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Research Paper

EFFECTIVENESS OF IMPREGNATION ON SELF-COMPACTED CONCRETE

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The Corrosion of steel reinforcement due to contamination by chloride ions from deicing salts is the major cause of deterioration of concrete structures. The research was undertaken to investigate the performance and effectiveness of impregnation on Self-compacted concrete by using water and Solvent based impregnates. Thirty six, 100 mm^3 concrete cubes were cast from two different design mixtures and cured, before being submerged in clean water to determine their sorption profiles at set times. The cubes were then dried before Water and Solvent based impregnation materials were applied. Twenty four cubes were treated and twelve cubes were left untreated and were used as control. All the cubes were then ponded with sodium chloride solution. The cubes were then dry drilled at various depths of 5, 10, 15 20, 25 and 30 mm for dust samples which were used to obtain chloride concentration levels by Volhard's method. The Chloride concentration profiles in treated and untreated cubes from two mix designs were compared and the results reflected a significant reduction in chloride ion penetration in treated cubes compared to the untreated ones. Water based impregnate material performed better than Solvent based product on concrete specimens that had 50 and 100% moisture content.

Keywords: Moisture content, Self-compacting concrete, Impregnation, Sorption, Water absorption, Chloride concentration, Degree of Saturation

INTRODUCTION

The concrete is a construction material which is widely used in various structures include houses, commercial buildings, roadways, underground structures, and waterfront structures. In fact these structures are subjected to continuous changes in moisture content. Moreover change in moisture content caused by wetting and drying has a considerable effect on the mechanical properties of concrete. In turn this is important for the design of concrete structures. From literature, it can be found that there exists uncertainty on the moisture effects on mechanical properties of concrete. Thus there have been various debates about moisture

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dependency of mechanical behavior of concrete. The mechanical properties of hardened concrete depend on the characteristics and volume fractions of components such as water, cement, fine and coarse aggregate. For several years beginning in 1980s, the problem of long-term durability of reinforced concrete structures was a major topic of interest in Egypt and worldwide. The long-term durability is greatly influenced by the compaction of fresh concrete during its placement stage. The use of congested and heavily reinforced concrete structural members, the limited access of mechanical vibrators in hard-to-reach areas, the lack of skilled labor, the necessity to shorten the construction period and the noise levels associated with mechanical vibrators, especially at concrete product plant, may compromise the compaction of fresh concrete. This has led the Japanese researchers to develop a new type of highly-flowable concrete called Self-Compacting Concrete (SCC), to alleviate these problems. This type of concrete can flow under its own weight through restricted sections without bleeding and segregation [1,2]. The main impetus behind the development of SCC being the desire to improve the quality of concrete work, reduce costs, improve the working environment and automate construction [3,4]. Since the development of SCC, an extensive research studies were performed to elaborate its various properties, during fresh and hardened state. Most of the previous studies have mainly been concerned with investigating the fresh parameters of SCC (flow ability, deformability, rheology, self-levelling and filling capacity) and developing suitable assessment techniques and methodologies for designing SCC mixes [5,6]. Whilst, few studies have been concerned with studying the mechanical properties of such concrete. It was shown that the mechanical properties (compressive, tensile and bond strength, elastic modulus and creep) of SCC did not differ from that of traditional vibrated concrete [1,7]. However, there is a lack of information and worldwide concern regarding the permeation properties of SCC, which mainly govern the long-term durability. As a consequence, a considerable effort has to be directed toward investigation of such properties. The main permeation parameters of concrete include the mechanisms of absorption, permeability and diffusion. A great number of tests have been introduced in literature for assessing these mechanisms, such as initial surface absorption, sorption, gas and water permeability, water absorption capacity, gas and ionic diffusion [8,9]. Moreover, there is a need to understand the microstructure of SCC, which has a great impact on the durability and permeation properties of concrete.

Thus the SCC was chosen for this research program because its use has been growing throughout the world in the last few years and for the above-mentioned reasons. Also there is a lack of information as well as worldwide concern regarding the permeation (absorption, permeability and diffusion) properties of SCC, and that to the effectiveness of impregnation on permeation properties in case of SCC which mainly govern the long-term durability This has led to the need for thorough investigation to characterize the permeation, and study the effectiveness of impregnation on Sorption, Chloride penetration with differential depth, mass gain and loss in Self-compacting and Normal concrete.

LITERATURE REVIEW

There is a lack of information as well as worldwide concern regarding the permeation (absorption, permeability and diffusion) properties of SCC, and that to the effectiveness of impregnation on SCC which mainly govern the long-term durability. As a consequence, a considerable effort has to be directed in this research work toward investigation of such properties by considering Water and Solvent based impregnate material. A great number of tests have been introduced in literature for assessing these mechanisms, such as initial surface absorption, sorption, gas and water permeability, water absorption capacity, gas and ionic diffusion. Moreover, there is a need to understand and develop the Sorption as well as Chloride penetration profile, along with various moisture content levels in the case of Normal and impregnated SCC, which has a great impact on the durability and permeation properties of concrete. Research done by [10] inferred that, there are several methods available for testing properties in the fresh state: the most frequently used are slum-flow test, L-box and V-funnel. In their work they presents properties of self-compacting concrete, mixed with different types additives: fly ash, silica fume, hydraulic lime and a mixture of fly ash and hydraulic lime. As concerned to the durability, the concrete was appraised through several properties, among them the capillary sorption, whose importance is allied to the factor that this is the first phenomenon of transport of aggressive materials that takes place in concrete. Sorption, which is an index of moisture transport into unsaturated specimens, has been recognized as an important index of concrete durability, because the test method used for its determination reflects the way that most concretes will be penetrated by water and other injurious agents and it is an especially good measure of the quality of near surface concrete, which governs durability related to reinforcement corrosion as per [11]. Similarly researcher [12] have shown that the sorption coefficient is essential to predict the service life of concrete as a structural and to improve its performance.

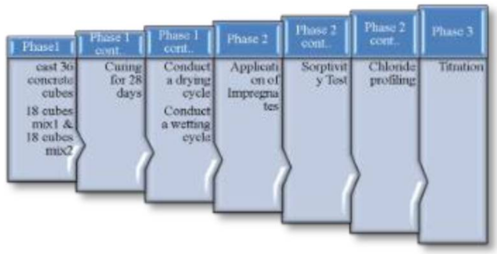
In normal concrete it has been shown that the condensed silica fume, under normal curing environments, to both increase strength and reduce sorption as confirmed by [13]. The research was carried out by [14] to investigate the influence of addition of pozzolanic materials and curing regimes on the mechanical properties and the capillary water absorption (sorption) characteristics of self-compacting concrete. Portland cement concrete (PC) and two types of SCC, SCC-I with Fly ash (30% FA/70% PC) and SCC-II with Silica fume (10% SF/90% PC) specimens were prepared and cured in three different curing conditions. (standard 200 C water, sealed and air cured) for periods of 3, 7, 14, and 28 days. At the end of each curing period, compressive and tensile strengths and UPV values were determined as well as Sorptivity coefficients were determined at 28 days. The results indicated that, SCC-II specimens gave higher compressive and tensile strength and lower sorptivity coefficient values than those of corresponding SCC-I and PC concrete specimens, regardless of curing regimes and age of concrete. The results also showed a good correlation between the strength development of concrete and its sorptiviy (as compressive and tensile strengths increased due to the hydration, the sorptivity coefficient decreased significantly).

EXPERIMENTAL WORK

In this research work Self-compacting concrete of grade C30 could be used. Mix design calculations will be performed to calculate the batch weights for the mixes. An appropriate water-cement ratio will be used. Before casting the specimens, an L-box, V-funnel and slump flow tests could be carried out. The experimental work conducted was laboratory based and mostly relied on the collection, recording, and analysis of data. The accuracy of the tests and the effectiveness of the impregnate materials were achieved by comparing and analyzing data. The main variables considered in this investigation were such as the duration of the test, type of concrete, moisture content and the type of impregnate materials (Water and Solvent based) in ordered to compare their performance in case of Chloride concentration profile, Mass gain or loss, Degree of saturation with control concrete. For this investigation, all the samples were kept under the same conditions and treated in the same manner. In order to meet the main objectives, the experimental work was divided into three phases and different tasks was carried out as shown in (Figure 1) experimental flow chart.

In order to achieve the main objectives, the investigation was divided into three phases.

Figure 1: Experimental Flow Chart



Phase 1-Casting concrete specimens from two mixture designs and development of sorptivity profile of SCC using clean water.

Phase 2- At this phase, the concrete specimens will be conditioned, treated and ponded in sodium chloride solution for a month.

Phase 3- This would be the final phase. Core samples will be taken by drilling the specimens at incremental depths. Collected dust samples will be checked for chloride concentration levels by conducting Volhard's method of titration.

Phase 1: In this phase casting of 36 in which (each 18 cubes for Mix1 and Mix 2) concrete cube specimens of size 100 mm x 100 mm x 100 mm from two different mixture designs and development of sorptivity profile of SCC by using clean water was carried out in this present research work. The SCC has to be fluid enough to ensure proper casting and sufficient uniformity between the constituent phases in ordered to avoid problems such as bleeding and segregation. To achieve this, the SCC has to conform to the basic idea of a dense viscous paste, which comprises of fine aggregate, cement, chemical additives coupled with water interacting with the larger sized particles such as coarse aggregates and coarse additives. In fact below mentioned tabulated data is a typical range of mix proportions as shown in Table 1 as per (EFNARC, 2005).

Table 1: Typical Range of Mix Proportions (EFNARC, 2005)

Material	Quantities kg/m³	Quantities l/m³
Cement	380-600	
Paste	300-380	
Water	150/210	150/210
Gravel	750/1000	210 - 360
Sand	48-55% of total aggregates	
Water/Binder	0.85/1.1	

The mixture design of SCC has to meet a certain criteria in order to progress at the casting stage. The primary aim was therefore to produce a concrete mix that which was satisfied the recommended European Guidelines for Self-compacting concrete. It was made sure that the concrete was easy to produce and had a long open time so that slump test, L-box and V-funnel tests could be carried out with the mixture variations as little as possible. In this research, the focus was mainly on the fresh properties of concrete and no attention was given to the properties in the hardening or hardened state. Locally available 10 mm gravel and natural sand were used. In order to achieve adequate fluidity, the SCC design mixes could be dosed with a polycarboxylic super-plasticiser (Glenium C315) and the properties of Super-plasticizer as represented in Table 2.

Table 2: Properties of Super-plasticizer

Appearance	Off White Opaque Liquid
Specific gravity @ 20°C	1.095 ± 0.02 g/cm³
pH-Value	6.5 ± 1
Alkali Content (%)	≤2
Chloride Content (%)	≤0.10

The two mixes which were close to meeting all the criteria were adopted after having done three trial mixes and details of various mix ingredients that was used for both mixes in this research as represented in Table 3. The difference was in the dosage of super plasticizer. The concrete mixer was washed and dried. The materials were then accurately measured using a scale and placed into the mixer and allowed to mix. When the materials were thoroughly mixed, the concrete was picked up in a small scoop and placed into 100 mm x 100 mm x 100 mm cube moulds which had their inner surfaces lightly coated with mould oil to ensure that concrete did not stick to them.

Table 3: Details of Mixture Design Material

	SCC CS1	SCC CS2
Gravel(kg)	13.11	13.11
Sand (kg)	25.14	25.14
CEM II/A-LL L (kg)	7.87	7.87
Water (kg)	4.15	4.15
sand (kg)	0.73	0.49

Consistency of Fresh Mixture

In this study, the recommended European Guidelines (EFNARC 2005) for Self-compacting concrete were adopted to assess flow ability (Slump flow test), viscosity by measuring the empty time as well as concentrated suspension

(V-funnel test) and Passing ability (L-box) test for fresh SCC mixtures.

Slump flow: The slump flow was used as the benchmark for filling ability and a succession of mixes were carried out where this was varied (up and down) and procedure followed as shown in Figure 2. It was made sure that passing ability and segregation resistance of the mixes, and hence the viscosity, were not adversely affected. This was achieved as follows: The aggregate contents were left unchanged and for decreased filling ability, the super plasticizer content was decreased and the water/powder ratio increased. Furthermore for increased filling ability, the super plasticizer content was increased and the Water/powder ratio reduced.

Figure 2: Slump flow+500 mm Flow Time (spread test) t500

The first three mixes were treated as trial mixes as they did not meet the requirements of SCC as shown in Table 4.

Workability

The flowability of concrete was tested by measuring flow time using a V-funnel test as shown Figure 3. The funnel was filled with concrete, once it was lifted off the ground, the lid at the bottom was opened and the time taken for concrete to empty was measured. As per European Guidelines for Self-compacting concrete (EFNARC, 2005), and further T5 min test was also carried out. The funnel was refilled with concrete and allowed 5 min to settle before the bottom stopper was opened. A significant increase in flow time indicates segregation. According to EFNARC (2005), the recommended test time for a concrete to qualify for SCC is 6 s.

Table 4: Slump, V-Funnel and L-Box Results

Mix No	Slump Flow (mm)	T50 cm (s)	V-funnel T5 min (s)	L-box H2/H1)
Trial1	400	8	5	0.94
Trial 2	600	5	14	0.91
Trial3	580	10	7	0.96
SCC1	610	4.1	8.9	0.97
SCC2	535	2.6	6.5	0.98

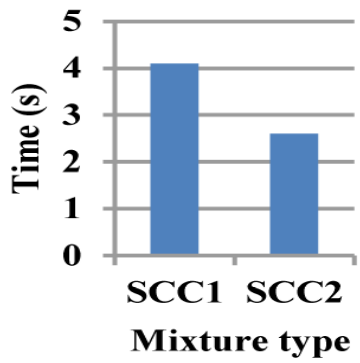
Figure 3: V-Funnel

Passing Ability

The passing ability ratio of concrete was determined by using a 3 bar L-box test as shown in Figure 4. This test was carried out by filling the vertical section of the L-Box with concrete before the gate was lifted to allow

Figure 4: L-box

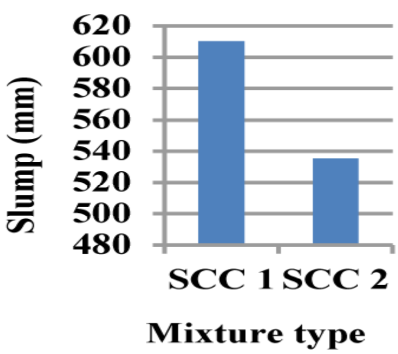
Figure 6: Passing Time



concrete to flow into the horizontal section. In determining the passing ability, the height of concrete at the end of the horizontal section (H2) was divided with height of remaining concrete in the vertical section (H1). EFNARC (2005), recommends a passing ratio of $\geq$0.8.

According to EFNARC (2005), the typical slump value of the SCC mixtures should be between 500 mm (minimum) to 700 mm (maximum). As seen in Figures 5 to 6, both mixes met the acceptance standards. Slump values of 500 mm or marginally less are

Figure 5: Slump Flow



indicative of highly viscous mixture which may increase chance of high yield point and segregation. The difference in slump flow indicates that an increase in quantity of super plasticizer improved the flow of SCC. Mix design 1 had high dosage of super plasticiser as compared to Mix design 2.

The results obtained from the above tests were compared to those of consistency classes as given in BS:EN 206-9. The first three mixes were treated as trial mixes as they did not meet the requirements of SCC as detailed in Table 4. When the results of SCC1 and SCC2 were found to be meeting specified guidelines, 18 moulds were filled to the top with concrete and any overflow was scraped off until it was flush with the top of the mould. The filled moulds were carefully moved to a designated area to allow the concrete to set. This procedure was repeated for the production of 18 cubes from Mix design 2. Thirty six, 100 mm cubes were cast from two different design mixtures. The first mixture design had a high dosage of super plasticizer and the second had a low dosage of super plasticizer. The concrete cube specimens were of C30 strength. After 24 h, all the concrete specimens were carefully removed from the moulds ensuring that their corners and surfaces were not damaged as the concrete was still not fully set. A cast date and an identification number were written using a water proof chalk on the sides of all the specimens before they were fully submerged in clean water for 28 days for curing. After 28 days all the cubes were removed from the water tank and a drying cycle was conducted. The cubes were weighed as they were taken out of the water tanks and they were reweighed after 5, 10, 20, 30 min, 1 h, 2 h, 24 h up to 168 h. From 100 h the cubes were oven dried overnight at 500 C. The concrete specimens were then removed from the oven and allowed to settle to atmospheric conditions for two days. The main reason behind drying the cubes in an oven was to ensure that they were all dried to the same condition before carrying out a sorption test. After 168 h of drying, a sorption test was carried out using clean water. The test was conducted as per BS:EN13057 (2002). The weight gain of specimens from both mix designs was recorded. The aim of the test was to measure the rate of absorption of water by capillary suction of unsaturated specimens fully submerged in water. This test will also help to determine the water content in each cube after set periods of time so that the moisture content can be used to compare the performance of impregnates when they were applied. The weight of the cubes was noted before they were submerged in clean water. The cubes were removed in groups of threes, surface dried using wet towels and then weighed at 5, 10, 20, 30 min, 1 h, 2 h, 19 h., 24 h, 72 h, 77 h, 98 h, 146 h and 170 h. The reason for having large gaps between weighing times was due to the laboratory being closed hence access was restricted. The results of this test were plotted against time. From the resultant graphs we can deduce the time taken for the specimens to be 50% and fully (100%) saturated. After the sorptivity test, the specimens were then left to dry under atmospheric conditions for 15 days. They were further dried in an oven for 72 h at a temperature of 80^{o}C. After removing the specimens from the oven, they were left for 3 days to adjust to atmospheric conditions before they were treated with SB and WB impregnate material.

Phase 2: In this phase, the concrete specimens will be conditioned, treated and ponded in NaCl solution for a month. Water Based (WB) and Solvent Based (SB) impregnate materials were used in this research. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed and they will be referred to as WB and SB, respectively. WB is water borne acrylic co-polymer based impregnate which is less hazardous and environmental friendly. It is silicone, solvent free and achieves a penetration of less than 10 mm. Whereas SB consists of a colorless silane with an active content greater than 80% and can achieve penetration greater than 10 mm. The impregnation materials were applied as per manufacturer's instructions. This was done after allowing the concrete cubes to dry under atmospheric conditions for 15 days. The concrete specimens were cleaned using compressed air. 12 concrete cubes were left untreated as a control, 12 concrete cubes were treated with WB and the other 12 concrete cubes were treated with SB. Each concrete cube required 9 g of impregnate material; however it was decided to use 10 g per cube as some material may be absorbed by the brush or washed off by moisture from the cubes. The impregnation materials were weighed in a glass beaker and carefully applied using a brush to all surfaces of the cube. In ordered to avoid cross contamination, separate containers and brushes were used for measuring and in the application of impregnate materials respectively. The maximum precautions were taken to ensure that all the surfaces of the cubes had equal applications of coating. All the cubes were weighed before and after being coated so as to determine the amount of impregnate material that was absorbed by the cubes. It was difficult to apply the impregnate materials on cubes that had been exposed to water. After treatment, all the cubes were propped up to allow air to circulate underneath them and were left to dry for 24 h before they were fully submerged in water with NaCl solution. A sodium chloride concentration of 10% was used. This was achieved by adding 10 g of rock salt per litre of water used. The specimens were then ponded on a fortnightly basis for a month in salt solution as per BS:EN13580 (2002) and the gain in weight was monitored against time. This test method will clarify how effective these materials can be if used solely as impregnates. The concrete cubes were weighed on a daily basis and weight gain of treated and untreated concrete cubes will be compared. The chloride ingress profile could be determined by chemical analysis by collecting concrete dust samples for different drill depth.

Phase 3: This would be the final phase. Core samples will be taken by drilling the concrete cube specimens at different drill depths. Collected dust samples will be checked for chloride concentration levels by conducting Volhard's method of titration. In this phase all the ponded concrete cubes were oven dried for 72 h at a temperature of 105°C. The cubes were then left to dry further under atmospheric conditions for two weeks before they were dry drilled using the diamond tipped drill bit at 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 30 mm depths. The drilling was done in the centre of each face and the resultant dust samples were collected before a chemical analysis was carried out to determine the chloride concentration levels at aforesaid depths. The dust samples were taken from the centre point of the face, as this would give the most realistic results. If samples were taken off centre, the chloride content would not be a complete representation of chloride ingress from one side but would also be representing chloride ingress through the adjacent faces which was not needed and would greatly impact the results. During the drilling process each concrete cube was clamped by using brackets. This was to ensure that the cubes were level with the brackets hence the drill bit was positioned at the centre of each face. Once the set depth was reached, the cube was unclamped and dust sample collected by placing a container on top of the drilled hole. As soon as the container was firmly positioned on the drilled hole, the cube was turned upside down and gently tapped making sure that all the dust fell into the container. After collecting the dust samples, each container was labelled with the representative cube identification number and drilled depth before being sealed using cling film to avoid spillage and contamination. The dust residue which was left in the drill bit was blown off using compressed air to avoid cross contamination before the next cube was to be drilled. This was done after drilling each hole. This method of collecting dust samples was chosen so as to avoid cross contamination. When drilling was finished, the collected dust samples were taken to the laboratory for chemical analysis as per (BS:EN 14629, 2007).

RESULTS AND DISCUSSION

This research work was conducted so as to develop a sorption profile of SCC, investigate the performance and effectiveness of Water and Solvent based impregnate materials in retarding the ingress of chloride ions into concrete structures, and investigate the influence of internal moisture content on the performance of impregnates as well as to assess the Chloride concentration at different drill depths in the concrete cubes. The results obtained from this investigation shows that there is a relationship between moisture content and the performance of impregnates. As the moisture content within concrete increases, the effectiveness of the impregnate decreases thereby allowing the ingress of chloride ions. The results also indicate that, internal moisture content increases the rate of absorption, depth and concentration of chloride levels by as much as 50%. The fully saturated cubes had less chloride concentration levels at 5 mm depth compared to the ones that had 50% moisture content. This may be as a result of the pores already being saturated with water. Despite being fully saturated, these cubes had more chloride concentration levels compared to control cubes. Chloride ions are likely to have migrated into the interstitial liquid phase by diffusion. The results also indicate that, the cubes that had protection applied under recommended conditions performed reasonably well, and as expected the silane based material were more effective compared to the water based product. The results clearly demonstrate that there is a slight difference in the performance of these two impregnate materials. From the results it was noted that, the effectiveness of the impregnate materials decreased with increase in moisture content as can be noted at 10 mm depth, the average chloride concentration levels were 0.048% compared to control cubes which had 0.032% at the same depth. As the internal moisture in cubes increased the effectiveness of the applied impregnates regardless of type was greatly hindered making them ineffective. However water based impregnate performed far better than silane based impregnate when internal moisture was present. For the cubes that had 50% moisture content on Mix design 1, SB impregnate reduced the chloride concentration levels at 20 mm depth by 0.011% whereas at the same depth WB impregnate managed to reduce the levels by 0.010%. It was also noted from the results of Mix design 2 (cubes with 100% MC), that at 15 and 20 mm depths the unprotected cubes and protected cubes had similar chloride concentration levels. This demonstrates that, the effectiveness of impregnates is greatly affected by increase in moisture. The impregnation products perform better when they are applied as per manufacturer's recommendations. The impregnation material should therefore be applied on dry surfaces to allow successful bonding and penetration to the concrete pores. In order to replicate the results obtained from the laboratories on site, it would be ideal that the concrete surfaces are artificially dried before applying the impregnate. Inadequate drying will render the products ineffective as concrete moisture will travel from the concrete core to the surface of the concrete structure to establish equilibrium. This will interfere with the effectiveness of the products. Water based impregnates could not perform as well as silane based impregnates when applied to dry surfaces however when moisture is present water based impregnates provide better performance.

Drying-Wetting Cycle

In this task after 28 days of curing in water, the cubes were removed from the water in which the drying and wetting cycle was monitored as shown in Figures 7 to 8 as shown below.

Figure 7: Drying Cycle

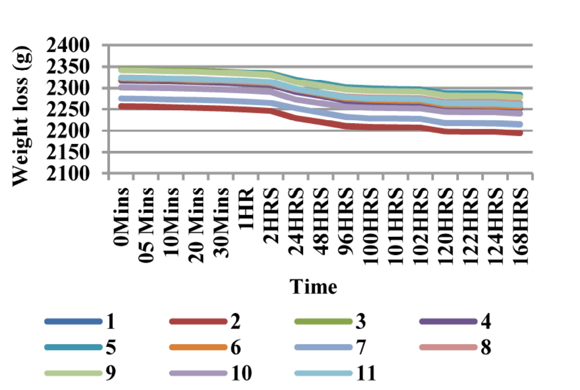
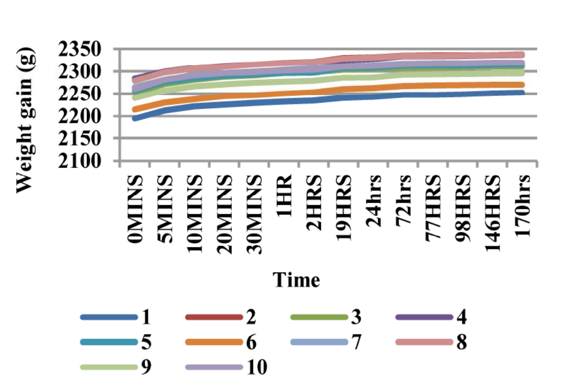


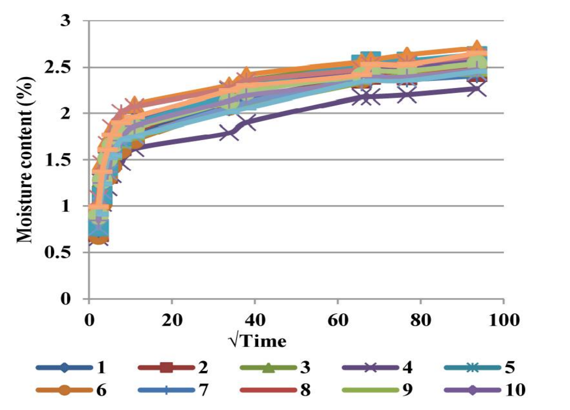
Figure 8: Wetting Cycle



The results show that all the cubes followed a similar trend in drying. The drying pattern was gradual and linear from 0 min up to 2 h. This minimal loss of moisture may be due to cubes acclimatizing to atmospheric conditions. A sharp decrease in weight is noticed between 2 and 102 h. From 102 h the drying pattern steadies up adopting a linear form. This continues up to 168 h when the test was discontinued.

In ordered to assess internal moisture content in concrete cubes, the moisture content uptake of the cubes was determined by weighing the cubes before submerging them in water and reweighing them after set times. The difference in weight indicated moisture intake as represented below in Figure 9. Once all the cubes were submerged in water,

Figure 9: Internal Moisture Content in Cubes



as expected for the first 24 h there was a rapid increase in moisture content uptake. After 24 h, the increase in weight slowed down as the specimen pores were saturated.

After 10 min of being submerged in water the first four cubes had an average moisture content of 1.16%. The same cubes had an increase in moisture content of 1.81% after 2 h in water and this was an increase of 0.65% from 10 min. The rate of water absorption decreased after 24 h. The increase in moisture content between 2 h and 24 h was 0.34%. As can be seen in the graph above, from 24 h the increase in moisture is steady and the plotted graph is linear from this point up to 170 h. The decrease in moisture is as a result of concrete pores being saturated with water. The results indicate that there is direct correlation between moisture content and the amount of time the cubes are exposed to water.

Sorptivity Test

This test involved the application of impregnate materials on concrete specimens. As mentioned earlier, 24 specimens were treated and 12 specimens were left untreated. All the cubes were then submerged in water with NaCl solution for a month. The increase in cube weight was observed on a daily and weekly basis. This was to observe if there was any trend in the mass increase after the application of impregnation products and includes the difference in mass over the 4 week period. When the cubes increased in mass it indicated that sufficient amount of NaCl solution was absorbed. In order to determine whether there was a pattern in the mass increase of the cubes over the four weeks period of being exposed to NaCl solution in which Figures 10 to 11 shows, Weight gain versus Time in weeks was plotted and illustrates the increase in mass of each cube on a weekly basis.

Figure 10: Weekly Weight Gain for Mix Design 1

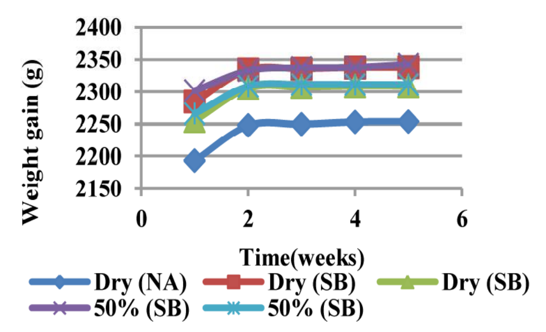
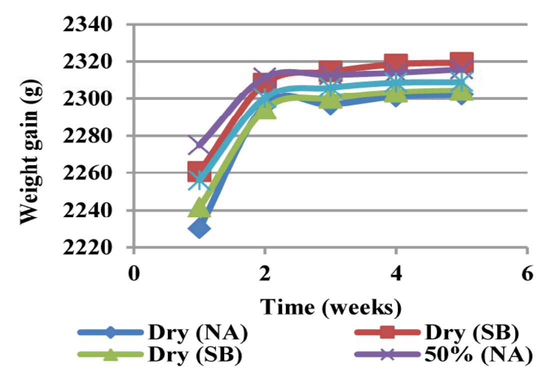


Figure 11: Weekly Weight Gain for Mix Design 2



The results shown in above graphs from (Figures 10 to 11) in case of two mix designs that, all the cubes followed a similar pattern where there was a slight increase in their mass each week. The treated cubes mass gain stabilized after two weeks whereas the untreated cubes continued to increase in mass until week three where it could be stabilized. It could observed from (Figures 12 and 13) that, the saturated cube did not have a considerable

Figure 12: Weight Gain in Untreated Cubes for Mix Design 1

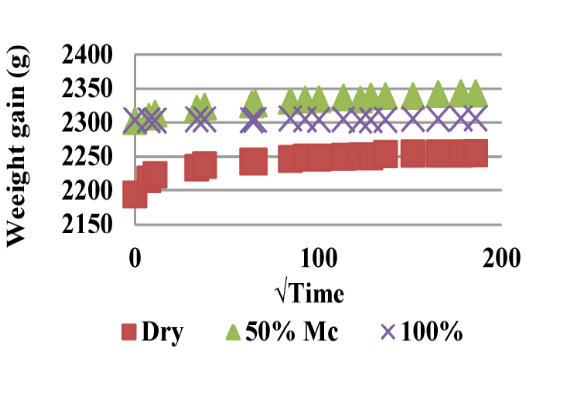
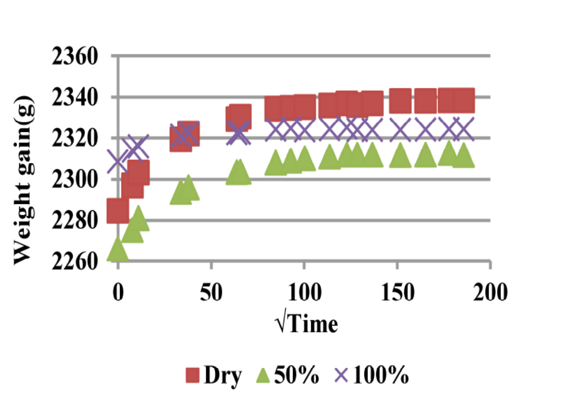


Figure 13: Weight Gain in Cubes Treated with SB



increase in weight in comparison with the dry and the one that had 50% moisture content.

The results from Figures 14 to 15 indicates that, the super plasticizer had no effect on water absorption as cubes with similar conditions from both mixes absorbed similar amounts of moisture at set periods. This is evidenced by specimen 11 and 30 that both adopted a similar trend from the moment they were submerged in water up to the end. The same is true with other combinations. Different combinations have been plotted against each other for comparison in Figures 16 to 23 as represented below.

Figure 14: Cubes Treated with SB for Mix Design 1 and 2

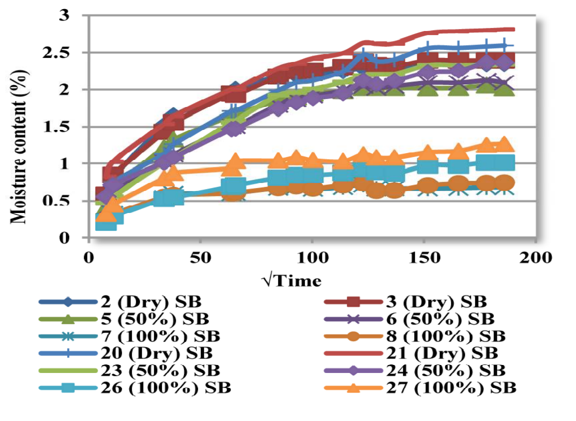


Figure 15: Cubes Treated with WB for Mix Design 1 and 2

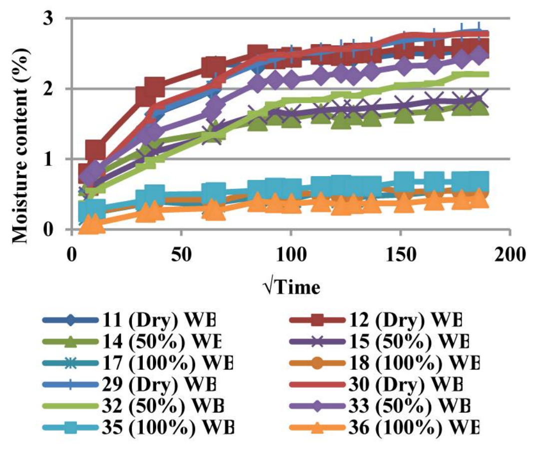


Figure 16: Cubes Treated with SB for Mix Design 2

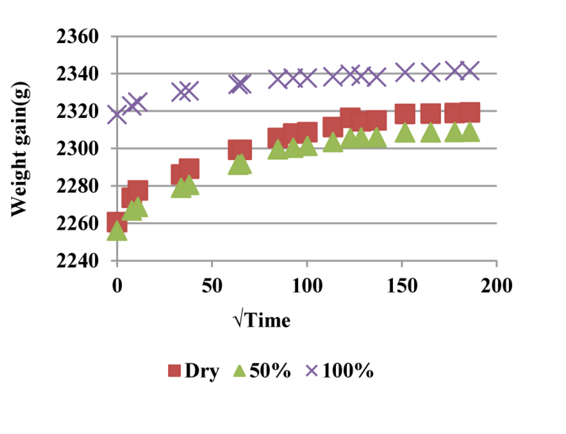


Figure 17: Weight Gain in Cubes Treated with WB for Mix Design 1

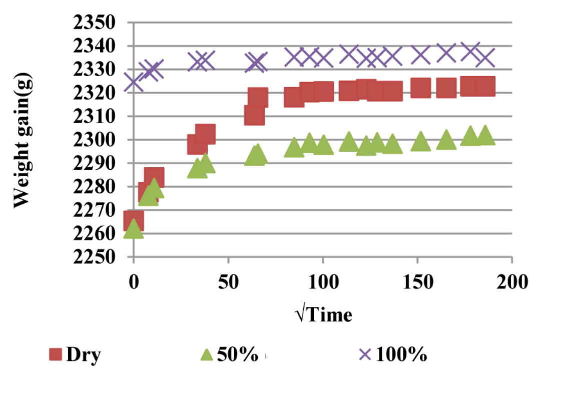


Figure 18: Weight Gain in Cubes Treated with WB for Mix Design 2

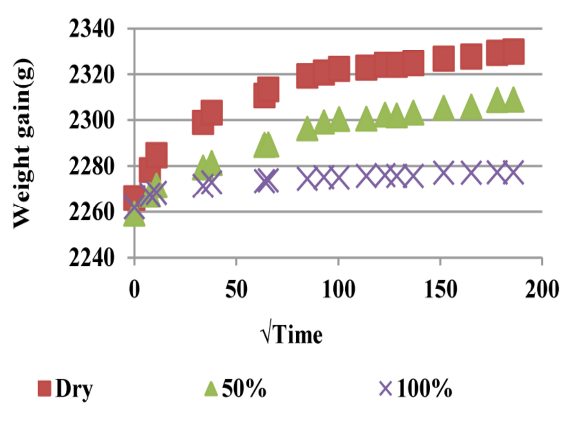


Figure 19: Weight Gain in Cubes for Mix Design 1(SB,WB and None)

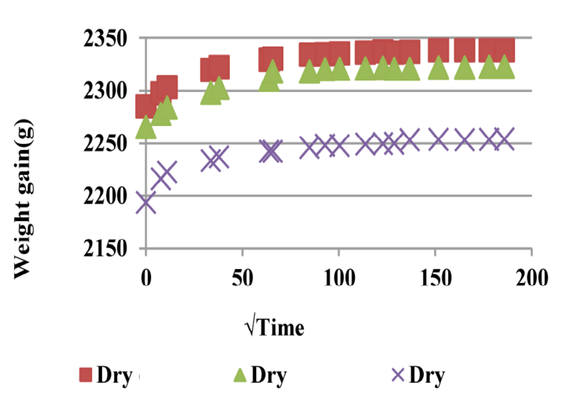


Figure 20: Weight Gain in Cubes for Mix Design 2(SB, WB and None)

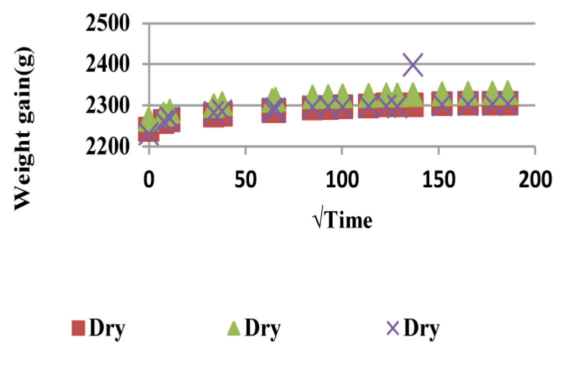


Figure 21: Weight Gain in Cubes for Mix Design1(WB, SB and None)

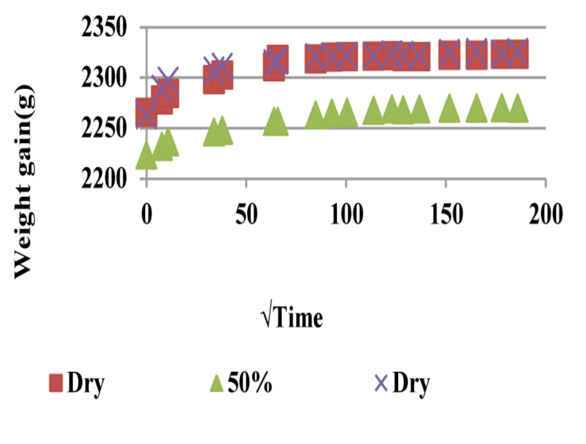


Figure 22: Weight Gain in Cubes for Mix Design 2(WB, SB and None)

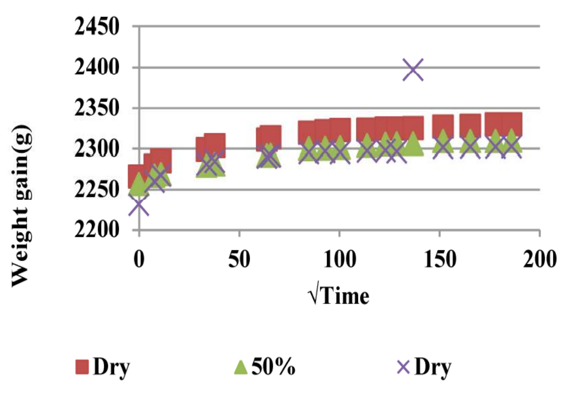
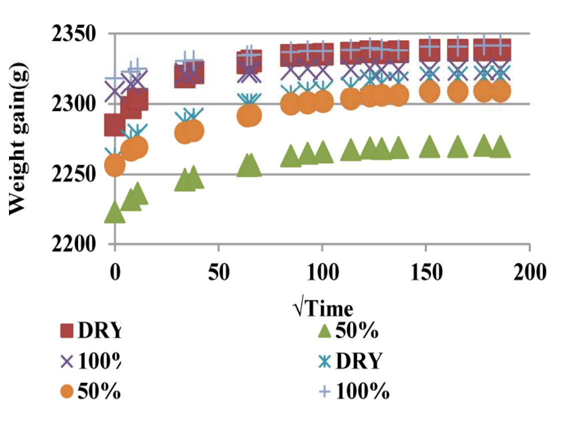


Figure 23: Weight Gain in Cubes for Mix Design 1 and 2(SB)



Chloride Concentration Profile in Concrete Cubes

For Mix design 1 from Figure 24, the results were as unexpected for the first 5 mm depth, the SB impregnant material was least effective at 5 mm depth as it had a chloride content of 0.094% however it was most effective at 10, 15,20, 25 and 30 mm depths as the chloride content was 0.03%, 0.028%, 0.023%, 0.023% and 0.018% respectively. WB impregnant material had a much lower chloride concentration at 5 mm depth compared to SB and the unprotected cubes. However at 10 mm and 15 mm depths, it had high chloride concentration levels compared to SB treated cubes. At 20 mm depth both WB and SB treated cubes had the same chloride concentration levels of 0.023 mm and at 25 mm depth the WB cube had 0.022% chloride content compared to 0.023% of SB at similar depth. The unprotected cube had a linear reduction in chloride content compared to treated cubes which had massive drops.

For Mix design 2 from Figure 25 as represented above shown that, SB impregnant was most effective at depths such as 5 mm, 10 mm and 15 mm as compared to WB cubes which had high chloride concentration levels at the same depths. At 20 mm both WB and SB cubes had 0.020% chloride levels, however at 25 mm WB performed better than SB as it had 0.017% chloride content compared to SB which had 0.019% at the similar depth. The results indicate that when the cubes had impregnation applied under recommended conditions SB generally performed the best in reducing the impact on chloride ingress. Similarly, WB performed well as it was most effective at a depth of 25 mm.

Figure 24: Cl⁻ Versus Depth (Control Cubes Mix Design1)

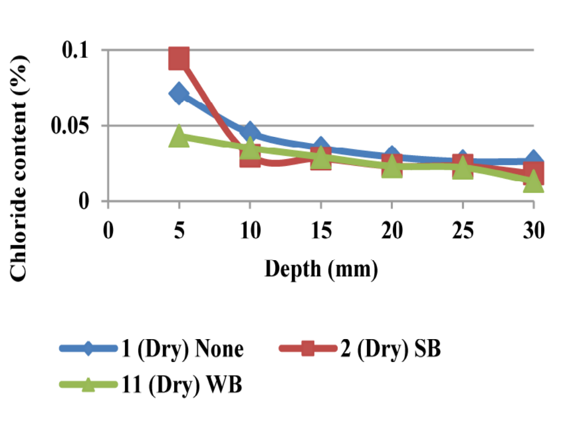
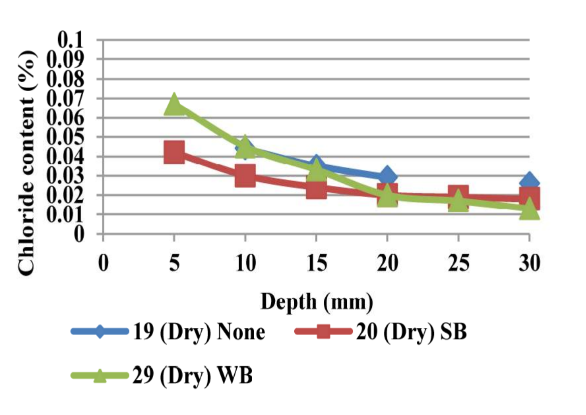


Figure 25: Cl⁻ Versus Depth (Control Cubes Mix Design 2)



Similarly Figure 26 as represented below shows the relationship between chloride concentration and depth for specimens treated with SB. From the graph, it can be seen that the highest chloride concentration levels was recorded at a depth of 5 mm (0.094%). There is a sharp decrease in chloride concentration between 5 and 10 mm and its the highest recorded decrease in penetration for this product. Thereafter the chloride ion concentration reduces gradually with depth. There is a decrease of 0.002% chloride concentration between 10 and 15 mm and 0.005% between 15 and 20 mm. The concentration levels are linear between 20 and 25 mm depth, however they reduce by 0.005% at 30 mm depth. SB was the most effective material in reducing the ingress of chloride ions into concrete. The results show that while the impregnate material managed to provide a protective membrane over the concrete surface, there was still a significant penetration of chloride ions. This penetration from areas of high concentration (surface) to areas of low concentration (inside the cubes). Whereas

Figure 26: Cl^- Versus Depth Analysis for SB

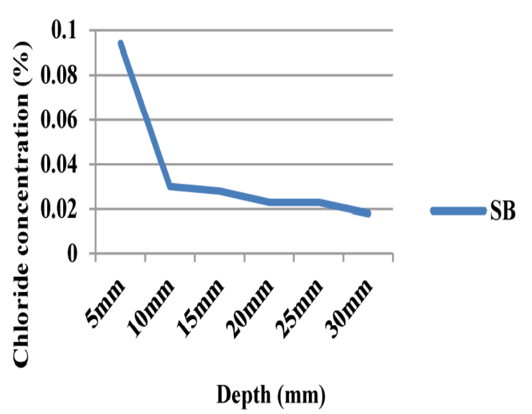
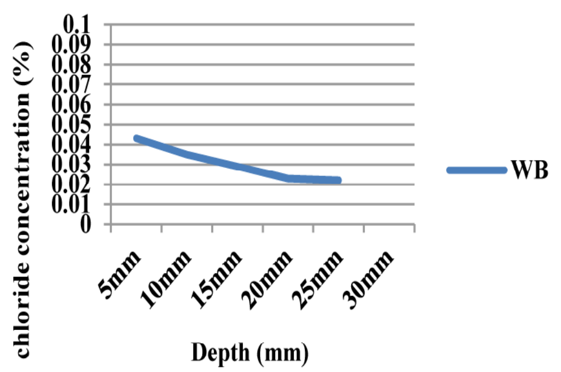


Figure 27 represented the chloride concentration profile against depth for specimens treated with WB impregnation material. The graph has a more linear shape compared to that of SB. The chloride penetration gradually decreases with depth. The highest chloride concentration levels were recorded at a depth of 5 mm. WB was most effective at this depth compared to SB as the highest chloride concentration levels on the control specimen was 0.043%. It could be seen that, there was a gradual and consistent decrease in chloride ion penetration in the cubes treated by this product averaging 0.05% per depth.

Figure 27: Cl^- Versus Depth Analysis for WB



The Figures 28 and 29 as shown below that in which cubes that had impregnated and after they had been fully submerged in water for 18 h. It was calculated that, the cubes could gain 50% moisture content if they are submerged in water for this period of time. From the graphs, it could be seen that all the cubes treated with SB from both mixes appear to start off with a relatively high chloride concentration levels 0.072% at 5 mm. WB seems to be the most effective at this depth

Figure 28: Cl⁻ Versus Depth for Mix Design 1 with 50% MC

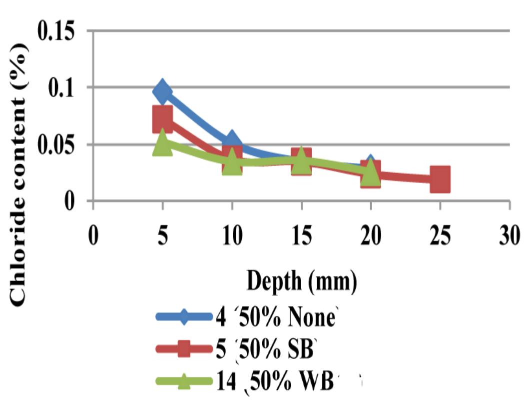
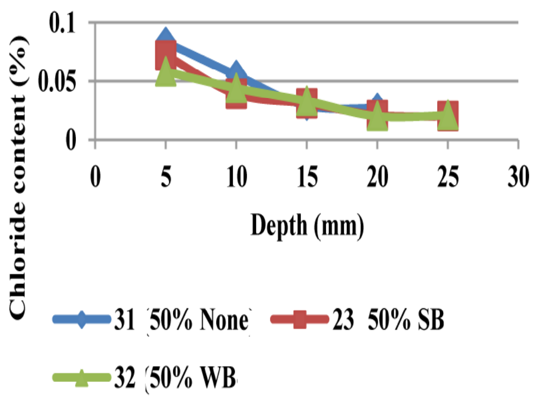


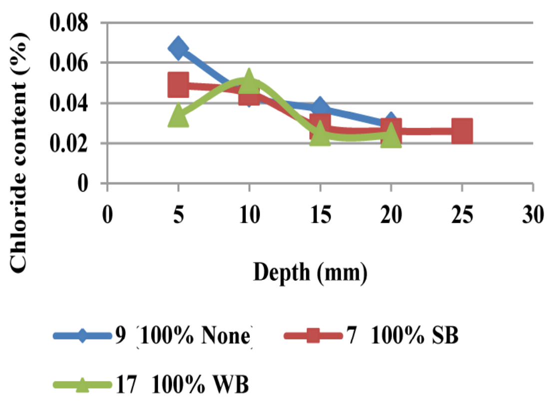
Figure 29: Cl⁻ Versus Depth for Mix Design 2 with 50% MC



as the average chloride concentration levels from both mixes is 0.055%. The unprotected specimens had the highest chloride concentration levels. In the Mix design 1 the average chloride concentration levels at 5 mm depth were 0.074% and for Mix 2 the average was 0.067%. At 10 mm it can be seen that there is a sharp drop in chloride concentration levels for specimens treated with SB in both design mixes. The concentration levels on specimens treated with WB seem to decreasing in a linear form. As expected, the concentration levels remain high on untreated cubes compared to the treated ones. In mix 1 at 15 mm the SB treated cube seem to have similar (0.035%) chloride concentration levels with untreated cube. WB appears to be ineffective as well as it had 0.036% chloride levels. An unexpected trend is noticed in mix 2 as the chloride concentration levels are lower on untreated cubes compared to treated ones. However at 20 mm the treated cubes seem to have less chloride concentration levels compared to untreated ones. SB is more effective in mix 1 at this depth whereas in mix 2, WB is more effective than SB. At 25 mm SB continues to be more effective compared to WB.

When the impregnate was applied to the cubes exposed to water for 170 h as observed from Figure 30 that, WB material in Mix design 1 was more effective at 5 mm depth with 0.034% chloride content compared to both SB and untreated specimen that had 0.049% and 0.067%, respectively. At 10mm drill depth, both treated cubes did not perform well against

Figure 30: Cl⁻ Versus Depth for Mix Design 1 with 100% MC



cubes without impregnation. The unprotected cube showed reduced chloride content at this depth and this is more likely to be an error that occurred during the titration test which is subjective to an individual's perspective of color change. However at 15 mm WB was most effective as it had 0.025% chloride levels compared to SB and untreated cubes that had 0.028% and 0.035% respectively. WB was again more effective than SB at 20 and 25 mm depths.

Whereas in Mix design 2, SB was most effective at 5 mm depth in comparison with WB and the untreated specimen. WB was however most effective at 10 mm depth as it had 0.032% chloride compared to 0.04% of SB and 0.066% of unprotected specimen. At 15 and 20 mm depths, SB performed better than WB and unprotected cubes. Again the WB impregnated cubes performed the best, drastically reducing chloride content at almost linear rate as the depth increased. The WB impregnate material was most effective at reducing chloride ingress. As the depth increased the chloride concentration decreased.

CONCLUSION

1. The obtained results indicate that the performance of impregnates is affected by the presence of moisture content within the concrete specimen. As the moisture content within concrete increases, the effectiveness of the impregnate decreases thereby allowing the ingress of chloride ions. The results also indicate that, internal moisture content increases the rate of absorption, and concentration of chloride levels by as much as 50%.
2. The fully saturated cubes had less chloride concentration levels at 5 mm depth as compared to the ones that had 50% moisture content. This may be as a result of the pores already being saturated with water. Despite being fully saturated, these cubes had more chloride concentration levels compared to control cubes. Chloride ions are likely to have migrated into the interstitial liquid phase by diffusion.
3. The results also indicate that, the cubes that had protection applied under recommended conditions performed reasonably well, and as expected the silane based material were more effective compared to the water based product. The results clearly demonstrate that there is a slight difference in the performance of these two impregnate materials.
4. From the results it was noted that, the effectiveness of the impregnate materials decreased with increase in moisture content as can be noted at 10 mm depth, the average chloride concentration levels were 0.048% compared to control cubes which had 0.032% at the same depth. As the internal moisture in cubes increased the effectiveness of the applied impregnates regardless of type was greatly hindered making them ineffective. However water based impregnate performed far better than silane based impregnate when internal moisture was present.
5. For the cubes that had 50% moisture content in Mix design 1, SB impregnate reduced the chloride concentration levels at

20 mm depth by 0.011% whereas at the same depth WB impregnate managed to reduce the levels by 0.010%. It was also noted from the results of mix 2 (cubes with 100% Moisture content), that at 15 and 20 mm depths the unprotected cubes and protected cubes had similar chloride concentration levels. This demonstrates that, the effectiveness of impregnates is greatly affected by increase in moisture

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