determine which form of impregnant performs the most effective. The concrete cubes will be tested via Sorptivity tests, before and after impregnation is applied, and an Initial Surface Absorption Test (ISAT) without impregnation. The concrete used for investigation saw the production of 24 concrete cubes, sized at 100

Table 1: Mix Proportions of Concrete (kg/m^3)

Concrete Grade	Water (Kg)	OPC (kg)	Sand (kg)	Aggregate(10mm) (kg)	Total Mass (kg)
C30	2.3	4.3	8.9	14.3	29.8
C40	2.0	3.4	9.4	14.2	29.0

mm^3, with twelve cubes forming C30 and the other twelve at C40. These concrete cube samples have been made following British Standards. The mixture ingredients used for the production of concrete cubes are as shown in the Table 1.

SORPTIVITY TEST

After 28 days of curing the concrete needs to be fully dried and preconditioned before any tests and experiments can continue. This requires the concrete specimens to be placed in an oven to dry off and eliminate any internal moisture that may have been left in. The oven is set at 100°C and dried overnight as well as wiping down the sample surface ensures that any loose aggregate is removed and therefore not considered within the results. The Sorptivity test is an experiment, which is employed to determine the rate of absorption of water through substrates by inspection of changes in mass. The Sorptivity measures the rate of water ingress through the concrete by recording an initial dry mass of the concrete, saturating the sample cubes in water and recording the values of the concrete mass at different time intervals. The change in mass compared to the original mass values will indicate how much water has entered the concrete and will determine the rate of water penetrates the concrete interior by the time it was recorded. This test was conducted by recording the masses of the concrete samples at different time intervals such as 5 min, 10 min, 30 min, 1 h and 24 h. The initial masses of the dry concrete cubes are recorded individually, using the digital scale and recording values to the nearest 2 decimal points. The concrete cubes are then saturated in the water bath filled with water at room temperature. After 5 min of saturation, the cubes are then taken out, and instantly wiped by using the cloths. This removes any excess water from the substrate samples and that the exterior is wiped dry. The cubes are then weighed again and recorded. The change in mass will indicate that there has been water transport through the concrete and that the values of mass recorded represent the original mass of the concrete with additional mass made from water build up within the concrete interior. This method is repeated for the time intervals at 10 min, 30 min, 1 h and 24 h. The concrete cubes are sorted into two groups differentiated by their concrete grades (C30 and C40), these concrete samples need to be divided further, into groups of three. These groups separate the concrete cubes by their impregnant materials, a control, solvent based and water based impregnants. C40 Concrete cubes (100 mm^3) x 12; Control (no impregnation) x 4; Water based impregnation x 4; Solvent based impregnation x 4 and C30 Concrete Cubes (100 mm^3) x 12; Control (no impregnation) x 4; Water based impregnation x 4; Solvent Based Impregnation x 4. As these cubes have been already labelled 1-12 for each concrete grade to help identify them individually. The first four cubes were not experience any impregnant treatment and will act as the control variable. Cubes 5-8 will have SB impregnants applied and cubes 9-12 with WB impregnants. On usage of impregnation application, it is essential that the concrete cubes have been preconditioned and fully dried initially and that the surfaces have also been cleaned, dried and dust free. This is so that the impregnant materials have been properly applied and so that more accurate and reliable data can be obtained. In order to proceed with this method, using a compressed air gun, fire compressed air over the concrete surfaces to remove dust and any loose aggregate from the surface. This is so that the impregnant layer can be suitably applied. The impregnant is applied using a brush and takes up to 4 h-1 day to completely set and ready to be worked on. In order to have these concrete samples readily available for testing it is important that they are left to dry and are protected from rain or water for at least 24 h to prevent any washout of the water repellent agents and that a fair test can be conducted and reliable results and recordings can be acquired.

INITIAL SURFACE ABSORPTION TEST (ISAT)

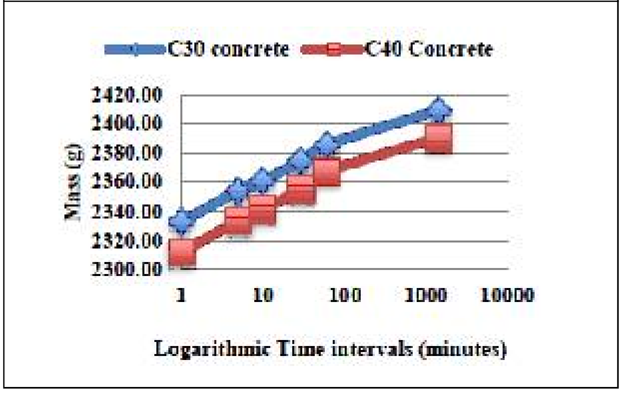
The ISAT is the test procedure developed by the British standards in accordance to (British Standards BS 1881-5, 1970) and (British Standards BS 1881-208, 1996). This test procedure is one, which is carried out under laboratory conditions and is designed in the present research work to determine the rate of flow of water into concrete at 10 min, 30 min and 1 h. It is the investigation of the porosity of concrete and water penetration via capillary suction through a specified unit area.

RESULTS AND DISCUSSION

Sorptivity Test

From the findings made regarding the Sorptivity test, the results provided a good gauge in the rate of absorption through concrete. Where the change in mass over time indicates the increase in percentage of moisture content building up within the concrete interior. Two Sorptivity tests were carried out before and after the application of impregnants. The first Sorptivity test identified the nature of unprotected concrete and the rate of which water enters it. The second test was carried out after the impregnant agents were applied to their respective cubes and absorbed the effected performance in water ingression between two Solvent-based, Water based and a control. The results from the second Sorptivity provided comparative values between these three variables to identify which impregnant materials perform the best and by how much.

Figure 1: Averaged Initial Sorptivity



The graph shown in Figure 1 shows the averaged recordings of the increase in mass over time between C30 and C40 concrete based on the Sorptivity readings. It can be seen from the graph that a similar trend is occurring in the rate of water ingression through untreated concrete. It can be identified that the characteristics in water absorption between the two concrete grades are alike and that they both allow water to flow through the concrete at a very similar rate. From the Figures 2-3, it is clear based on average Sorption result that the cubes impregnated with Solvent-based impregnants performed more better than the Control and Water-based impregnated concrete cubes. This is identified by the low

Figure 2: Average Sorption Results for C30 concrete

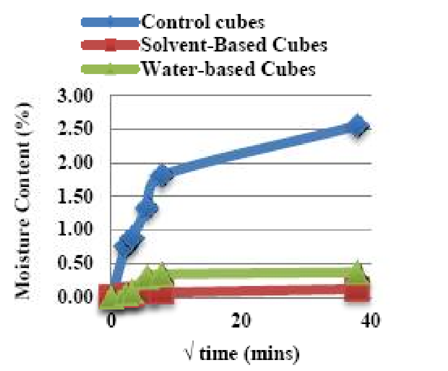
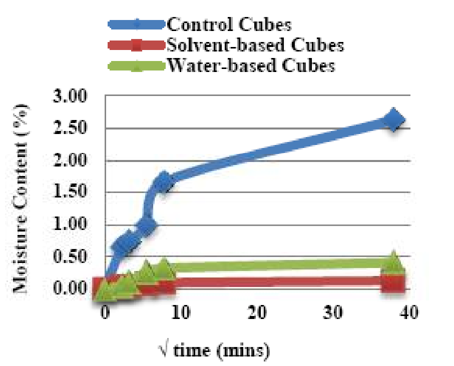


Figure 3: Average Sorption Results for C40 concrete



moisture content maintained throughout the experiment, significantly lower than the Water-based impregnated samples and it is also proven to be most effective in both Grades of concrete.

The results from the second Sorptivity test shows the changes in mass of the concrete cubes and the effects after impregnant materials have been applied. In which concrete cubes 1-4 without impregnation and are used as a control specimen to comparative values with concrete cubes 5-8 and 9-12 which have Solvent-based and Water-based hydrophobic impregnants applied respectively. After revising these results, it was found that the change in mass from its initial mass recordings after 24 h of saturation, the impregnant materials applied to concrete cubes 5-12 could achieved significant reductions in water penetration. These results indicate that these cubes do not completely stop the penetration of water through the substrate material but the application of impregnants make significant reductions in water ingression. In comparison, the control samples experience a higher rate of water ingression compared to the rest of

Figure 4a: Sorptivity Results in Control Samples at C30

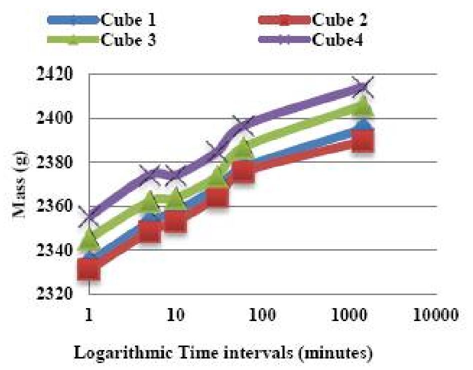


Figure 4b: Moisture Content via Sorptivity with Control samples at C30

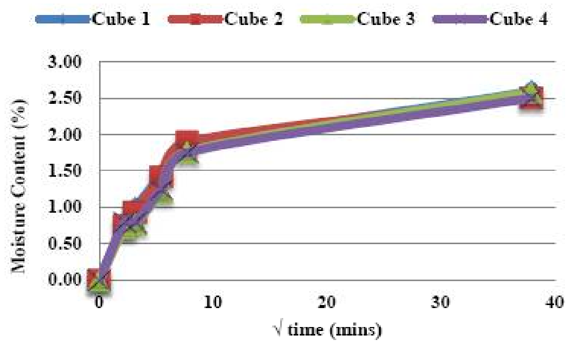


Figure 5a: Sorptivity results in SB samples at C30

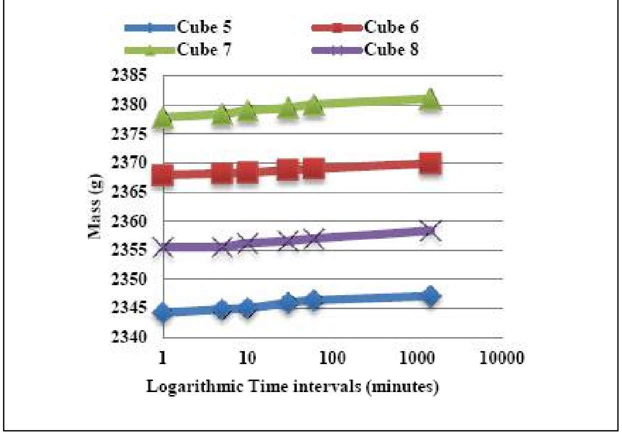


Figure 5b: Moisture Content via Sorptivity with SB samples at C30

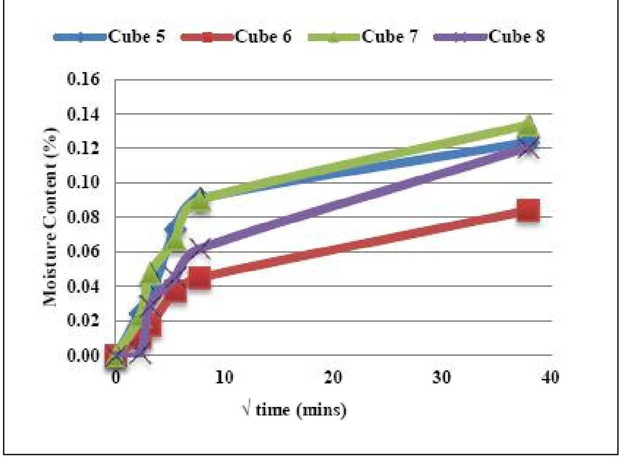


Figure 6a: Sorptivity results on WB samples with C30

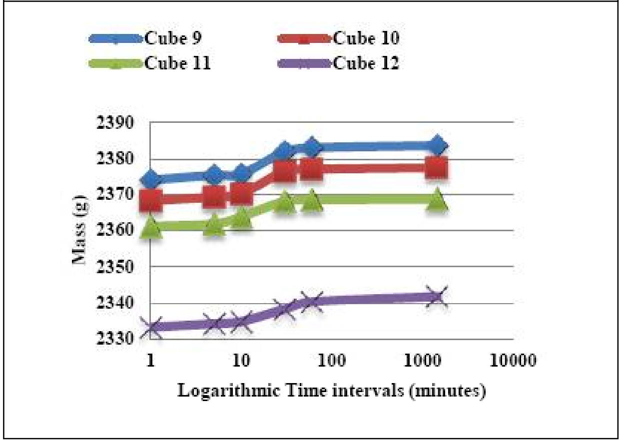


Figure 6b: Moisture Content via Sorptivity with WB samples at C30

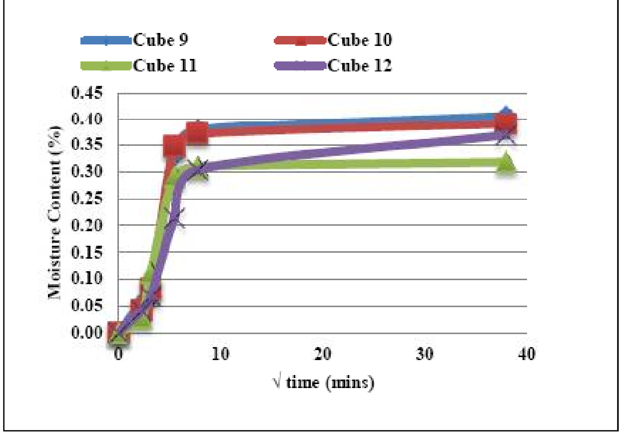


Figure 7a: Sorptivity results on Control samples at C40

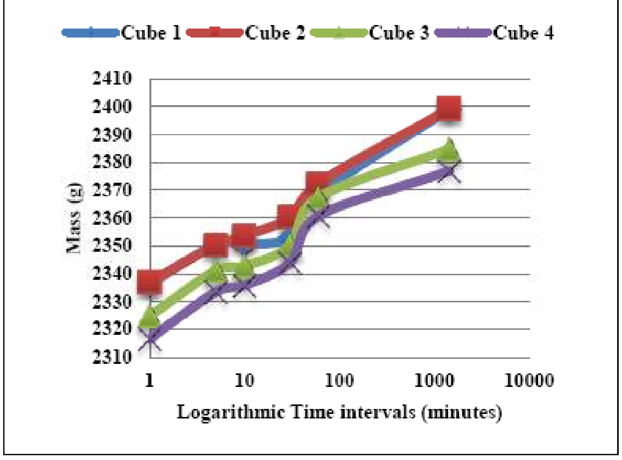


Figure 7b: Moisture Content via Sorptivity with Control samples at C40

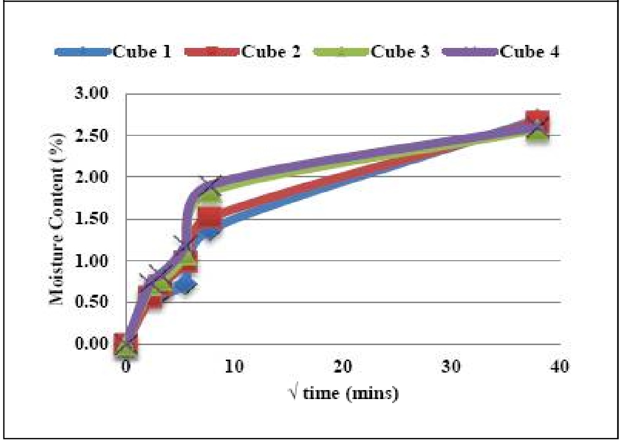


Figure 8a: Sorptivity results on SB samples at C40

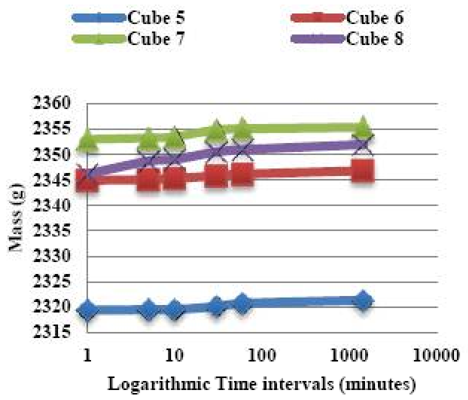


Figure 8b: Moisture Content via Sorptivity with SB samples at C40

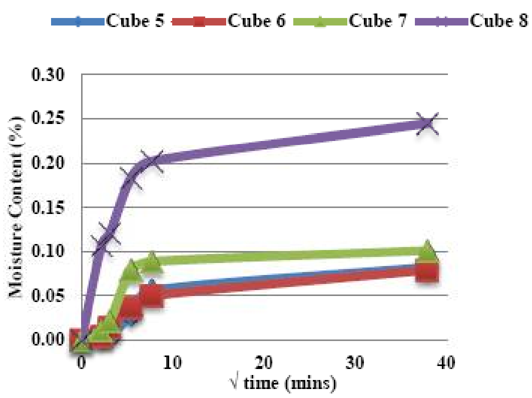


Figure 9a: Sorptivity results on WB samples with C40

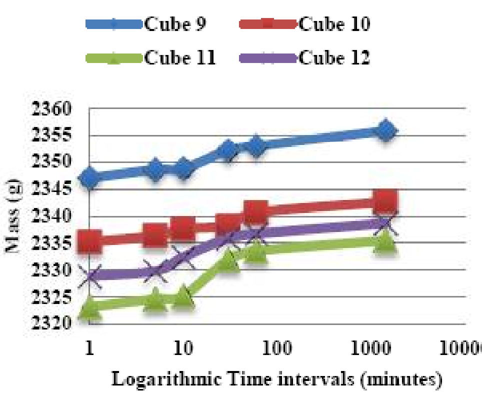
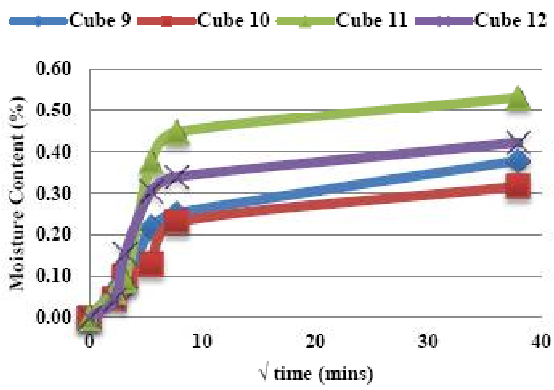


Figure 9b: Moisture Content via Sorptivity with WB samples at C40



the cubes, where the masses at each time intervals are consistently increasing. The Sorptivity results in Control, Solvent and Water based concrete cube can be represented in the Figures 4(a)-9(a) and Moisture content variation with Sorptivity which is also shown in Figures 4(b)-9(b).

The graphs have been separated between the Grades of concrete and grouped based on the type of impregnation applied. The first graphs, labelled 4(a)-9(a) are presented across a logarithmic time scale displaying the changes in mass over different time intervals. The graphs labelled 4(b)-9(b) demonstrate the increase in moisture content over the square root (√) of the time intervals. It could be observed from the graphs above, based on the Sorptivity experiments carried out, it's clear that both forms of impregnant materials successfully work in the protection of concrete from water penetration. However it can also be seen that the impregnated cubes do not completely prevent water penetration, and that there is still some water entering it. Between the two types of impregnant materials, it can be seen from the graphs that the Solvent-based product performs more efficiently in the prevention of water intrusion through the concrete. This is backed from both results carried out on the two concrete grades where in which concrete cubes 5-8 maintain a fairly consistent mass over the increase of time and increases small fractions of percentage of moisture content. The water-based product shows a similar trend in mass increase over time between the two Grades of concrete , and they do not perform as well as the results obtained by the solvent based impregnants. Comparing the all the outcomes from the Sorptivity tests, the Grade of concrete C40 permits more water through the substrate more than in C30.

Initial Surface Absorption Test

The results show from (Figures 10 to 18) that in both Grades of concrete (C30 and C40), the first four concrete cubes shows higher flow rate of water ingression in case of without impregnation. The results also indicate significant effective performance in case impregnation. In reference to cubes samples 1-4, Grade of concrete C40 absorbs a higher flow rate of water than in C30. As it was earlier

Figure 10: Flow rate/time for Cube 1, C30

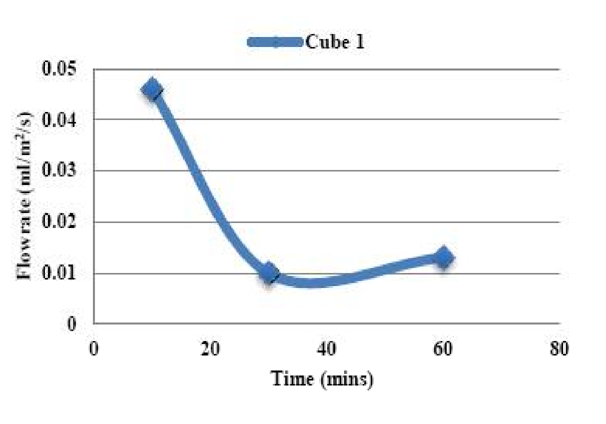


Figure 11: Flow rate/time for Cube 2, C30

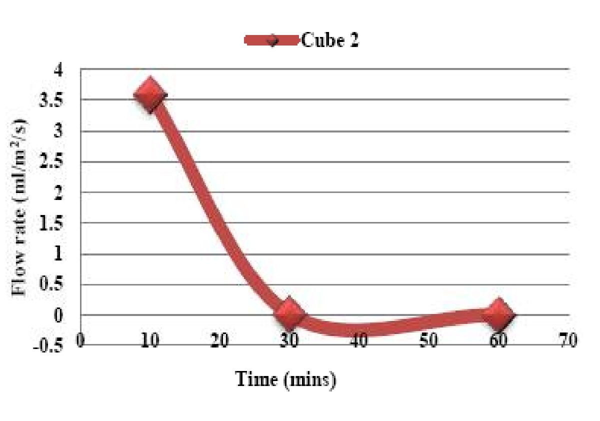


Figure 12: Flow rate/time for Cube 3, C30

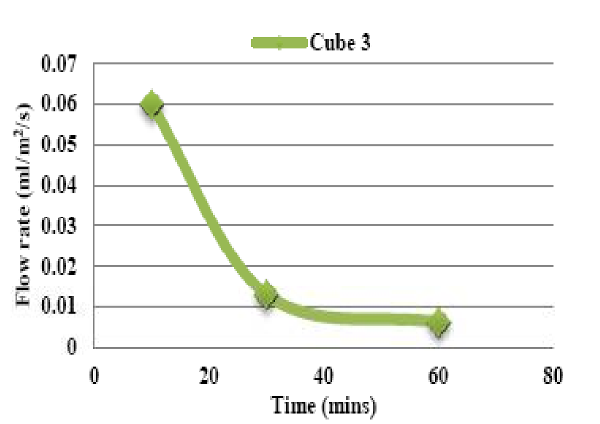


Figure 13: Flow rate/time for Cube 4, C30

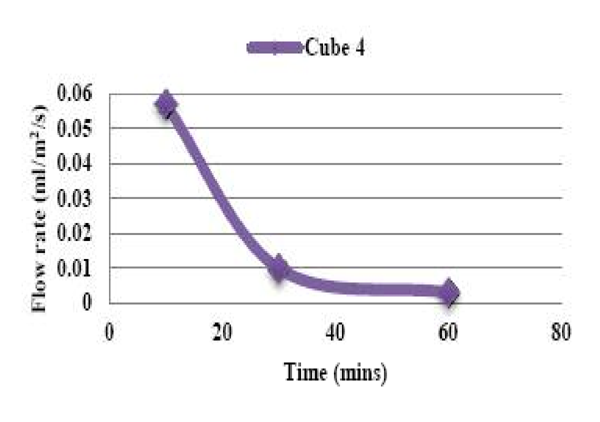


Figure 14: Flow rate/time for Cube 1, C40

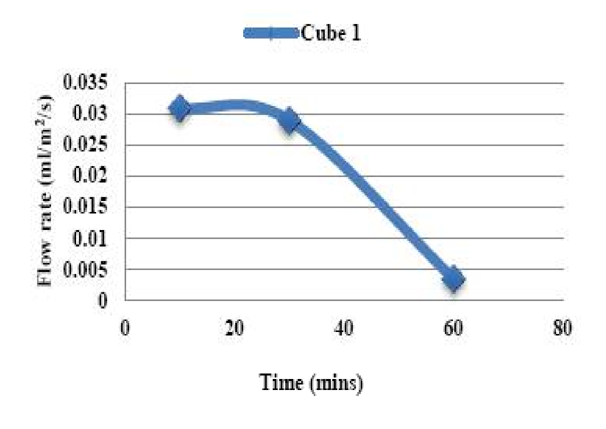


Figure 15: Flow rate/time for Cube 2, C40

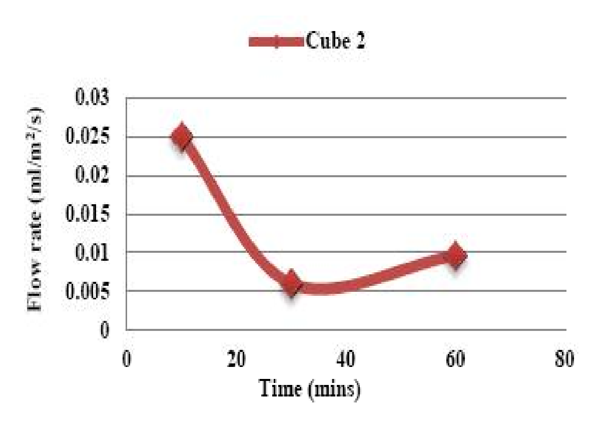


Figure 16: Flow rate/time for Cube 3, C40

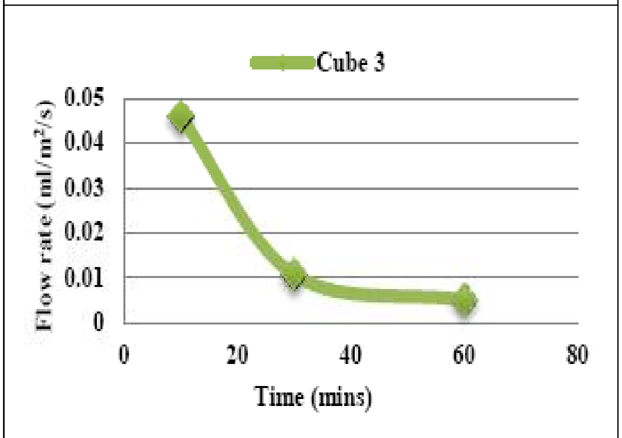


Figure 17: Flow rate/time for Cube 4, C40

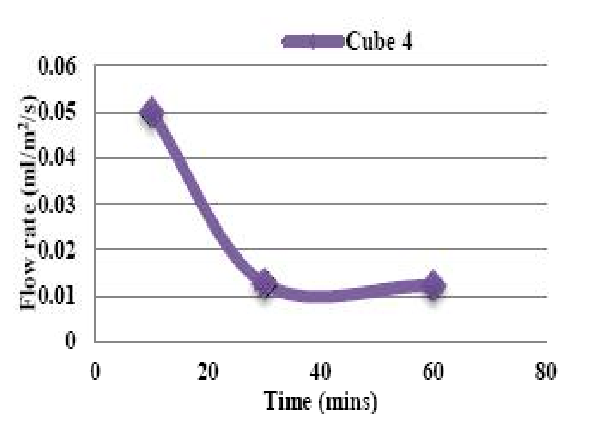
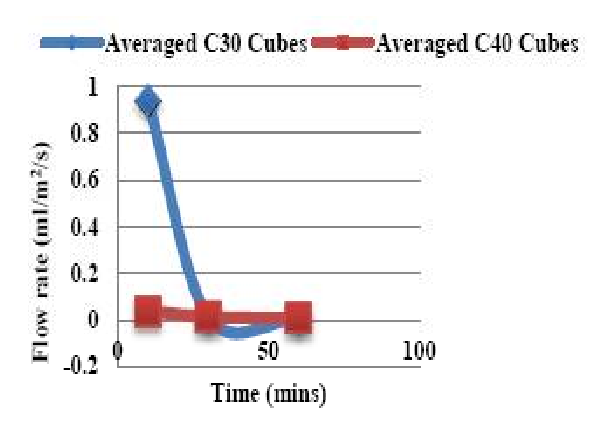


Figure 18: Average Flow rate/time for Cubes, C30 &C40



identified that if the graduation of the water level decreases 20% or more within 20 min it is considered as a failure. Where 20% of the tube is marked at the 1 ml graduation, the results suggest that the C40 concrete control cubes have experienced failure whereas in C30, it can be identified that none of the concrete samples can be considered as failed.

From the results shown in the graphs above (Figures 10 to 18), there is a general gradual decrease trend in flow rate of water with the increase in time during the ISAT test. It can be observed from these graphs that the rate of flow of water by capillary action slowly decreases as time increases represented in graphs. Results also indicate where the time measured is extended for 2 min, the flow rate at that given time is higher than what would be predicted from this trend identified. Taking averages from the readings between the two concrete grades it can be absorbed that C30 experiences a greater flow rate of water and a higher fall in flow over time. This is due to the fact that where more than 30 divisions have passed within 5 s and flow rate is then already determined as 3.60 (ml/m^2/s).

CONCLUSION

1. It could be confirmed from the present research that the Solvent-based impregnant, Alkylalkoxysilanes base performs most effectively in the process of water ingress and its represented by its consistency results in both Grades of concrete as concerned
2. In the ISAT experiment it was found that, it is not possible to determine the best performing impregnate material by using British Standards method from this test.
3. Based on the results obtained by the experiments conducted, it can be concluded that, generally hydrophobic impregnants provide good protection from the ingress of water through the concrete. However, where it was found that the tests conducted do not reflect the long-term effects of impregnate on water ingress. This would suggest that the requirement of further developments in the testing methods to fully investigate how effective impregnants are during long-time duration.
4. It could be determined from research that between two Grades of concrete (C30 and C40), the initial Flow rate of water through untreated concrete is relatively the same which is represented in the similar gradient lines from the results.

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