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Chloride penetration in binary and ternary blended cement concretes as measured by two different rapid methods

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ABSTRACT

In this study, the two rapid chloride permeability tests; the AASHTO's rapid chloride permeability test (RCPT) and the University of Cape Town (UCT) chloride conduction test were employed and compared using concrete specimens cast with effective *w*/*b* ratio of 0.48 and applying seven days of curing. Fly ash and blast furnace slag were used in a systematic replacement of cement at the levels of 25%, 50%, and 70%. In addition, silica fume was added at 10% cement replacement. The matrix therefore, was either a binary or ternary blend of cementitious materials. The experimental results were tested for significance using standard statistical methods. The results indicate that ternary blends of 25% fly ash and 10% silica fume exhibited significant decrease in charge passed compared to 25% fly ash. Similarly, the charge passed in the ternary blends of 25% BFS and 50% BFS with addition of 10% silica fume showed lower charge compared to their respective binary blends. The UCT test has been faster and more convenient to use than the RCPT. However, when binary and ternary blends were compared, the RCPT proved to be more sensitive in showing appreciable differences in the values obtained while such differences were insignificant when the UCT test was used.

1. Introduction

It is widely known that diffusion of chloride ions in concrete is an important aspect related to corrosion of reinforcement. The conventional diffusion test is based on steady-state diffusion comprising two reservoirs in which one reservoir is filled with sodium chloride solution of known chloride concentration and the other reservoir comprises a neutral solution such as saturated $Ca(OH)_2$ [1]. The concentration of chloride ions is monitored with time in the neutral solution of the cell by standard spectrophotometric technique [1] or ion selective electrode [2]. Nevertheless, the primary driving force in the diffusion of chloride ions in concrete is the difference in the concentration of chloride ions present in different sections of concrete [3].

The limitations of the diffusion process is that it needs a long time to completely attain steady-state condition and therefore it is not a practical method to assess the resistance of concrete to chloride ions [2]. However, the diffusion process as quoted by Streicher and Alexander [4] can be accelerated not only by decreasing the specimen thickness but also by increasing the chloride concentration upstream. Various methods have been employed to evaluate steady-state diffusion. Dhir et al. [2] used specimens of 100 mm diameter and 25 mm thickness with 10 V potential difference applied for about two weeks. It has been claimed that by applying a strong electric field both electrostatic restrictions and the effect of chloride binding can be minimized [5]. Therefore, chloride diffusivity determined by accelerated methods may be considered a satisfactory value and has been called the intrinsic diffusion property [5]. Nevertheless, a new mechanism in which conduction is superimposed on diffusion by applied potential difference results in a pure conduction test with diffusion playing a smaller role. This type of steady-state conduction test yields zero concentration gradient [6] in the concrete. The arrangement of diffusion and conduction tests is similar with the exception of the application of an electric field in the latter which forces the ions through the concrete. In addition, the chloride ions move through the concrete under the electric field as a well defined front. This is the basis of University of Cape Town (UCT) chloride conduction test. The details of the test will be discussed later.

The rapid chloride permeability test (RCPT) is increasingly being used because of its simplicity. However, several researchers [7,8] have raised concerns over this test. The RCPT is an index test in which no steady-state conditions exist. The test measures the

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conductivity of all ions in the pore solution which include OH^-, Cl^-, Na^+, K^+, SO_4^{2+}, and Ca^{2+}, whose concentrations vary for different pozzolanic concretes [4]. Feldman et al. [9] using Type I cement reported that a simple measurement of current or resistivity gives the same ranking as observed from the charge passed in the RCPT developed by Whiting [10]. Hale et al. [7] argued that RCPT does not directly measure the true permeability but instead measures concrete resistivity. Shi et al. [11] stated that replacement of cement with silica fume can result in an order of magnitude reduction in Na^+, K^+, and OH^- concentrations. On the other hand, fly ash might either increase or decrease the Na^+ and K^+ ions, and usually decreases the Ca^{2+} and OH^- concentration in the pore solution [11]. Therefore, the comparison of pozzolanic materials using various percentage blends with the RCPT may not be representative because of the effect of the pore solution chemistry involved in these materials. The major limitation in the RCPT is that it does not account for the current exclusively carried by chloride ions as distinguished from the total ions [3]. Other problems with the RCPT include heat evolved in the test [8] and alteration in the pore fluid characteristics when used with pozzolanic materials. In addition, the flux in the RCPT may not be in steady-state condition due to the high potential difference of 60 V [12]. Consequently, the results obtained may not represent true chloride diffusion in concrete. However, it is being used because of its convenience and short-term duration. Several researchers [7,13,14] have used the RCPT to evaluate the pozzolanic materials. A virtual RCPT has been developed, which accounts for pore solution conductivity and the potential presence of various cementitious materials [15].

The other very rapid test is the UCT-chloride conduction test, initially developed by Streicher and Alexander [6]. The UCT test is criticized [12,13] because of oven drying of specimens for a period of seven days at 50 °C which could affect the microstructure of concrete. However, this is necessary to ensure uniform saturation with chloride solution and to prevent dilution effect of the saturating solution [6]. The specimens are subjected to vacuum saturation in high chloride concentration of 5.0 M NaCl solution (292.2 g NaCl/l). This vacuum saturation reduces the time to pull the chloride front in the concrete specimen when compared with the work of Dhir et al. [2] who did not vacuum saturate specimens in NaCl solution. The UCT chloride conductivity test relies on measuring the conduction of concrete which depends on the intrinsic microstructure and amount of charge carriers in the solution, mostly the hydroxyl ions [16]. Therefore, by saturating the concrete specimens with highly conductive solution, the variability of pore water becomes much less significant. Different concrete specimens would yield different conductivities because of the differences in their pore structure [6].

A limitation in the UCT test stems from slicing smaller size specimens of 65 mm diameter and 25 mm thickness which results in disturbance in the microstructure. Nevertheless, this is regarded as only surface effect [2]. However, concrete specimens with smaller thickness may not be representative of in situ concrete with large aggregate [12]. Compared with the RCPT, there are apparently many advantages of using the UCT test, such as achieving steady-state conditions from the start by saturation in chloride solution. The reading of current is observed quickly as the chloride ion flux and no measurements are required at the down stream reservoir. Chloride conductivity can be calculated using Eq. (1) of Streicher and Alexander [6].

$$\sigma = \frac{it}{VA} \tag{1}$$

where σ is the conductivity of concrete specimen (mS/cm); i is the electric current (mA); V is the potential difference (V); t is the thickness of specimen (cm); and A is the cross-sectional area of the specimen (cm^2).

In this research, the effect of chloride penetration was evaluated for the following blends:

(i) Binary blends comprising (a) OPC and silica fume, (b) OPC and 25%, 50%, or 70% fly ash and (c) OPC and 25%, 50%, or 70% BFS.
(ii) Ternary blends comprising OPC, silica fume, and fly ash.
(iii) Ternary blends comprising OPC, silica fume, and BFS.

These binary and ternary blends were tested using both the RCPT and UCT methods. The significance of the results was examined using statistical analysis. The aim is to be able to recommend using the easier of the two methods (the UCT method) where both methods are expected to give similar results.

2. Experimental program and details

2.1. Materials

Crushed dacite coarse aggregate of maximum size 9.5 mm complying with ASTM C 33 was used. The fine aggregate was washed river bed sand. The specific gravity and absorption of coarse aggregate was 2.68% and 0.61%, respectively, while these parameters for the fine aggregates were 2.60% and 0.81%, respectively. All the binary and ternary concrete blends were proportioned for an invariant effective w/b ratio of 0.48 and total cementitious content of 450 kg/m^3. A total of 14 concrete mixes of various binary and ternary blends were cast. The relevant physical and chemical properties of the cement and the other mineral additives are shown in Table 1. The concrete specimens were de-moulded after 24 h of casting then cured for a further period of seven days. Immediately afterwards, the specimens were placed in an environmental room that was maintained at 50% RH and 23 °C until the time of testing. In all mixes, coarse aggregates were washed and dried to remove dust, excessive fines and any possible chloride contamination.

2.2. Mix designations and properties

The mixes in this study are designated as follows: the letters OPC, S, F, and B stand for the ordinary Portland cement, silica fume, fly ash, and blast furnace slag, respectively. For example, in Mix B50: B50 represents 50% replacement of cement by blast furnace slag; in B70S10: B70 represents 70% replacement of cement by blast furnace slag and S10 represents 10% replacement of cement with silica fume; in F25S10: F25 represents 25% replacement of cement by fly ash and S10 represents 10% replacement of cement with silica fume, while OPC is the control concrete mix made with ordinary Portland cement using 0.48 w/b ratio. The fresh and hardened concrete properties are reported in Tables 2 and 3.

For each mix, eight cylindrical specimens of 100 mm diameter and 50 mm thickness were cast for the RCPT, while 65 mm diameter and 200 mm length cylindrical specimens were cast for the UCT

Table 1
Chemical and relevant properties of the OPC, SF, FA and BFS

Chemical composition	Cement (%)	SF (%)	FA (%)	BFS (%)
SiO_2	21.1	90	67.5	34.1
Al_2O_3	5.2	0.9	23	13.2
Fe_2O_3	4.3	1.5	4.5	0.7
CaO	64.2	0.4	1	41.8
MgO	1.2	0.1	1	6.3
Na_2O, K_2O	0.05, 0.47	0.4, 0.9	0.5, 1.5	0.27, 0.34
SO_3	2.6	0.03	0.1	2.4
Loss on ignition (%)	0.8	–	1.0	−0.5
Specific gravity	3.13	2.24	2.13	2.86
Fineness index (m^2/kg)	350	23, 500	310	425

Table 2
Mix design and the relevant fresh and mature properties of mixes[a]; *w*/*b*: 0.48[b]

Properties	OPC	S10	F25	F25S10	F50	F50S10	F70	F70S10
Cement (kg/m^3)	450	405	337.5	292.5	225	180	135	90
Silica fume (kg/m^3)	–	45	–	45	–	45	–	45
Fly ash (kg/m^3)	–	–	112.5	112.5	225	225	315	315
Total cementitious content (kg/m^3)	450	450	450	450	450	450	450	450
Coarse aggregate (kg/m^3) – (oven dried)	1051	1042	1024	1015	996	987	978	969
Fine aggregate (kg/m^3) – (oven dried)	645	639	627	621	611	605	600	594
Superplasticizer L/100 kg binder	0	0	0	0	0	0	0	0
Water-effective (kg) – (free)	216	216	216	216	216	216	216	216
Slump (mm)	140	80	180	160	220	190	250	200
Air content (%)	0.58	0.7	0.2	0.4	0.25	0.25	0.2	0.3
Hardened concrete (kg/m^3) – 365 days	2300	2281	2220	2211	2160	2130	2092	2070
Compressive strength (MPa) – 365 days	55.7	60.2	45.7	38.2	27.4	21.8	10.3	6.1

[a] Control, silica fume, and fly ash mixes.
[b] Aggregate quantities are based on oven dry condition, while the water quantity recorded is the free water.

Table 3
Mix design and the relevant fresh and mature properties of mixes[a]; *w*/*b*: 0.48[b]

Properties	OPC	S10	B25	B25S10	B50	B50S10	B70	B70S10
Cement (kg/m^3)	450	405	337.5	292.5	225	180	135	90
Silica fume (kg/m^3)	–	45	–	45	–	45	–	45
Blast furnace slag (kg/m^3)	–	–	112.5	112.5	225	225	315	315
Total cementitious content (kg/m^3)	450	450	450	450	450	450	450	450
Coarse aggregate (kg/m^3) – (oven dried)	1051	1042	1047	1037	1041	1032	1042	1033
Fine aggregate (kg/m^3) – (oven dried)	645	639	641	636	639	633	639	633
Superplasticizer L/100 kg binder	0	0	0	0	0	0.25	0.28	0.6
Effective water (kg) (free)	216	216	216	216	216	216	216	216
Slump (mm)	140	80	160	55	95	70	160	105
Air content (%)	0.58	0.7	0.5	0.95	0.85	1	0.85	1.3
Hardened concrete (kg/m^3) – 365 days	2300	2281	2297	2265	2263	2235	2254	2302
Compressive Strength (MPa) – 365 days	55.7	60.2	55.1	50.6	38.3	36.3	37.6	36.2

[a] Control, silica fume, and blast furnace slag mixes.
[b] Aggregate quantities are based on oven dry condition, while the water quantity recorded is the free water.

test. The UCT specimens were sliced down to 25 mm thickness. This test was performed on a minimum of five specimens, except in the mixes B25S10 and F70S10 in which three specimens were used. As for the RCPT, eight specimens were used for each mix, except mixes OPC, B50, B50S10, B70, and F50S10 where seven specimens were used. Compressive strength testing was performed after one year of drying, while the RCPT and UCT tests were done after 350 and 250 days of the controlled environmental room exposure, respectively. The difference of age for both tests was a consequence of the time needed for fabrication of test apparatus.

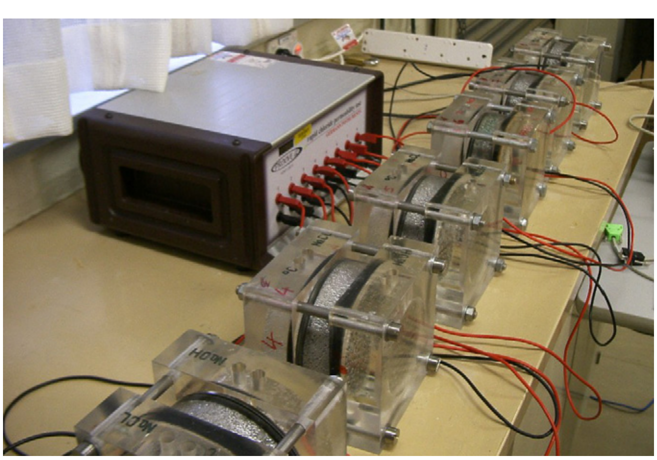

Fig. 1. The processor equipment connected with cells of the RCPT.

2.3. Description of test procedure for the two rapid tests

2.3.1. The rapid chloride permeability test

The permeability of concrete to chloride ions is evaluated based on the charge passed as measured in the RCPT in accordance with the procedures described in AASHTO T277 [17]. In this test, the concrete specimens are conditioned by achieving vacuum pressure of 1000 mtorr (133 Pa) on the dry specimen and maintained for 3 h, vacuum saturation for a period of 1 h after adding de-aerated water, and further soaking under water for a period of 18 h. Each specimen is then enclosed in a cell comprising two reservoirs on both sides of the specimen. The processor records the current passed through the specimens every 5 min and at the end of test it calculates the charge passed in coulombs. Fig. 1 shows the processor and the eight cells used in this study. The eight specimens representing a single mix were tested at the same time.

2.3.2. The University of Cape Town chloride conduction test

For the UCT test, the concrete specimens are conditioned by drying at 50 °C for a period of seven days to ensure uniform saturation of chloride solution. Drying is followed by saturation in a 5 M NaCl solution placed under constant vacuum for a period of 5 h then left to soak for an additional period of 18 h in order to pull the chloride front into the specimen. Each saturated specimen is then placed in the conduction cell comprising 5 M NaCl solution on either ends of the reservoirs and a 10 V potential difference is applied. The current is read immediately at the start of the test and chloride conductivity is calculated [6]. Fig. 2 shows the test configuration used for the chloride conduction test.

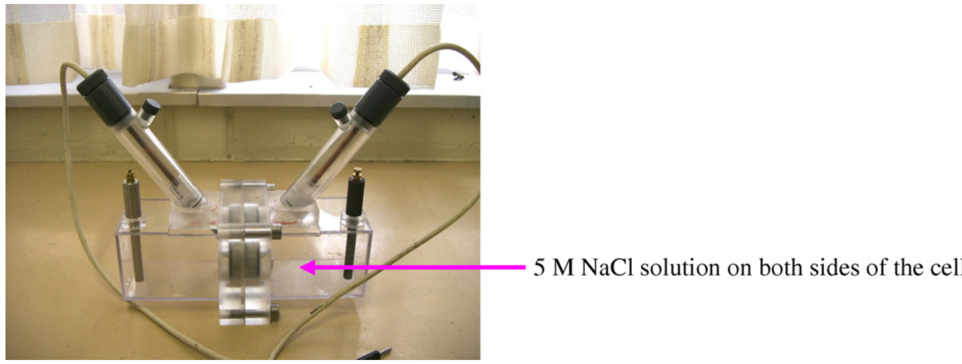

Fig. 2. The setup of UCT chloride conduction test.

3. Experimental results

3.1. Rapid chloride permeability results

Fig. 3 shows the average charge passed in the plain and blended concrete mixes. The silica fume specimens exhibited the lowest average charge passed. The average charge passed in the silica fume concrete blend was 60% less than in the control (OPC) concrete.

The concrete specimens with 70% fly ash (F70) and 70% fly ash and 10% silica fume (F70S10) drew excessive current because of porous concrete, and the test automatically stopped after only 1.5 h. Therefore, the values that correspond to these mixes after 1.5 h duration could not be plotted together with the rest of the mixes whose values are after the standard 6 h. However, in order to provide a comparison between all the mixes, a plot of the charge passed after 1.5 h is presented in Fig. 4.

The trends of average charge passed in the specimens after 90 min are similar to the average charge passed after 6 h, except in the ternary blend of 70% BFS and 10% silica fume (B70S10) which exhibited decrease in charge passed after a period of 90 min compared to an increase in the charge observed in the complete 6 h test.

To compare mixes a statistical analysis was carried out on the data using a logarithmic transformation of the response variable (charge) in order to obtain an error distribution that was reasonably normal with equal variance for each mix. Analyses of variance were carried out using the control, silica fume, and either fly ash or BFS. The factors included were silica fume with two levels (either present or absent), and either fly ash with three levels of replacement (absent, 25%, 50%) or BFS with four levels (absent, 25%, 50%, 70%). Dunnett's test [18] was used to compare mixes with control, and Tukey's paired comparison test [19] was used to determine whether two mixes were significantly different. The significance levels were 5% unless otherwise stated. All comparisons were done on the log scale, thus effectively comparing the significance of proportional increases or decreases in charge, rather than absolute differences in charge. The effects of the addition of silica fume and the effects of changes in levels of fly ash were highly significant at the 0.1% level, as was the interaction between silica and levels of fly ash. The interaction plot of fly ash and silica fume is shown in Fig. 5.

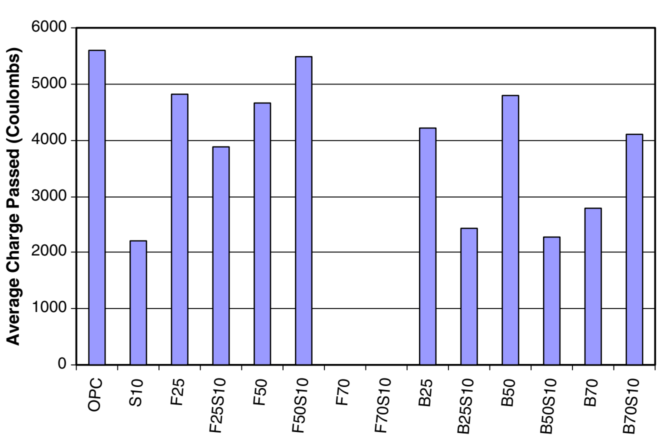

Fig. 3. Charge passed in the standard (RCPT) in the different blended concrete specimens.

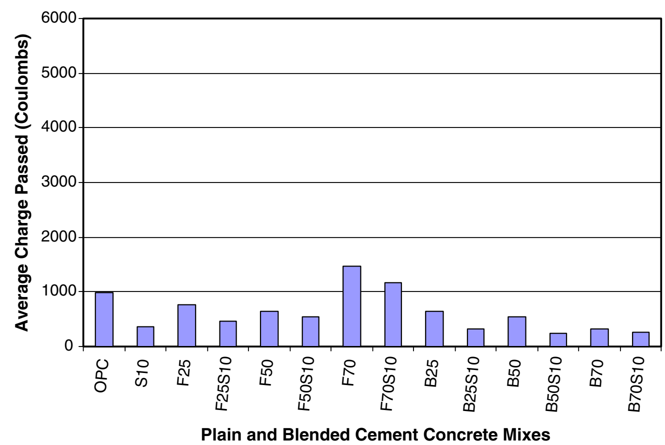

Fig. 4. Charge passed in plain and blended concrete specimens computed after a period of 90 min.

The estimated reduction in charge between the blend F25S10 and the average of F25 and F50 was about 18%. On the other hand, the decrease in charge passed between F25S10 and OPC was 30%. However, the ternary blend containing 50% fly ash and silica fume was not significantly different from the binary blend that contained 50% fly ash only.

Similarly, an analysis of variance was carried out using silica fume (either present or absent) and BFS as a factor with four levels (absent, 25%, 50%, and 70%). The effects of the addition of silica fume and their interaction effect with BFS were highly significant at the 0.1% level, while the effects of changes in the levels of BFS were only significant at the 10% level. Nevertheless, the interaction between silica fume and levels of fly ash was also highly significant at the 0.1% level. The interaction plot of BFS and silica fume is given in Fig. 6.

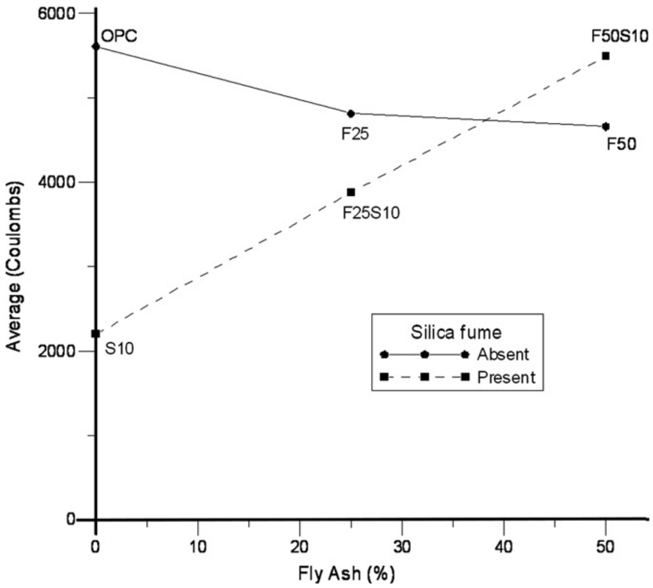

Fig. 5. Interaction plot of charge: silica fume with the levels of fly ash.

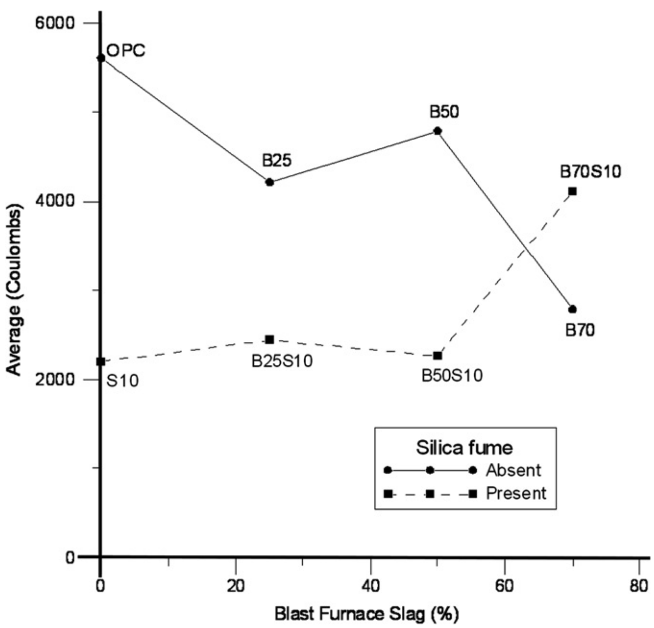

Fig. 6. Interaction plot of charge: silica fume with the levels of BFS.

The ternary concrete specimens comprising 25% and 50% BFS and silica fume showed a decrease in the charge passed compared to their respective binary blends of BFS. However, the ternary blend (B70S10) showed a significant increase in charge compared to its corresponding binary blend that did not contain silica fume. The average charge passed in the 25% and 50% binary blends of slag and fly ash were not significantly different either between levels of blend or between slag and fly ash at each blend level.

3.2. Absorption of chloride solution – RCPT

The percentage absorption in the concrete mixes was calculated from the difference in the weights of the specimens before and after conducting the RCPT. The average percentage absorption in the concrete specimen is shown in Fig. 7.

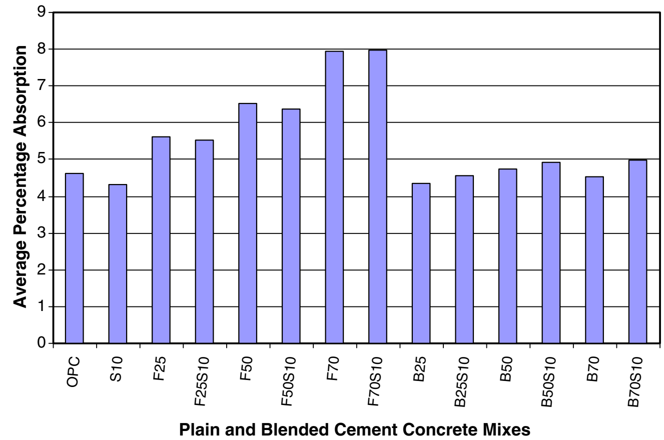

Fig. 7. Percentage absorption in the various blended concrete mixes.

The percentage absorption in the BFS concrete ranged from 4.4% to 5%, whereas in the fly ash concrete it ranged from 5.5% to 8%. On the whole, the BFS concrete blends showed lower charge and lower absorption characteristics indicating dense concrete compared to the fly ash counterparts.

3.3. Chloride conductivity results – (UCT test)

The average chloride conductivity in the plain and blended concretes cast with 0.48 *w*/*b* ratio is shown in Fig. 8.

A statistical analysis was carried out using the logarithmic transformation of response variable (conductivity) to ensure normality of the error distribution and homogeneity of variance. Significance testing of difference between mixes was performed at the 5% level using the Tukey's paired comparison test and Dunnett's test. The chloride conductivity in the control (OPC) and silica fume (S10) blends was 1.24 and 1.08 mS/cm, respectively showing about a 13% reduction in the silica fume mix. The interaction plot of silica fume with the levels of fly ash is shown in Fig. 9.

The conductivity increased with the increase in the level of fly ash. The average chloride conductivity in the mixes with 25%, 50%, and 70% fly ash was 1.95, 2.64, and 3.17 mS/cm, respectively compared to 2.20, 4.12 and 4.98 mS/cm in their respective ternary blends. The increase in charge from binary to ternary blend was significant in the case of the 50% and 70% blends, but not in the case of the 25% blend.

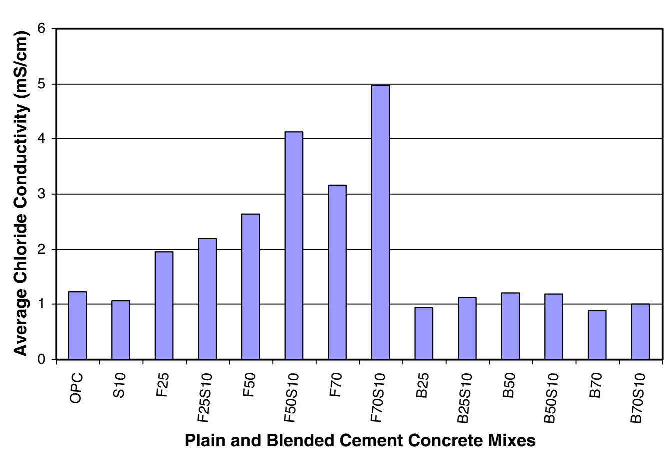

Fig. 8. Chloride conduction in plain and blended concrete mixes.

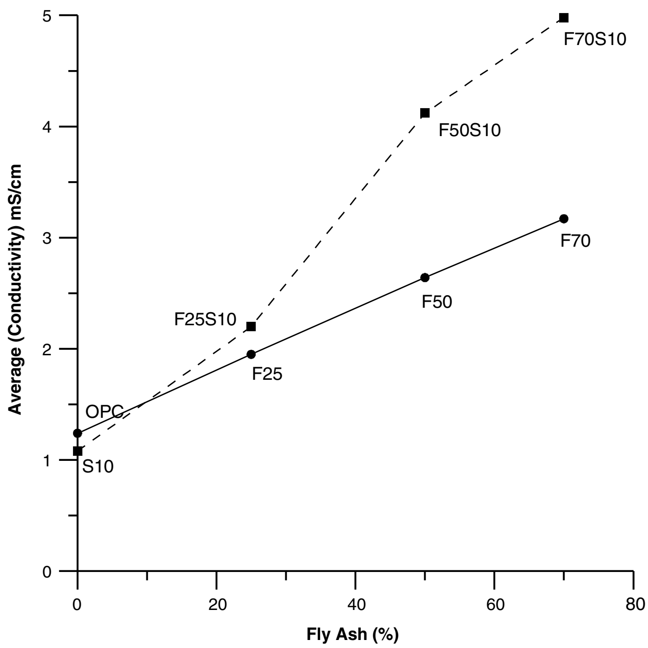

Fig. 9. Interaction plot of conductivity: silica fume with the levels of fly ash.

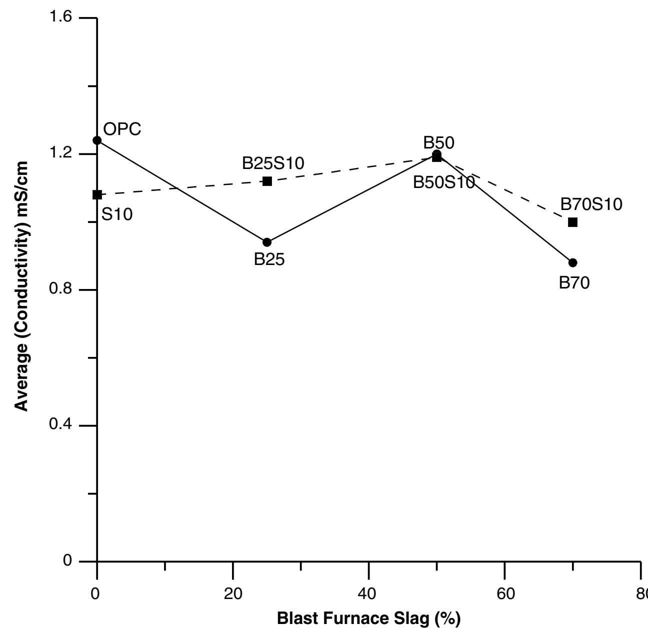

Fig. 10. Interaction plot of conductivity: silica fume with the levels of BFS.

The interaction plot of silica fume with the levels of BFS is shown in Fig. 10. The addition of silica fume to the binary blends of BFS gave no significant difference in chloride conductivity between binary and ternary blends. The chloride conductivity values in the binary blends of BFS varied from 0.88 to 1.2 mS/cm, while the ternary blends of BFS and silica fume ranged from 1.0 to 1.12 mS/cm. All binary and ternary blends of BFS had lower average conductivity than binary and ternary blends of fly ash.

4. Discussion of results

4.1. Plain control and silica fume concretes

The average charge passed using the RCPT in the control (OPC) concrete was much higher than its average value in silica fume specimens. It is worth noting that the same trend was observed in a study by these authors using long-term ponding under 3% NaCl solution. The results of that study will be reported in a separate publication.

In the RCPT, silica fume concrete exhibited the lowest charge passed compared to both fly ash and BFS concrete. This can be attributed not only to the reduction of permeability of the transition zone around the aggregate in presence of silica fume, but also the reduction of permeability in the bulk paste compared to the hydrated cement paste [20]. In addition, silica fume decreases $Ca(OH)_2$, and further C/S ratio in C–S–H is also reduced [21]. Thus, silica fume concrete is less permeable and highly resistant to aggressive chemical solutions [21]. Mehta [22] reported that silica fume blended concrete cast with a low *w*/*b* ratio of 0.33, and exposed for a period of six months to 1% HCl, 1% lactic acid, and 5% acetic acid exhibited better performance than the reference concrete.

Significance testing of the RCPT results using Dunnett's method [18] indicated a highly significant difference at the 0.1% level between the control and silica fume blended specimens. However, no significant difference existed between the control and silica fume specimens in the UCT test.

Lower values of chloride conductivity in silica fume specimens were also reported by Mackechnie and Alexander [13] using the UCT test, with values of 1.04 and 0.37 mS/cm in the control and silica fume concrete specimens, respectively cast using 0.5 *w*/*b* ratio. Thus, although silica fume specimens exhibited lower values as charge passed and lower conductivity, the difference is very much more pronounced in the RCPT.

4.2. Binary and ternary blends including fly ash

An important result in the RCPT is that the charge passed in the ternary blend of 25% fly ash and addition of silica fume was significantly lower than its corresponding binary blend that did not contain silica fume. This indicates the importance of these ternary blends compared to binary blends of fly ash. It is worth stating that addition of silica fume on its own or with 25% fly ash resulted in significant decrease in the charge passed compared to the mix with 25% fly ash only. This clearly indicates the importance of silica fume presence in fly ash blends (25% replacement level) in reducing the charge and densifying the concrete. In contrast, no difference was observed between these blends when the UCT test was used. The difference obtained in the RCPT specimens between these blends may stem from the larger number of the RCPT specimens and their larger size compared to the UCT test.

4.3. Binary and ternary blends including BFS

The average charge passed using the RCPT in the ternary blends of 25% and 50% BFS and addition of silica fume was much lower than those passed in the respective binary blends. However, an increase in the charge passed was observed in the ternary blend of 70% BFS and addition of silica fume compared to its binary blend. On the other hand, the chloride conductivity measured by the UCT chloride conduction test indicated no significant difference between the ternary blends of slag and silica fume and their respective binary blends of slag.

5. Conclusions

In this paper, two rapid chloride penetration tests were used to measure the effect of binary and ternary blends of Portland cement with fly ash, blast furnace slag and/or silica fume on the resistance of concrete to chloride penetration. Statistical analysis was employed in order to compare the results obtained from the two methods. The conclusions of this study are summarized in the following points:

1. It has been clearly seen that the inclusion of silica fume in binary blends with Portland cement positively contributes to reduce the permeability of concrete to chloride ions. The densification of the matrix brought about by the pozzolanic reactions of silica fume blocks the pores and results in reducing permeability.
2. The presence of fly ash together with silica fume in ternary blends with portland cement has been seen to increase permeability to chlorides. The reason is likely to be the relatively large proportion of silica fume in blends containing a large proportion of fly ash. If the proportion of silica fume is relatively high in comparison to portland cement, then the pozzolanic activity of the surplus silica fume may frustrate the hydration of Portland cement grains. The relatively fast pozzolanic reactions of silica fume further eliminate the opportunity of fly ash to react and thus prevent realizing its potential in contributing to strength and impermeability of the matrix. It is therefore envisaged that in ternary blends, the proportion of silica fume should be kept to a maximum of 10% of the portland cement content.
3. Ground granulated blast furnace slag is an efficient pozzolanic material that has been shown to be more effective than silica fume in resisting chloride permeability. It has been shown that when using slag there is no need to include silica fume whether for strength or chloride resistance purposes. There has even been an indication that silica fume presence together with slag in ternary blends, reduces strength and the resistance to chloride penetration. These authors believe that the fast pozzolanic reactions of silica fume reduce the availability of calcium hydroxide for further reaction with the BFS particles.
4. The trends exhibited in the development of compressive strength of the various blends have been quite well reflected in the results of the University of Cape Town (UCT) test for chloride conductivity. In view of this relatively simple and much less costly test when compared to the AASHTO rapid chloride permeability (RCPT), the authors believe that the UCT test provides an adequate and convenient method to perform and may accurately reflect the trend of chloride permeability in various concrete mixtures and blends.

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