THE UNIVERSITY OF NEW SOUTH WALES

BUILDING RESEARCH CENTRE

COMMERCIAL IN CONFIDENCE

Report Prepared by the
Building Research Centre

on

LABORATORY EVALUATION OF RADCON FORMULA #7

for

RADCRETE PACIFIC PTY. LTD.

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EXECUTIVE SUMMARY

The Building Research Centre was commissioned by Radcrete Pacific to evaluate the effectiveness of their product, Radcon#7, in improving the durability properties of concrete.

Three concretes were selected with a range of strengths, and permeability characteristics. Samples were cast and treated with Radcon#7 and compared with untreated samples. The treated and untreated specimens were subjected to water permeability testing, ISAT and chloride diffusion testing. The results indicate a consistent trend of improvement in these properties.

1.0 INTRODUCTION

The Building research Centre (BRC) was commissioned by Radcrete Pacific Pty., Ltd., to conduct tests on their product Radcon #7 to assess the performance of their product. This report fulfils part of the requirement of the ABSAC appraisal process.

Radcon Formula #7 is a low viscosity liquid sealer for concrete. The manufacturer describes the product as:

> "Radcon #7 is a clear, colourless and odourless sodium silicate-based material which penetrates up to 20mm into builders concrete. No change to the appearance of the concrete surface will occur after treatment. Unlike surface coatings and membranes, Radcon #7 seals deep into the concrete and is therefore not affected by surface damage. Radcon #7 will prevent water leakage and the ingress of salts and contaminants whilst allowing water vapour transmission."

The testing carried out considered Radcon #7's behaviour in improving the ability of various concretes to restrict the movement of water and chlorides.

A full presentation of test results and analysis is not included in this document, however a separate document has been produced incorporating all test results and calculations and is available from Radcrete Pacific on request.

2.0 TESTING PROGRAM

The testing program included the following tests:

- Initial Surface Absorption Test (ISAT), BS1881: Part5:1970
- Water Permeability
- Chloride Diffusion Coefficient (by Taywoods)

As no universally recognised standard exists for water permeability, permeability was determined using the BRC's own method. The equipment used in the BRC method is similar to that described by German Standard DIN1048 for use in water permeability measurement.

The purpose of the testing was to evaluate the effect of treatment using Radcon#7 on the characteristics described by the tests. The tests are briefly described in the following section.

2.1 BRIEF DESCRIPTION OF TESTS

2.1.1 ISAT

The Initial Surface Absorption Test (ISAT), BS1881: Part5:1970 involves the measurement of flow into a concrete surface of water under a head of 200mm. The flow is measured at discrete intervals over a 2 hour period and is reported in $ml.m^{-2}.s^{-1}$ for each measurement time.

2.1.2 Water Permeability

Water permeability is calculated by forcing water through a concrete specimen at a given head and measuring the flow rate. From Darcy's equations we can then calculate the permeability coefficient for that specimen. Water permeability is measured with the specimens in a saturated state so that the surface tension of the water against the concrete is discounted.

Permeability tests carried out at high pressures are known to have problems of repeatability believed to be associated with the effect of the high pressure on the internal structure of the cement matrix. Accordingly, we conduct our permeability tests at the relatively low pressure of 200 kPa or 2 atmospheres.

2.1.3 Chloride Diffusion

The Chloride Diffusion Coefficient is a measurable characteristic of a concrete that can be objectively compared to other concretes. This value is evaluated by measuring the chloride ion concentrations at discrete depths within a block of concrete which has been allowed to absorb chlorides by diffusion, that is without the assistance of an electric current or the pumping action of wetting and drying cycles. By applying Fick's equation for diffusion to the values measured, we can determine the Chloride Diffusion Coefficient.

2.2 CONCRETE MIX DESIGNS

In order to do this evaluation, five concrete mix designs were selected from information provided by Mr John Ashby of Australian Steel Mill Services. Mr Ashby has long been involved in the concrete industry providing highly regarded advice in the design of concrete and its components.

The mix designs closely approximate the proportions and behaviour that can be expected in commercially available concrete. From the five mixes, three mixes were selected on the basis of the ISAT and water permeability tests for treatment and further testing.

The batch masses of the five mixes are as follows:

Mix Designation	Unit	25A	40A	50A	25FA	50FA
		Batch Quantities				
Type A Cem.	kg/m^3	270	360	430	215	370
Fly Ash	kg/m^3				85	75
20 mm Agg	kg/m^3	700	710	710	720	730
10 mm Agg	kg/m^3	380	380	380	400	400
Coarse Sand	kg/m^3	570	520	490	530	480
Fine Sand	kg/m^3	290	240	200	230	150
Water	kg/m^3	170	170	170	160	160
w/c		0.63	0.47	0.40	0.53	0.36
WRA:MBT Pozzolith 300R	ml/m^3	810	1,080	1,290	900	1,335

All batch quantities for aggregates are SSD.

All mixes were executed in accordance with AS1012, Part 2, Method for the Preparation of Concrete Mixes in the Laboratory. All materials were preconditioned at 23°C before mixing. Mixing was done in a 200 litre Bennet pan mixer.

All test specimens were consolidated by rodding as per the procedure set out in AS1012, Part 8, Method for Making and Curing Concrete Compression, ... Test Specimens in the Laboratory or in the Field.

All specimens were cured for 24 hours at 23°C and 95% relative humidity. All specimens were then demoulded and placed into lime saturated water at 23°C until required for processing or test.

2.2 ASSURANCE OF MIX QUALITY

The numerical portion of the mix designation refers to the proposed target strength. As confirmation of the mix quality, compressive strength cylinders were cast, cured and tested at 28 days in accordance with AS1012, Part 8, Method for Making and Curing Concrete Compression, ... Test Specimens in the Laboratory or in the Field and AS1012, Part 9, Method for the Determination of the Compressive Strength of Concrete Specimens.

The results are given in the table below:

	25A	40A	50A	25FA	50FA
	26.37	43.06	56.3	23.52	51.04
	26.48	43.41	57.55	21.49	51.81
	25.44	41.95	54.9	21.75	51.02
Mean	26.1	42.8	56.3	22.3	51.3
Std Dev.	0.57	0.76	1.33	1.10	0.45
CV	2.2%	1.8%	2.4%	5.0%	0.9%
f'c	25.0	41.3	53.7	20.1	50.4

As can be seen from the above table, the results confirm the strength designations, with the exception of mix 25FA, which achieved a lower characteristic strength. Discussion of the cause for this is beyond the scope of this report. In any event this mix was culled as the permeability characteristics were similar to that of the 40MPa OPC mix and therefore not used in the final comparison testing.

3.0 DURABILITY ASSESSMENT OF MIXES

Specimens of the five mixes above were subjected to ISAT and permeability testing to determine their relative durabilities. From these five mixes, we selected a subset of three mixes which would then be evaluated, comparing treated and untreated specimens for certain characteristics of durability.

3.1 Initial Surface Absorption Test (ISAT)

For each mix, four specimens measuring 160 mm x 160 mm x 40 mm were cast and cured according to the provisions of AS1012.8. At 28 days each specimen was air dried at 60°C until constant mass was achieved. The specimens were then allowed to cool to 23°C in air at 50% relative humidity. The specimens were then stored in an air tight container at 23°C until required for test. According to the provisions of BS1881: Part5:1970, the samples were tested for initial surface absorption.

The following results were obtained, averaged over four specimens per sample:

	25A $ml.m^{-2}.s^{-1}$	40A $ml.m^{-2}.s^{-1}$	50A $ml.m^{-2}.s^{-1}$	25FA $ml.m^{-2}.s^{-1}$	50FA $ml.m^{-2}.s^{-1}$
10 mins	0.90	0.60	0.35	0.70	0.37
30 mins	0.47	0.35	0.22	0.38	0.20
60 mins	0.31	0.26	0.17	0.27	0.14
120 mins	0.24	0.19	0.15	0.19	0.10

From the above it can be seen that the mixes can be ranked in order from greatest absorption to least:

1. 25A
2. 25FA
3. 40A
4. 50A
5. 50FA

3.2 Water Permeability

At 25 days age, 20mm thick slices were cut from the tops of two cylinder specimens cast for each mix. The slices were then vacuum saturated using deionised and deaerated water under a vacuum of 1 mm Hg absolute. After 48 hours of immersion under vacuum, the specimens were returned to normal atmospheric pressure. The cylindrical surface of each specimen was then coated with an underwater setting epoxy. At 28 days the specimens were fitted into the BRC water permeability rig and the "top" face was subjected to water at 200kPa. The test was performed at 23°C.

Testing extended over the period from 28 days to approximately 42 days.

The quantity of water passing through over time was measured and the permeability of the specimens was then calculated using Darcy's Law below:

$$k_p = \frac{q \times l}{\Delta h \times A}$$

Where:

k_p = permeability coefficient ($m.s^{-1}$)
q = flow rate ($m^3.s^{-1}$)
l = length of specimen (m) = nominally 0.02 m
Δh = pressure head (m) = 20.4m, equivalent to a pressure of 200kPa
A = Area of flow (m^2) = 6.36×10^{-3} m^2

The table below shows the water permeability values calculated:

	25A $\times 10^{-12} m.s^{-1}$	40A $\times 10^{-12} m.s^{-1}$	50A $\times 10^{-12} m.s^{-1}$	25FA $\times 10^{-12} m.s^{-1}$	50FA $\times 10^{-12} m.s^{-1}$
Specimen 1	188	81	8.6	101	3.39
Specimen 2	196	91	12.4	120	3.74
Mean	192	86	10.5	111	3.57
Variance	2%	6%	18%	9%	5%

As can be seen from the above tabulation the ranking of permeabilities from highest to lowest is:

1. 25A
2. 25FA
3. 40A
4. 50A
5. 50FA

The ranking is as per the ISAT data. Accordingly, the three mixes selected for the comparison phase were 25A, 40A and 50FA.

4.0 MAIN TEST PROGRAM

4.1 General

From additional cylinders cast at the same time as the original samples, 20 mm thick slices were cut for use in water permeability testing and 50 mm thick slices were cut for use in chloride diffusion testing. The square specimens used in the original ISAT testing were reused in this stage.

These specimens were then divided into two lots, one lot of each was to be left untreated as a control, while the other lot was treated using the Radcon standard method of treatment.

The standard method of treatment is to flood the surface being treated with Radcon#7 and allow to penetrate until the surface becomes "tacky" approximately two hours after application. At this stage apply the first watering, ensuring that all the Radcon has dissolved and been drawn into the concrete. Allow the watering to be absorbed fully for 24 hours then rewater, repeating this process 48 hours after first watering. To ensure that all specimens, whether treated or untreated received the same degree of curing, the untreated specimens were also watered at the same time as the treated specimens.

Due to the small size of the specimens, care had to be taken to ensure that the Radcon did not flow down the sides onto the underside of the specimen. In order to guarantee this, dams of flexible material were clamped to the specimens with hose clamps of various sizes to seal the sides.

Treatment of the specimens was done at approximately 56 days.

After treatment, all cylindrical specimens, (water permeability and chloride diffusion) were vacuum saturated using deionised and deaerated water under a vacuum of 1 mm Hg absolute. After 48 hours of immersion under vacuum, the specimens were returned to normal atmospheric pressure and stored in the water used for saturation in sealed containers kept at 23°C. The cylindrical surface of each specimen was then coated with an underwater setting epoxy. The 50mm thick specimens used in the chloride diffusion test were also coated on the underside so that only the top struck surface was free to absorb chlorides.

Treated and untreated specimens were stored separately.

4.2 Permeability

At approximately 90 days of age the 20 mm thick specimens were progressively fitted into the BRC water permeability rig, four at a time, and the "top" face was subjected to water at 200kPa. The test was performed at 23°C. Due to the low flows experienced, the testing period extended between 90 and 120 days.

At the request of Radcrete Pacific, an additional pair of specimens of the 25A mix were subjected to a 12% carbon dioxide atmosphere for 28 days before Radcon treatment to induce carbonation. These specimens were then treated with Radcon #7 in the same manner as the other specimens and tested at approximately 90 days. The purposes of this test was to determine the effect of carbonation on the Radcon treatment.

As during the previous permeability tests the quantity of water passing through over time was measured and the permeability of the specimens was then calculated using Darcy's Equation below:

$$k_p = \frac{q \times l}{\Delta h \times A}$$

Where:

k_p = permeability coefficient ($m.s^{-1}$)
q = flow rate ($m^3.s^{-1}$)
l = length of specimen (m) = nominally 0.02 m
Δh = pressure head (m) = 20.4m, equivalent to a pressure of 200kPa
A = Area of flow (m^2) = 6.36×10^{-3} m^2

According to the table below, water permeability in treated compared to untreated specimens was reduced in all cases. The greatest improvement was achieved in the 25MPa Portland cement only mix. All "new" concretes showed a significant reduction in permeability, while the carbonated concrete showed only a very small improvement. That there was any improvement at all suggests that the concrete may not have been completely carbonated, therefore not using up all of the available free calcium.

The reduction of 33% in the fly ash mix compared to the higher values in the OPC mixes may be influenced by two factors, the amount of free calcium available for use by the Radcon had been depleted by the hydration of the fly ash, and secondly, greater improvement may not be possible due to the fly ash filling the voids between the cement particles.

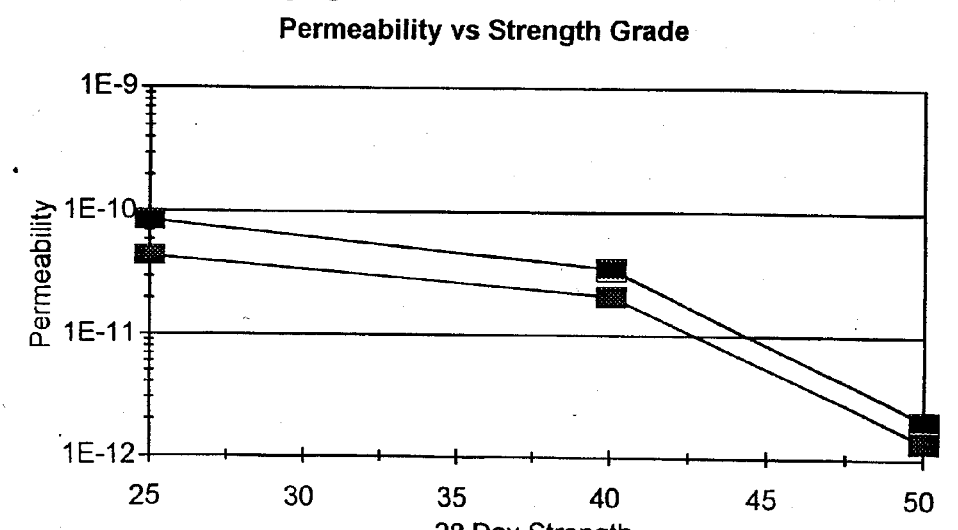
The table below shows the water permeability values calculated:

	Measured Permeability $\times 10^{-12} m.s^{-1}$	Mean Permeability $\times 10^{-12} m.s^{-1}$	Improvement ((U-T)/U)%
25A, U	83, 89	86	
25A, T	43, 46	44	49%
25A, CU	65, 73	69	
25A, CT	59, 61	60	13%
40A, U	33, 37	35	
40A, T	20, 22	21	40%
50FA, U	1.9, 2.1	2.00	
50FA, T	1.3, 1.4	1.35	33%

Key to suffixes:
A Type A Portland Cement only mix
FA Portland / Fly Ash blend
U Untreated
T Treated with Radcon #7
C Carbonated

The following log-linear graph shows the relationship between permeability in treated and untreated samples and strength grade:

Permeability vs Strength Grade



The upper line on the above graph represents the untreated concrete while the lower line represents the treated specimens. It can be seen from the above graph that the treated 25MPa concrete displayed similar permeability to the untreated 40MPa concrete at 35 and 44 x $10^{-12} m.s^{-1}$ respectively. As can be expected the 50MPa concrete being a fly ash blend type concrete had lower permeability than even the treated 40MPa which is an OPC concrete, however, we cannot say that this would be the same circumstance if a 40MPa fly ash blend concrete were used.

4.3 Initial Surface Absorption Test (ISAT)

Of the four ISAT samples originally cast for each mix, two were treated using Radcon # 7 while two were left untreated. Between 28 days and until treatment, the specimens were maintained at 23°C in air at 50% relative humidity. At approximately 90 days of age the specimens were air dried at 60°C until constant mass was achieved. The specimens were then allowed to cool to 23°C in air at 50% relative humidity. The specimens were then stored in air tight containers at 23 °C until required for test at approximately 95 days. According to the provisions of BS1881: Part 5: 1970, the samples were tested for initial surface absorption. The values in the table below are the average of two results.

	25A Treated $ml.m^{-2}.s^{-1}$	25A Untreated $ml.m^{-2}.s^{-1}$	40A Treated $ml.m^{-2}.s^{-1}$	40A Untreated $ml.m^{-2}.s^{-1}$	50FA Treated $ml.m^{-2}.s^{-1}$	50FA Untreated $ml.m^{-2}.s^{-1}$
10 mins	0.27	0.56	0.19	0.34	0.10	0.14
30 mins	0.25	0.35	0.17	0.25	0.07	0.09
60 mins	0.21	0.25	0.12	0.19	0.04	0.07
120 mins	0.15	0.19	0.10	0.15	0.02	0.05

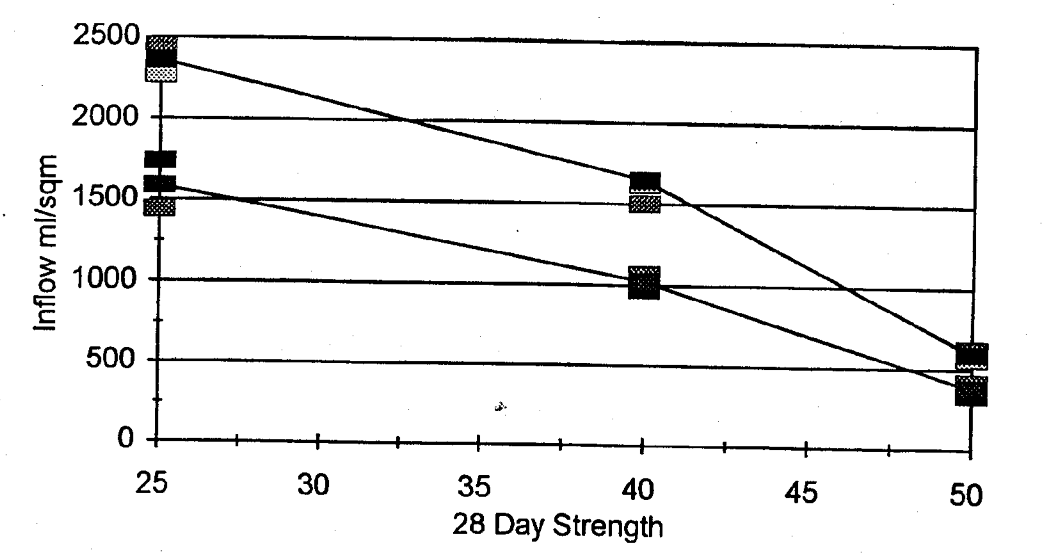
Integrating absorption over time to give inflow we obtain the following total inflows at two hours:

	25A Treated $ml.m^{-2}$	25A Untreated $ml.m^{-2}$	40A Treated $ml.m^{-2}$	40A Untreated $ml.m^{-2}$	50FA Treated $ml.m^{-2}$	50FA Untreated $ml.m^{-2}$
	1740	2270	940	1620	340	570
	1440	2450	1070	1500	420	630
Average	1590	2360	1005	1560	380	600
Improvement	33%		35%		37%	

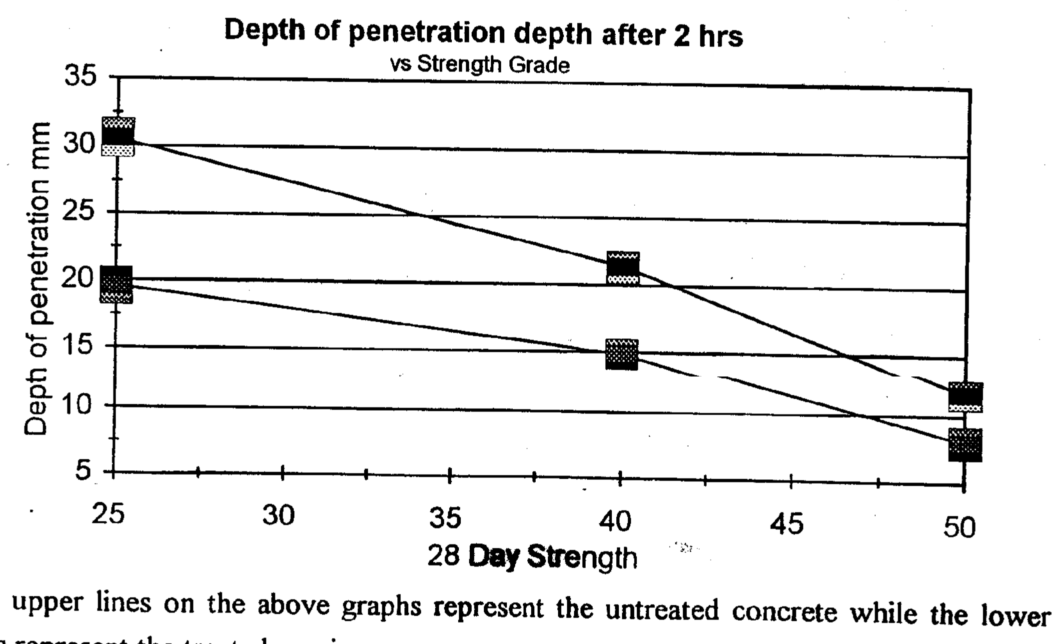
At the end of each test, each specimen was split open. The average depth of penetration was calculated from ten measured depths on each specimen and gave the following results:

	25A Treated mm	25A Untreated mm	40A Treated mm	40A Untreated mm	50FA Treated mm	50FA Untreated mm
Max/Min	21,17	27,35	13,16	19,23	7,10	10,13
Average	19.6	30.6	14.9	21.4	8.0	11.7
Improvement	36%		30%		32%	

Inflow after 2 hrs vs Strength Grade



Depth of penetration depth after 2 hrs
vs Strength Grade



The upper lines on the above graphs represent the untreated concrete while the lower lines represent the treated specimens.

It is clear from the above tabulations and graphs that the treatment produced a reduction in inflow and depth of penetration in the order of 35% over the two hours of the test. Specifically, it can be said that the treated 25MPa concrete had similar properties with respect to initial surface absorption to the untreated 40MPa concrete. The treated 40MPa concrete approached the properties of the untreated 50MPa fly ash blend concrete.

4.4 Chloride Diffusion Coefficient

At 56 days, the vacuum saturated, 50mm thick slices coated on the sides and underside set aside for the chloride diffusion test were immersed in a 4% saline solution with the top of the specimens under a hydrostatic head of 20mm. Four specimens for each concrete were exposed, two treated and two untreated. An additional specimen of the 50 Fly Ash mix (50FA) was included to enable assessment of the best duration of exposure. Control specimens for each concrete grade were left unexposed for the period of the exposure.

Fick's Law postulates that the rate of diffusion of one material through another can be expressed as an error function as described by:

$$C_x = (C_s - C_i) \times erfc(y)$$

where:

$$y = \frac{x}{2\sqrt{D_c.t}}$$

and:

C_x= Cl^- concentrattion at depth x
C_s= Cl^- concentration at the surface, interpolated
C_i= Cl^- concentration of unexposed material, obtained from the control samples
x = Depth in profile (mm)
D_c= Diffusion Coefficient (mm^2s^{-1})
t = Time of exposure (s)

According to the procedure, concretes containing supplementary cementitious materials should be exposed for a minimum of 56 days to achieve a measurable profile. At 56 days exposure the additional 50FA sample was measured however the profile was too flat for a good evaluation. The samples were immersed for an additional 21 days to improve the profile.

At the completion of the exposure period the samples were removed from the solution and oven dried at 60°C for 24 hours at which time the specimens were placed in a purpose made milling machine and powdered in 2 mm increments from the top surface. The powdered samples were then assayed for chloride ion concentration using the Merck Chloride Test. The concentrations were adjusted by weight of cementitious material; that is the mass of cement and fly ash, if any in the mix. The profiles so determined were then subjected to curve fitting to obtain an approximation of the surface concentration, C_s and the diffusion coefficient D_c.

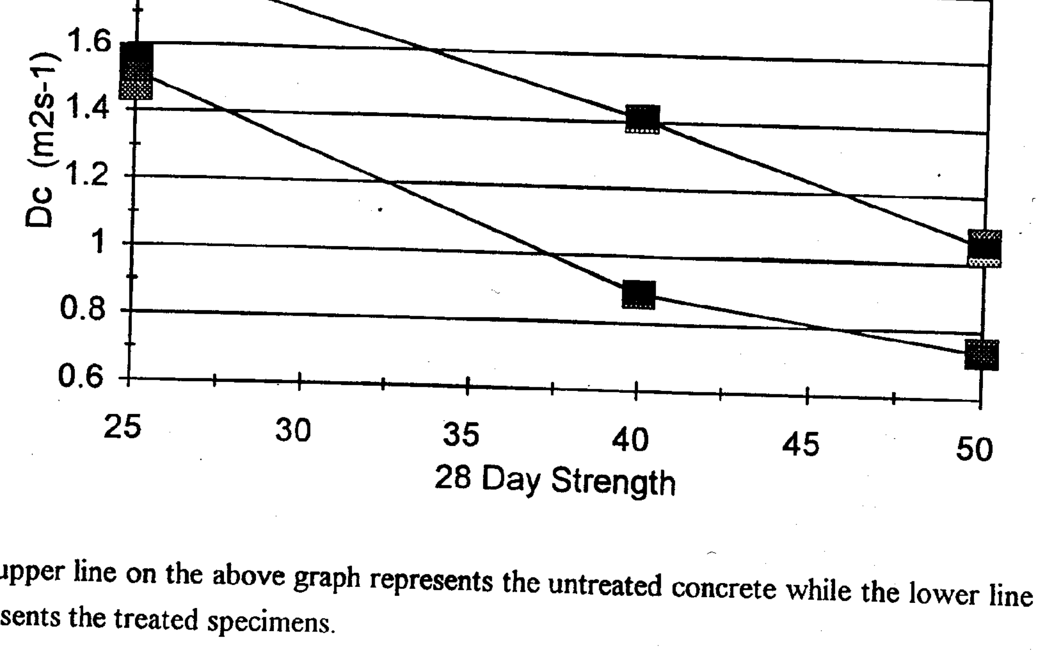
The measured chloride profiles are included in the separate annexure to this report.

The following table summarises the Diffusion Coefficients:

	25A Treated $x10^{-6}mm^2s^{-1}$	25A Untreated $x10^{-6}mm^2s^{-1}$	40A Treated $x10^{-6}mm^2s^{-1}$	40A Untreated $x10^{-6}mm^2s^{-1}$	50FA Treated $x10^{-6}mm^2s^{-1}$	50FA Untreated $x10^{-6}mm^2s^{-1}$
	1.570	1.863	0.900	1.401	0.722	1.030
	1.456	1.848	0.876	1.421	0.753	1.080
Average	1.513	1.855	0.888	1.411	0.738	1.055
Improvement	18%		37%		30%	

As can be seen from the above tabulation and graph below, Radcon provides some measure of improvement in the ability of a concrete to resist the movement of chlorides.

Chloride Diffusion Coefficient
vs Strength Grade



The upper line on the above graph represents the untreated concrete while the lower line represents the treated specimens.

The treated 25MPa concrete was similar in behaviour to the untreated 40MPa concrete, while the treated 40MPa concrete appeared to have better properties than the untreated 50MPa fly ash concrete, although this can not be generalised on the basis of the limited testing in this program.

5.0 CONCLUSIONS

The testing carried out confirms the claims that, within the limitations of the testing program, that Radcon#7 does improve the durability of a concrete by reducing the movement of water and chlorides through the matrix.

The testing was carried out on OPC concretes as well as a fly ash blend concrete. One cross correlation test was conducted on a carbonated concrete. At the age of application of the Radcon, approximately 56 days there appeared to be sufficient free calcium available in the uncarbonated matrix to permit treatment without any supplementary calcium treatment. The carbonated concrete did not afford the same improvement in permeability as the uncarbonated specimens, and we can therfore surmise that the treatment was not as successful here, due probably to the lack of free calcium due to carbonation.

The tests generally indicate the same degree of improvement for all the uncarbonated concretes, all other things being equal. Many variables affect the availablity of free calcium in concrete at any given age and environment. Accordingly, the effectiveness of Radcon treatment would also be affected, provided appropriate steps are taken to augment the level of free calcium to a sufficient concentration. The manufacturer, Radcrete does recommend in instances where concrete is carbonated or known to be depleted of free calcium that calcium acetate be applied to the concrete before treatment with Radcon#7 to ensure sufficient free calcium for the treatment to be effective.

From the relatively small sample in the testing program, it is not feasible to generalise on the degree of improvement that the treatment will afford due to variations in constituents and condition. However the test program indicates that the treatment holds the potential to increase the durability class of a concrete element, as defined by AS3600 given a certain strength grade and cover provided.

A full presentation of test results and analysis is not included in this document, however a separate document has been produced incorporating all test results and calculations and is available from Radcrete Pacific on request.