CTI Consultants Pty Ltd

Materials and Environmental Investigations

ACN 003 824 815

Phone: (02) 736 3911
Fax: (02) 736 3287

4 Rothwell Avenue
Concord West NSW 2138

Postal Address
P.O. Box 153
North Strathfield
NSW 2137

8 November, 1996

DryTreat Australia
PO Box 551,
ST LEONARDS NSW 2065

382rdta081196.doc

Attention: Mr. Stuart Anderson

Dear Stuart,

Re: Evaluation of Waterproofing Treatment for Concrete

Thank you for submitting your product for inclusion in the evaluation program of water treatments for concrete under conditions of atmospheric exposure which we conducted on behalf of the Roads and Traffic Authority of NSW earlier this year.

Attached is a copy of the report on that investigation for your interest. Your product, DryTreat 100N, was Product A.

Yours faithfully,
CTI CONSULTANTS PTY LTD,

F. SALOME,
Director.

Fred Salome, B.Sc. (Hon.)
Director - Materials Technology
& Environmental Investigations

Peter J. James,
B.Sc. (Eng.), M.I.E. Aust.
Assoc. - Project Engineering.

Bill McEwan
Dip. Ap. Chem; Dip. Met.
Assoc. - Corrosion & Metallurgy

Carol Bodle
B.Med.Sc. (Hon.)
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INVESTIGATION REPORT

FURTHER INVESTIGATION OF WATERPROOFING MEASURES FOR THE LONG TERM DURABILITY OF CONCRETE

PREPARED FOR:	ROADS AND TRAFFIC AUTHORITY of NSW		
CONTACT:	Mr. Howard Morris Manager, Durability and Protection RTA Technology - Bridge Branch		
PHONE:	(02) 9662 5810	**FAX:**	(02) 9662 5748

Prepared By: Fred Salome
Report Number: C9314/A
Date: 7 November, 1996
CTI Project Number 382

Fred Salome, B.Sc. (Hon.)
Director - Materials Technology
& Environmental Investigations

Peter J. James,
B.Sc. (Eng.), M.I.E. Aust.
Assoc. - Project Engineering.

Bill McEwan
Dip. Ap. Chem; Dip. Met.
Assoc. - Corrosion & Metallurgy

Carol Bodle
B.Med.Sc. (Hon.)
Environmental Health

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1. INTRODUCTION

During 1993 and 1994, CTI Consultants Pty Ltd carried out a comprehensive investigation into the "Role of Silanes in Long Term Durability of Concrete Structures" on behalf of the Roads and Traffic Authority of NSW (RTA). This investigation included a literature survey on experience with and use of silanes world-wide, a review of the RTA's own experience with silanes and related products, and the development of a suite of screening tests for initial evaluation of water repellents for concrete.

The investigation specifically addressed the durability of concrete under conditions of atmospheric exposure in the prevailing conditions in NSW coastal areas, where periodic wetting from precipitation is intermingled with drying periods, often prolonged, and where air-borne salts can be deposited on the surface of the concrete.

The report on that investigation, CTI Report No. C9158, dated 24/04/95, suggested that the screening tests could be simplified and made more discriminating by combining two of the main tests into a single procedure. This would involve determining the effect of treatments on water uptake by (cyclic) immersion of the test specimens in salt water rather than in fresh water. By doing this, the effect on chloride ingress would be determined by analysing the same specimens after cyclic immersion in the 15% sodium chloride solution, instead of carrying out a separate exposure series in a salt-fog environment.

The further investigation reported herein was designed to act on this recommendation and involved performing the proposed simplified test on a number of products used in the earlier investigation, and comparing the results obtained from either method.

Since the initial test program was undertaken, a number of other products have been marketed for water proofing concrete, and it was decided to include a number of these newer products in the test program as part of an ongoing assessment of available materials. Included in this additional product evaluation were three hydrophobic additives which, unlike post-applied surface treatments, are designed to be added to the concrete mix at time of manufacture.

The concrete mix used in the initial screening tests was a (nominal) 50 MPa mix, being used at that time in the construction of the Glebe Island Bridge. Since not all structures require concrete of such strength, it was also decided to evaluate the performance of selected products on concrete of lower strength.

This report is an abridged version of the full report prepared for the RTA, and was prepared specifically for distribution to the manufacturers or suppliers of the materials included in the product-evaluation phase of the work. This abridged report presents the details and results of the evaluation of the various products tested, without disclosing the name or manufacturer of the individual materials.

2. DETAILS OF TEST PROGRAM

2.1 Preparation of Test Specimens

Two basic concrete mixes were used in the test procedures. The 50MPa concrete used earlier was again the basis for the "high strength" specimens. Details of this mix are found in Appendix A.

To evaluate the hydrophobic additives, the same basic concrete mix was used, but the suppliers were asked to nominate their preferred additives, and to advise the appropriate dosage of their materials. The suppliers were also invited to supervise the mixing and casting of the concrete based on their hydrophobic additive, which was accepted in each case.

For a lesser quality concrete, pre-mixed bags of concrete were purchased from a hardware store and mixed according to the instructions. The material was Melcam pre-bagged concrete, which has a cement content of 16%.

All concrete mixes were cast into the required number of 100 mm diameter cylinders, were allowed to cure in the mould overnight, and were transferred to a standard fog-room immediately on de-moulding next day. After six days in the fog-room, they were towelled to saturated surface dry and weighed, after which they were stored on drying racks under standard laboratory conditions for a further three weeks, with weighing at weekly intervals.

Additional cylinders of each concrete mix, including the hydrophobic mixes, were cast for the determination of the 28 day unconfined compressive strength (UCS), in accordance with AS 1012.09; "*Methods of Testing Concrete, Compressive Strength of Specimens*". These cylinders were cured in the fog-room for the full 28 days.

2.2 Application of Water-Repellent Products

All penetrating-type products were applied by fully immersing the concrete specimen in the product for 15 seconds. The specimens were then placed on a drying rack until drip-dry, at which stage the cylinders were weighed to allow application rates to be calculated.

After a six-hour drying period, the cylinders were reweighed and a second treatment was carried out by another 15 second immersion, again weighing immediately before and after.

For the surface-coating type products, application was by brush, using the manufacturer's recommended recoat intervals.

All cylinders were again weighed 24 hours after the final product application, and all specimens were left to air-cure for another two weeks after the final product application.

2.3 Product Performance Tests

2.3.1 Reduction in Water Uptake

This test consists of immersing the specimens in a 15% sodium chloride solution at room temperature for a 48 hour period. Duplicate specimens were tested for each product, and untreated specimens of both high and low strength concrete were included as standards. The cylinders were weighed immediately before immersion, and on removal from the bath were towelled to saturated surface dry (SSD) and again weighed.

This allowed the reduction in water uptake after 48 hours to be calculated and reported as RW_{48}. Appendix A contains full details of the experimental procedure and calculations.

After weighing, the specimens were placed in a drying oven for 3 days, with the oven controlled at 40°C. On removal from the oven, the cylinders were again weighed, and left overnight to return to room temperature. A further four 6-day-cycles of 48 hour immersions interspersed with 3 days drying at 40°C and one day cooling were carried out to monitor the long term performance. At the completion of the five cycles a graph of the % weight change at each stage of the cycles was produced to characterise the product's performance over the duration of the test program.

2.3.2 Reduction in Chloride Ion Penetration

After completion of the above sequence of cyclic immersion and oven drying, the cylinders were wiped with a damp cloth to remove deposits of salt on the surface. Powder samples were taken from the specimens by drilling into the surface with a 15 mm masonry drill bit to the specified depth. Samples were taken from four location midway along each cylinder, and the four samples from each specimen were combined with those from the duplicate, so that any one analysis of the chloride level for each product over any particular horizon was an average of eight separate sampling locations. This reduces the effect of localised abnormalities or of inadvertently sampling coarse aggregate particles.

Powder samples were taken from the following depths, 0-5 mm, 10-15 mm and 20-25 mm, and analysed for chloride content using the Volhard method as described in BS 1881: Part 124, (1988). The reduction in chloride ion penetration (RC_d) for each depth "d" was then calculated by comparing the result to that for the appropriate untreated standard, as described in Appendix A.

2.3.3 Alkali Resistance

Another pair of treated cylinders for a number of the products under test[1] were immersed in 0.1 M KOH for 14 days, then allowed to dry for 14 days (including some days as appropriate at 40°C) until they returned to their approximate weight before immersion.

The above test for reduction in water uptake was again carried out on the KOH-exposed cylinders. By comparison with the results obtained without KOH immersion, the loss in performance in the reduction of water uptake, ΔPW_{KOH}, were calculated, as described in Appendix A.

1 Not all products in the program were tested for alkali resistance. All hydrophobic mixes, and products A, C, D, E, F and I were tested.

2.3.4 Depth of Penetration

The Depth of Penetration (DoP) of penetrating water repellents was determined from the cylinders used for the performance tests (after all other tests had been carried out).

After splitting the cylinders in a plane perpendicular to the main axis, the freshly expose faces were wet with a spray of a 10% solution of red food dye in water. The water and hence the dye is absorbed into the inner, untreated concrete but not into the effected outer layer which remains uncoloured. When the water dries out, the red colour remains giving a permanent record of the DoP.

The width of the uncoloured outer layer was measured with a pair of sliding callipers. Eight evenly spaced measurements were taken around the perimeter of one face of each cylinder (two cylinders per product). The average value was calculated and reported as the DoP. The range of values was also reported.

The DoP depends on the quality and condition of the concrete as well as on the nature of the penetrating sealer. Long term performance is greatly influenced by the DoP. From the earlier work, a minimum penetration of 3 to 4 mm was regarded as acceptable for the 50 MPa concrete used in these tests. There was no firm basis for quantifying the expected DoP for the lesser strength concrete but it was expected that this DoP would be measurably greater than for the 50 MPa mix.

2.3.5 Product Application Rates

The application rate actually achieved for each of the products was determined from the weights of the cylinders before and immediately after product application. The specific gravity of the products was used to convert these applied weights to applied volumes. By dividing the total applied volume by the surface area of a cylinder (0.0785 m^2) the actual spreading rate was calculated.

2.4 Products Tested

A generic description of each products included in this test program is given in Table 1. This table also shows the actual application rates achieved or dosages used in the program.

Where only one figure is shown in the usage column, it applies for the high strength concrete, and where two figures are shown, the second applies for the lower strength specimens.

Table 1. Details of Product Tested

Product Code	Generic Type	Solvent or Diluent	Usage
Penetrating Sealers or Coatings			**Spreading Rate (ml/m²)**
A	100% iso-butyltriethoxysilane ¥	None	195/346
B	Low viscosity 2-pack epoxy	None	92
C	40% silane siloxane	Iso-Propyl Alcohol	132/243
D	100% iso-octyltriethoxysilane	None	152/238
E	20% silane micro-emulsion	Water	107/204
F	11% silane micro-emulsion/water borne epoxy.‡	Water	Primer: 77/128 Topcoat: 197/190
G	Oligomeric siloxane	Mineral Turps	165
H	100% iso-butyltriethoxysilane ✝	None	240
X I	Sodium Silicate	Water	102/204 X
J	Water-borne bitumen emulsion	Water	308
Hydrophobic Additives			**Dosage (/m³)**
X1	Crystal Growth	None	3.5 kg
X2	Hydrophobic pore-blocker	Water	30 litre
X3	Hydrophobic pore-blocker	Water	15 litre

‡ Primer and Topcoat System

¥ DRY-TREAT 100N

3. RESULTS AND DISCUSSION

3.1 Compressive Strength of Concrete Mix Designs

The unconfined compressive strengths (UCS) for the various mix designs are shown in Table 2. The full report from the concrete testing laboratory[2] is included in Appendix A.

Table 2. Unconfined Compressive Strength of Concrete Mixes

Concrete Type	28 Day UCS (MPa)
Untreated Concrete Standards	
High Strength Mix	51
Low Strength Mix	36
Hydrophobic Concrete Mixes	
Product X1	46
Product X2	48.5
Product X3	54

These results confirm that the high strength mix is directly comparable to that used in the previous work.

Addition of hydrophobic additives had a minor effect on the concrete strength, with products X1 and X2 resulting in a slight loss of strength and X3 resulting in a gain of 3 MPa. These variations are probably linked to slight differences in water content associated with these admixtures, and to variations in the admixture content.

Given the usual spread of results obtained for different batches of concrete made to any one mix design, these variations are not considered to be significant. However where hydrophobic additives are to be used to achieve a minimum target strength, the final mix design should be fully evaluated for UCS, and dosage strictly controlled.

The UCS result for the lesser strength mix was 36 MPa, which is consistent with the specification for concrete used by the RTA (or DMR in earlier days) for substructures of bridges. Concrete of this type will be present in many existing structures, for which condition surveys and maintenance regimes are now required.

2 Testrite Laboratories Pty Ltd Report No. 25736, 23-01-96.

3.2 Reduction in Water Uptake and Alkali Resistance

The results for the reduction in water uptake after the initial 48 hour immersion (RW_{48}) are shown in Table 3. This table shows the result for each product on both types of concrete (where applicable) and also shows the effect of the alkali immersion on RW_{48} (for the relevant products).

The RW_{48} results for each product on the 50 MPa concrete are shown graphically in Figure 1, allowing direct comparison to be made between the various products.

Table 3 Reduction in Water Uptake and Alkali Resistance

Product Code	High Strength Concrete (50 MPa)		Low Strength Concrete (36 MPa)	
	Reduction in Water Uptake RW_{48} (%)	Alkali Resistance ΔPW_{KOH} (%)	Reduction in Water Uptake RW_{48} (%)	Alkali Resistance ΔPW_{KOH} (%)
Penetrating Sealers or Coatings				
A	94.45	- 2.2	97.45	- 3.7
B	88.73	-	-	-
C	93.73	+ 1.4	97.20	+ 0.88
D	95.77	+ 1.5	98.34	+ 0.36
E	92.14	- 0.35	95.69	+ 0.46
F	90.35	+ 9.5	95.61	+ 2.7
G	93.81	-	-	-
H	94.15	-	-	-
I	59.24	- 76.3	6.28	+ 527.0†
J	47.02	-	-	
Hydrophobic Additives				
X1	12.52	+ 23.6	not tested	-
X2	92.35	+ 1.6	not tested	-
X3	91.51	- 0.10	not tested	-

† RW_{48} after alkali immersion was 39.4%, which although much greater than 6.28% is still unacceptably low.

The weights for each cylinder at each stage of the cyclic immersion program are shown graphically on Figures B1 to B19 in Appendix B.

In the earlier work a minimum value for RW_{48} of 92% was regarded as being indicative of a high level of performance for penetrating sealers. All of the silane/siloxane product types in the current program achieved this minimum figure except for Product F, the silane primer + water-borne epoxy system, on the high strength concrete. It is thought that the 8:1 dilution of the organo-silane primer with water results in insufficient coverage, which is not fully compensated for by the water-borne epoxy top-coat. The greater application rate achieved when this system was used on the lower strength concrete[3] raised the RW_{48} to 95.61%.

[3] Refer to Table 1 for application rates achieved.

The two surface coatings, products B and J, did not achieve the threshold level of performance, which is consistent with the results from the earlier work. The solventless low-viscosity epoxy gave a result of 88.7% which is better than other coatings tested to date. The bitumen emulsion performed poorly.

The sodium silicate sealer (Product I) performed poorly especially on the low strength concrete.

The alkali resistance of all products tested was satisfactory, with the exception of product I. All other products had a ΔPW_{KOH} greater than the - 4 % limit on performance derived from the earlier test program.

In this program, most products in fact had a slightly positive value for ΔPW_{KOH}. This is most probably due to slight variations in the initial moisture content of the cylinders after the 14 day alkali immersion, although there is a probability that alkali immersion actually improved the performance of some products by catalysing the reaction of any residual functionality of the organo-silane materials.

Of the hydrophobic additives, product X1 ("crystal growth" type) performed very poorly, while the two hydrophobic pore-blockers (products X2 and X3, with RW_{48} of 92.35 and 91.5% respectively) gave performance almost equal to the organo-silane penetrating sealers.

Products X2 and X3 both had satisfactory alkali resistance. Product X1 performed comparatively better after alkali immersion, although still well short of acceptable levels with a RW_{48} after alkali immersion of only 15.48%.

Examination of the weight change graphs for the entire 5 immersion/drying cycles (Appendix B) shows that the organo-silanes all demonstrate the characteristic pattern with the concrete losing more weight during each drying stage than was absorbed in the previous immersion phase, and with a continual overall weight loss leading to drier concrete. They show this pattern for both concrete types.

Although some surface coatings do inhibit moisture uptake during immersion, they generally do not allow efficient evaporation during the drying stage and the net effect is that the concrete does not become as dry as with the organo-silanes. Product B best illustrates this.

The hydrophobic pore-blocking additives display a similar pattern to the organo-silanes and result in ultimately drier concrete. The inorganic materials (sealer product I and hydrophobic additive X1) both show little difference to untreated concrete, absorbing and losing water freely during each stage of the test.

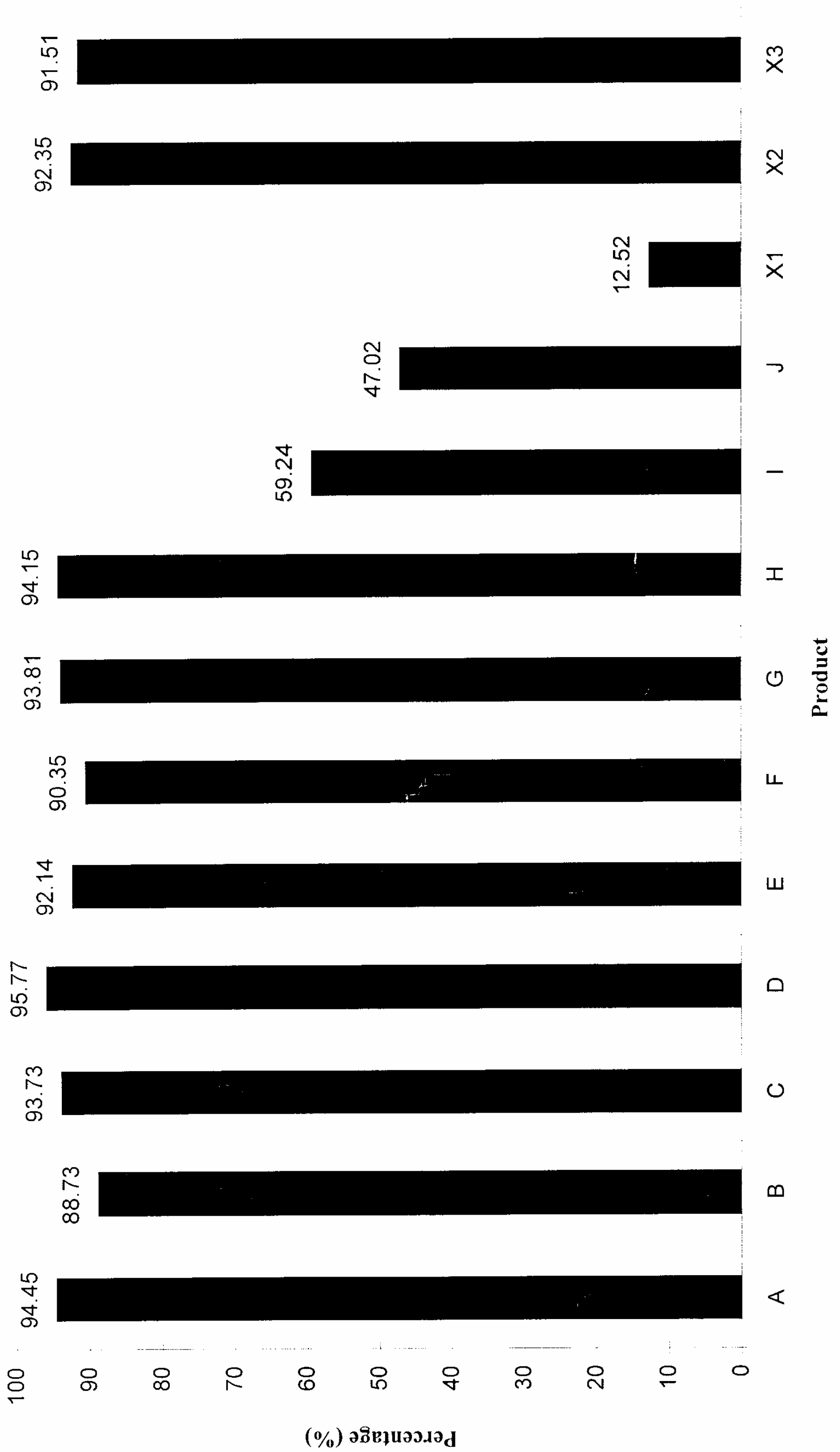


Figure 1. Reduction in Water Uptake (RW_{48}) - 50 MPa Concrete

3.3 Reduction in Chloride Ion Penetration

Table 4 summarises the reduction in chloride ion penetration at the three depths from which the chloride ion profiles were determined, ie 0-5, 10-15 and 20-25 mm. The chloride ion profiles are also shown graphically on Figures B1 to B19 in Appendix B.

Table 4. Reduction in Chloride Ion Penetration

Product Code	Reduction in Chloride Ion Penetration (RC_d) (50 MPa Concrete)			Reduction in Chloride Ion Penetration (RC_d) (36 MPa Concrete)		
	0 - 5 mm	10 - 15 mm	20 - 25 mm	0 - 5 mm	10 - 15 mm	20 - 25 mm
Penetrating Sealers or Coatings						
A	84.69	98.03	96.82	94.96	98.59	95.66
B	81.62	86.00	86.26	-	-	-
C	89.28	98.09	98.05	93.13	99.05	100.0
D	90.32	97.29	95.17	99.17	97.55	91.31
E	83.99	95.15	96.40	91.49	97.65	96.91
F	90.13	96.99	96.33	92.54	99.85	100.0
G	82.33	90.07	81.98	-	-	-
H	85.48	91.74	89.68	-	-	-
I	-1.75	-15.14	41.84	3.14	5.11	80.98
J	40.78	38.27	24.92	-	-	-
Hydrophobic Additives						
X1	3.15	30.98	25.35	-	-	-
X2	76.42	99.77	98.41	-	-	-
X3	62.05	97.86	100.0	-	-	-

These results cannot be compared directly to the reduction in chloride ion penetration reported in the earlier work since a cyclic salt-fog exposure was used in the original tests, and the chloride content was based on a single analysis of the entire cylinder (after crushing).

From Table 4 and the performance graphs, it can be seen that although there was some variation for the chloride ion content of the outer 5 mm, for the 10-15 mm interval, all the organo-silanes had reductions in excess of 90%. In the low strength concrete the reductions were more dramatic, due to the greater chloride absorption of the untreated standard[4].

Product I gave very poor results, although there was a greater reduction in chloride levels at the deeper interval of 20-25 mm. However this reduction is still well below that offered by the organo-silanes, and with more time the chloride front would be expected to move more deeply into the concrete.

Surface coatings again gave inferior performance to the organo-silanes, although in this case system F (silane primer plus epoxy top-coat) performed as well as any of the pure silanes. This suggests that although this system may allow penetration of slightly more water than the

4 The chloride concentrations for the untreated standard are shown on the performance graphs for each product in Appendix B.

organo-silanes, it is able to act to some extent as a chloride-ion filter thereby preventing the water carrying its equilibrium ion content with it as it penetrates the protective system.

The pore-blocking hydrophobic additives performed very well, especially at the deeper intervals where chloride reductions in excess of 97% were recorded. These results are better than those for the organo-silanes sealers, and are probably due to the presence of the hydrophobic additive throughout the concrete rather than only in the outer layer as is the case for the post-applied sealers.

The inorganic hydrophobic additive X1 performed very poorly.

3.4 Depth of Penetration

The depth of penetration measured for the various sealers and coatings are given in Table 5.

Table 5 Depth of Penetration (Penetrating Sealers or Coatings)

Product Code	High Strength Concrete (50 MPa)		Low Strength Concrete (36 MPa)	
	Mean	Range	Mean	Range
A	5.1	3.0 - 8.1	5.4	4.4 - 7.4
B	0	< 1	-	-
C	4.2	2.2 - 9.9	3.3	2.0 - 4.4
D	3.6	2.1 - 9.9	4.7	3.6 - 6.8
E	2.0	1.0 - 4.3	2.6	1.9 - 3.6
F	2.9	1.8 - 4.2	1.8	1.0 - 2.5
G	2.8	1.3 - 6.8	-	-
H	6.3	4.7 - 7.9	-	-
I	0	< 1	1	0 - 2
J	0	< 1	-	-

Products A, C and H (all based on iso-butyltriethoxysilane) each have a DoP of 4 mm or better on the 50 MPa concrete. Product H had a narrower range, 4.7 to 7.9 compared to the other two. This may be due to it having been applied some six weeks after the others (due a delay in obtaining the sample) and the outer layer of the concrete cylinders may have been drier and subsequently more absorbent.

Product D (100% iso-octyltriethoxysilane) had a DoP of 3.6 mm and a range of 2.1-9.9 mm, which is almost identical to that for products A and C. Products E and F had poorly defined hydrophobic layers and were difficult to read, probably because they were applied as more dilute mixtures with a resultant lower amount of hydrophobic material in the affected layer.

The results for the lower strength concrete were about the same, but the affected layer was better defined, again thought to be due to the greater absorption of this mix.

The inorganic sealer (Product I) did not show any repellent layer, and the surface coatings (Products B and J) did not penetrate at all.

4. CONCLUSIONS

4.1 Revised Test Procedure

The revised test procedure based on immersion in 15 % sodium chloride solution gives similar results for the reduction in water uptake as found in the earlier tests where fresh water immersion was used. The threshold figure for RW_{48} of 92% for high performance penetrating sealers, based on the earlier work, is also applicable to the revised test procedure.

The revised test procedure for evaluating the reduction of chloride ion penetration involves chemical analysis for determining the chloride ion concentrations at three depth, 0-5 mm, 10-15 mm and 20-25 mm. From the results, the thresholds figures for RC_d for high performance penetrating sealers should be 80% for the 0-5 mm interval, and 90% for the 10-15 mm and the 20-25 mm intervals.

Using a coloured food dye in conjunction with the Depth of Penetration test gives a permanent record and allows a vivid photographic record to be made of the test result.

The entire suite of tests (including the alkali resistance) requires only four cylinders treated with each product under evaluation, together with two cylinders of the untreated concrete as standards. It is recommended that this procedure be adopted for future evaluation of sealers and allied products.

4.2 Lower Strength Concrete

The tests were found to be applicable to the lower strength concrete, and it is concluded that these tests can be used to evaluate the performance of water repelling sealers and allied products over a wide range of concrete types.

The results for the products tested indicated that they generally gave better results on the lower strength concrete than on the high strength substrate. This is thought to be due to the greater absorption (ie. lower durability) of the lower strength concrete. The greater absorption of the substrate ensures a greater coverage rate of the product under test, as can be seen from Table 1. Furthermore, the untreated concrete absorbs more salt water, resulting in higher water-uptakes and chloride ion concentrations for the standards. If the sealer is effective, this usually results in improved values for the reductions in water uptake and chloride ion penetration parameters.

In most cases it will be possible to apply results for sealer performance determined from tests using high strength concrete to lesser strength mixes, but where precise performance information is required for a particular mix design, the test program should be carried out using that mix as the substrate.

APPENDIX A

EXPERIMENTAL

A1 50 MPa CONCRETE MIX DESIGN

Mix A Standard 50 MPa OPC Concrete

Ingredient	*Kg*	*Kg*
Portland Type A cement	13.2	440
20 mm crushed Basalt	24.9	830
10 mm crushed Basalt	9.0	300
5 mm minus	9.15	305
Fine sand	14.2	480
Water	5.28	176
Porzite L78	40 ml	1.36 Litre
Rheobuild 716	75 ml	2.50 Litre
Total	*30 Litres*	*1 cubic metre*

Water-cement Ratio =	0.40		
Density (spec) =	2420	Actual (@ 28 Days)	2360
UCS (@ 28 Days)	51 MPa		
Chloride Content (actual)	0.123 % bwoc.		

MIX B 50 MPa Mix with Hydrophobic Additive X1

As Mix A, varied as follows.

- Hydrophobic Additive X1 added at 100 g per 30 litre mix (= 0.8% on cement)
- No other additives included in mix
- 10% reduction in added water.

MIX C 50 MPa Mix with Hydrophobic Additive X2

As Mix A, varied as follows.

- Hydrophobic Additive X2 added at 900 ml per 30 litre mix
- Other additives replaced by "Superplastet F", 158 ml.
- 15% reduction in added water.

MIX D 50 MPa Mix with Hydrophobic Additive X3

As Mix A, varied as follows.

- Hydrophobic Additive X3 added at 450 ml per 30 litre mix
- Other additives replaced by "Superplastet F", 158 ml.
- 8% reduction in added water.

A2 DETAILS OF PERFORMANCE TESTS

Reduction in Water Uptake Test

Two treated cylinders for each product under evaluation, and two untreated control cylinders, are carefully weighed to 0.1 g accuracy. This figure is used as initial weight "W_0" in future calculations. The cylinders are then placed in a bath containing 15% sodium chloride solution in water at 25°C, so that there is approximately 15 to 20 mm water covering the top of the cylinders. Ideally, use a 120mm deep tray, fill with water, and allow to overflow as cylinders are placed in the bath. The cylinders should not touch each other and should not be stacked on top of each other in layers.

Determine the weight after first immersion at 48 hours ± 1 hour. Take each cylinder from the bath, towel it dry to "saturated surface dry", weigh immediately and record the weight.

At the end of the 48 hour immersion, place the cylinders in a 40°C ventilated oven for 3 days. Remove from the oven and re-weigh to determine weight after first drying. Leave cylinders on rack for 24 hours to cool before re-immersing (6 day cycle). This cycle is repeated five times.

Calculate ΔW_{48}, the weight change after the first water immersion as a percentage as follows:-

$$\Delta W_{48} = \frac{W_{48} - W_0}{W_0} \times 100$$

Calculate RW_{48}, the reduction in water uptake (after the first 48 hours immersion) for the product under test as follows:-

$$RW_{48} = \frac{S - P}{S} x100$$

where
S = Average ΔW_{48} for untreated standard
P = Average ΔW_{48} for product under test

Similarly calculate the percentage weight gain at the end of each immersion and each drying phase as above, and on a separate graph plot the % Weight Change (as an average for the two cylinders for each product) versus time over the 30 day period, and on the same graph show the corresponding % Weight Change for the untreated standard.

Test for Reduction in Chloride Ion Penetration under Cyclic Salt-Water Immersion

Take the two cylinders for each product (and for the standard) from the "Water Uptake" test above. Wipe with a damp cloth to remove deposits of salt on the surface. Using a 15 mm masonry bit, drill to a depth of 5 mm at four locations separated by 90° on the plane bisecting the cylinder perpendicular to the longest axis. Collect all powder from all eight holes, homogenise and analyse for chloride content by weight of cement (bwoc) using the Volhard method as described in BS 1881: Part 124, (1988). The chloride content is converted to the "chloride uptake" for that depth by subtracting the background chloride content of the concrete mix[1].

Extend the holes to 10 mm, angling the drill to widen the opening and discarding all powder. Clean the hole carefully, taking care to dislodge loose material around the opening. Drill to 15 mm, collecting all powder and analysing it as above.

Repeat this process to obtain and analyse a further sample from the 20 - 25 mm interval.

Calculate RC_d, the reduction in chloride ion penetration for the product under test over the depth interval "d" , as follows.

$$RC_d = \frac{S_d - P_d}{S_d} x100$$

where

S_d = Chloride uptake for the untreated standard at depth "d".

P_d = Chloride uptake for the treated samples at depth "d".

On a bar graph, show S_d and P_d for each depth "d".

1 The chloride content of the untreated, unexposed controls were found to be 0.123 % for the 50 MPa mix and 0.121 % for the 36 MPa mix.

Alkali Resistance

Two treated cylinders for each product under evaluation are carefully weighed to 0.1 g accuracy. The cylinders are then placed in a bath containing a 0.1 M KOH solution at 25°C, so that there is approximately 15 to 20 mm KOH solution covering the cylinders. The cylinders should not touch each other and should not be stacked on top of each other in layers.

After 14 days ± 1 hour, take the cylinders from the bath and rinse thoroughly with fresh water. Place the cylinders in a 40°C ventilated oven and weigh at appropriate intervals as required until the weight has again fallen to within 0.5 gram of the weight before immersion, or for 14 days maximum. Remove from the oven, re-weigh and record the weight as W_0.

Now perform the Reduction in Water Uptake test as described above on these cylinders, and record to result as RW_{KOH}.

Calculate ΔPW_{KOH}, the decrease in water uptake performance, as follows

$$\Delta PW_{KOH} = \frac{RW_{48} - RW_{48/KOH}}{RW_{48}} x\, 100$$

where

RW_{48} = 48 hour reduction in water uptake for the product
$RW_{48/KOH}$ = 48 hour reduction in water uptake after KOH-immersion

Depth of Penetration (DoP)

Use the cylinders from the above Water Uptake test program to determine the DoP after all other tests have been completed. Split the cylinder along the plane of the chloride sampling holes, and liberally wet the one freshly exposed face with a 10% solution of red food dye in water. Allow the water to dry out.

With a pair of sliding callipers, measure the thickness (to 0.1 mm accuracy if possible) of the outer layer, which should remain unaffected by the red dye due to its water repellancy. Make 8 measurements on one exposed face of each cylinders, and express the result for the DoP as an average figure of the 16 readings for the two cylinders. Also record the maximum and minimum readings and report these as the "range".

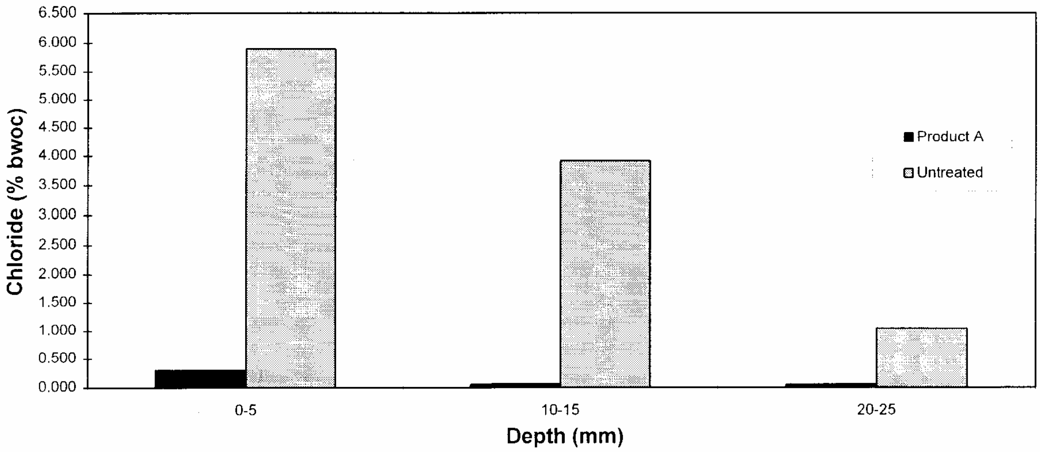
APPENDIX B

PRODUCT PERFORMANCE GRAPHS

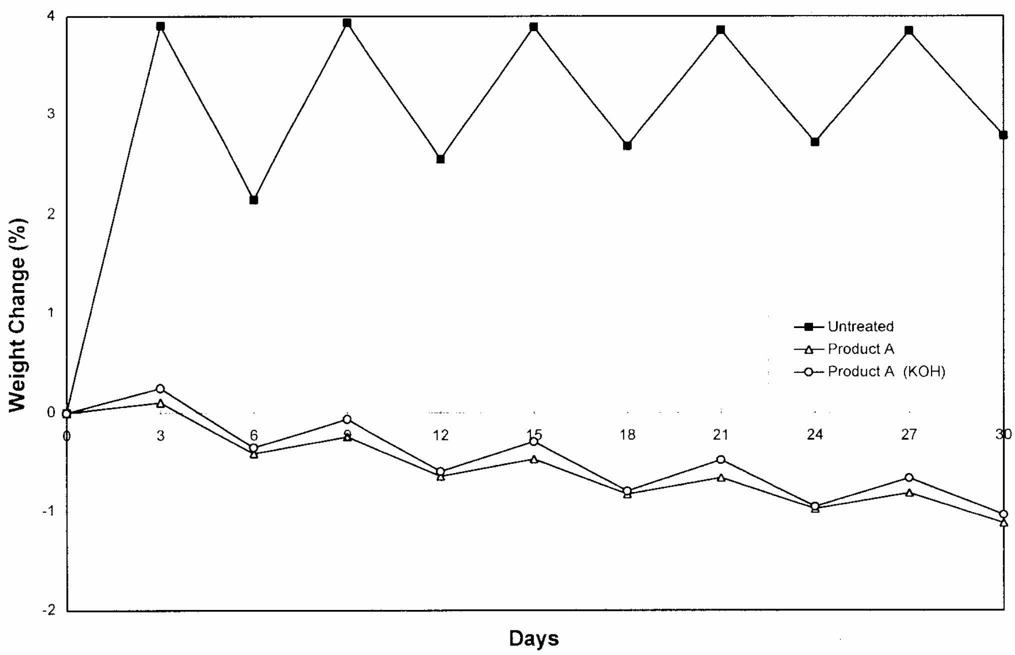
PRODUCT NO.: A 36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product A	Untreated	
0-5	0.297	5.896	94.96
10-15	0.055	3.913	98.59
20-25	0.045	1.036	95.66

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



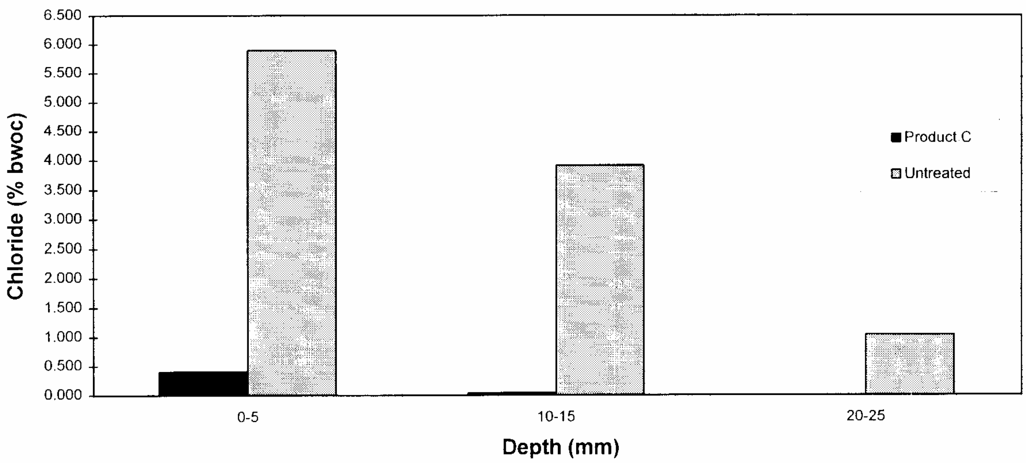
CYCLIC IMMERSION TESTING

Figure B14. Performance Data for Product A: 36MPa Concrete

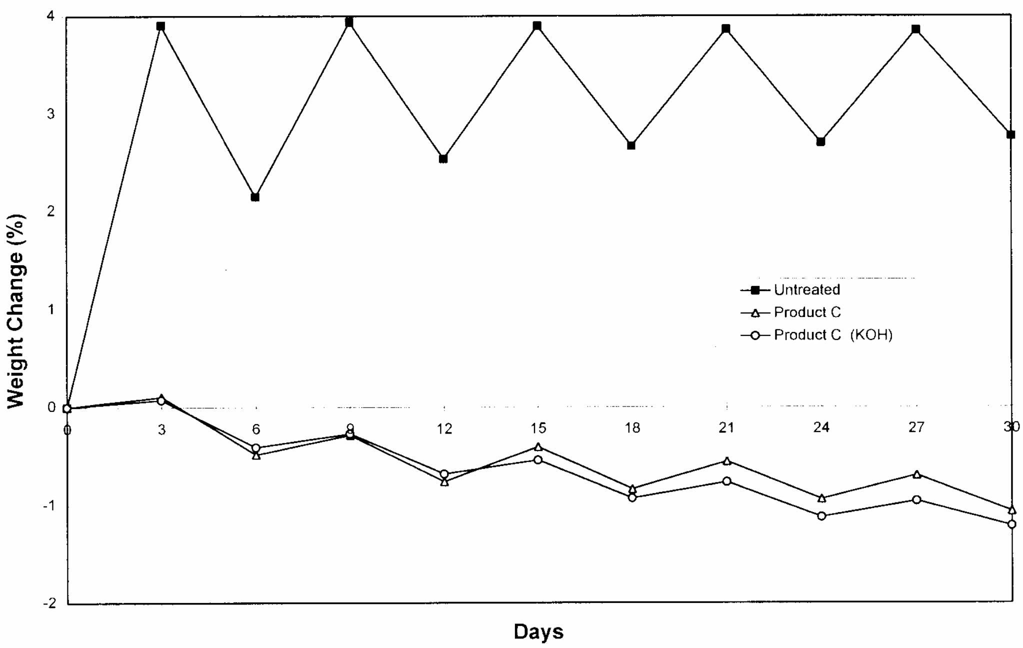
PRODUCT NO.: C 36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product C	Untreated	
0-5	0.405	5.896	93.13
10-15	0.037	3.913	99.05
20-25	0.000	1.036	100.00

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

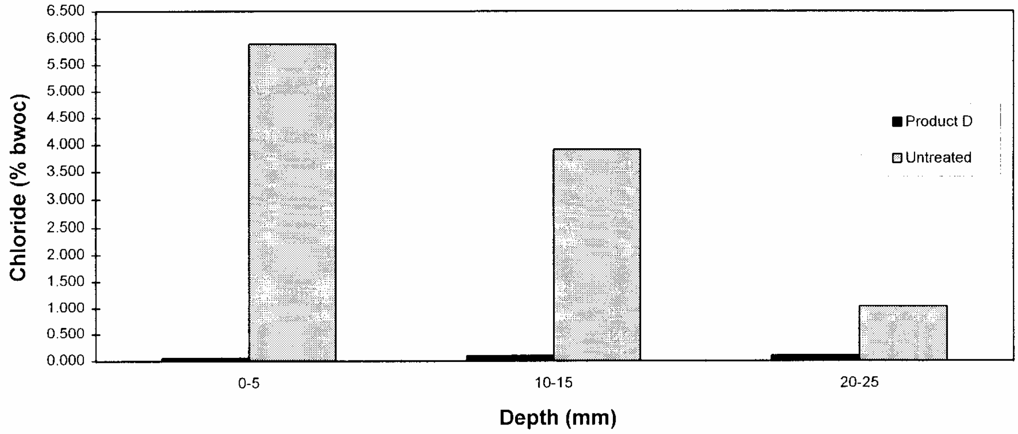
Figure B15. Performance Data for Product C: 36MPa Concrete

CTI

PRODUCT NO.: D 36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product D	Untreated	
0-5	0.049	5.896	99.17
10-15	0.096	3.913	97.55
20-25	0.090	1.036	91.31

‡ increase over background
* bwoc = by weight of cement



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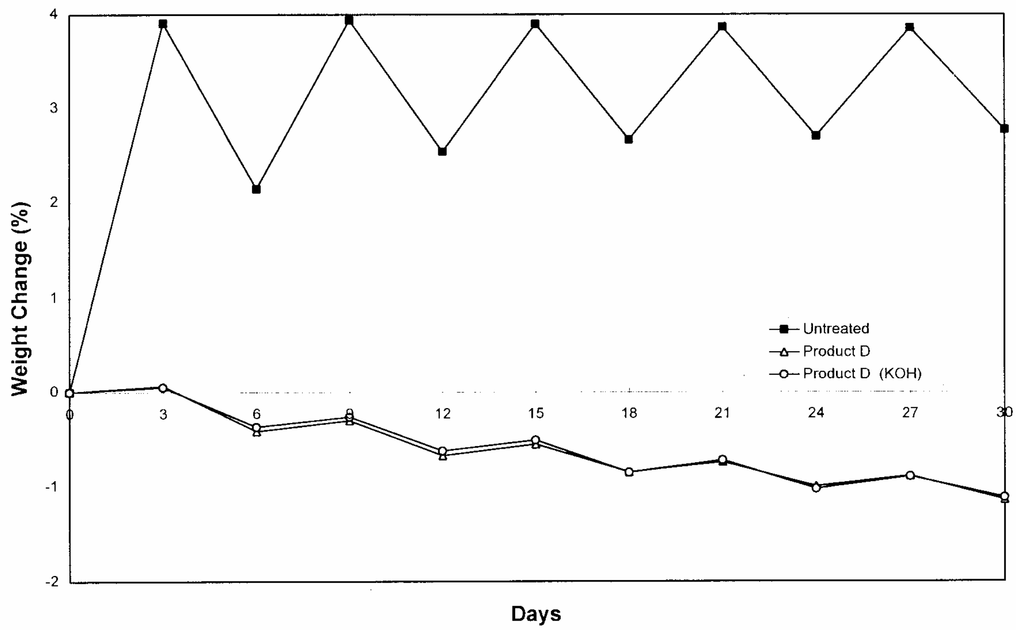


CYCLIC IMMERSION TESTING

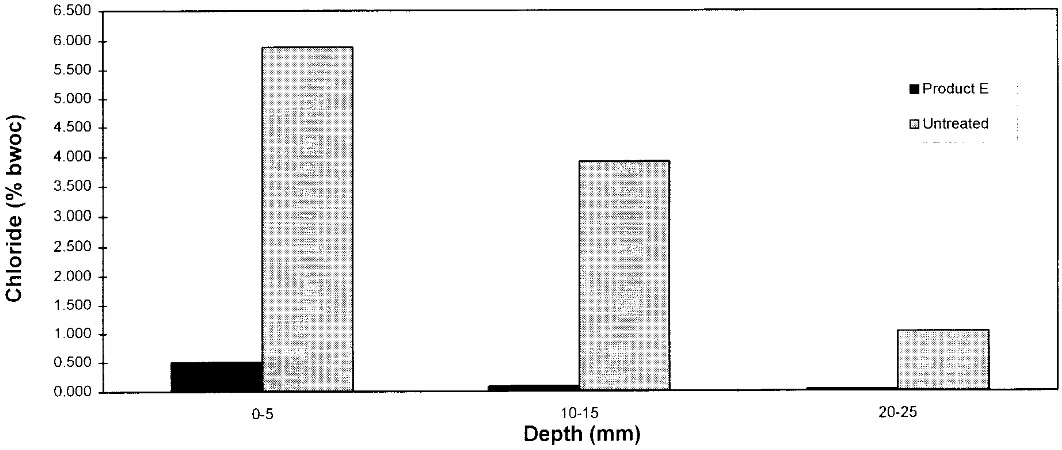
Figure B16. Performance Data for Product D: 36MPa Concrete

CTI

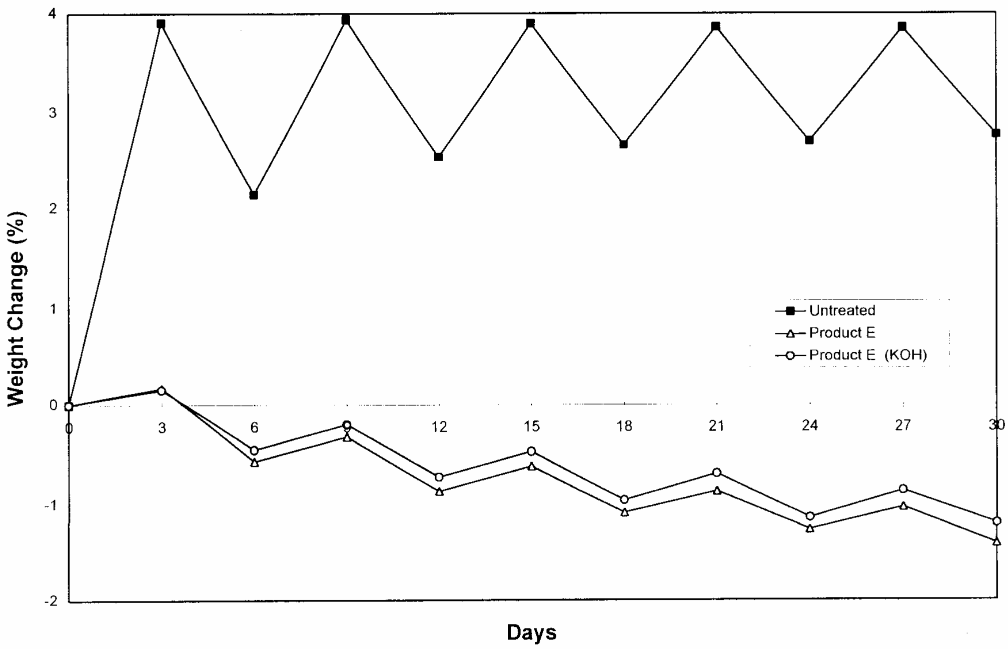
PRODUCT NO.: E 36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product E	Untreated	
0-5	0.502	5.896	91.49
10-15	0.092	3.913	97.65
20-25	0.032	1.036	96.91

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

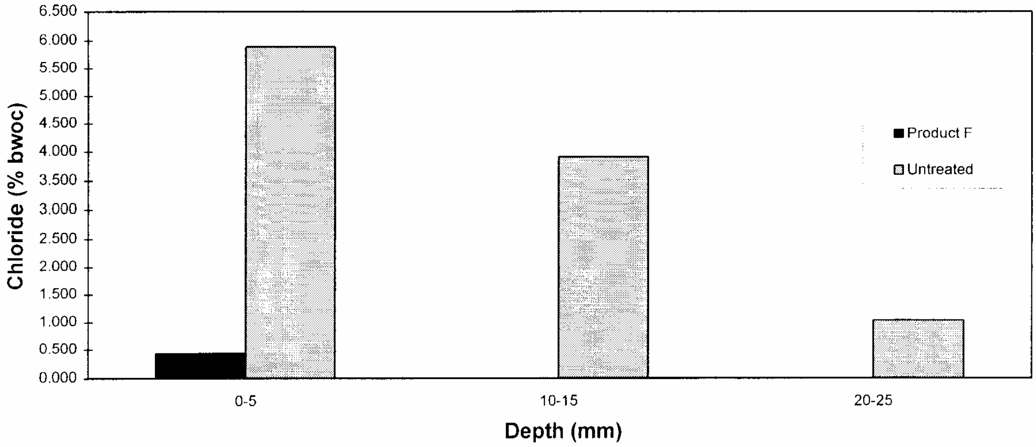
Figure B17. Performance Data for Product E: 36MPa Concrete

CTI

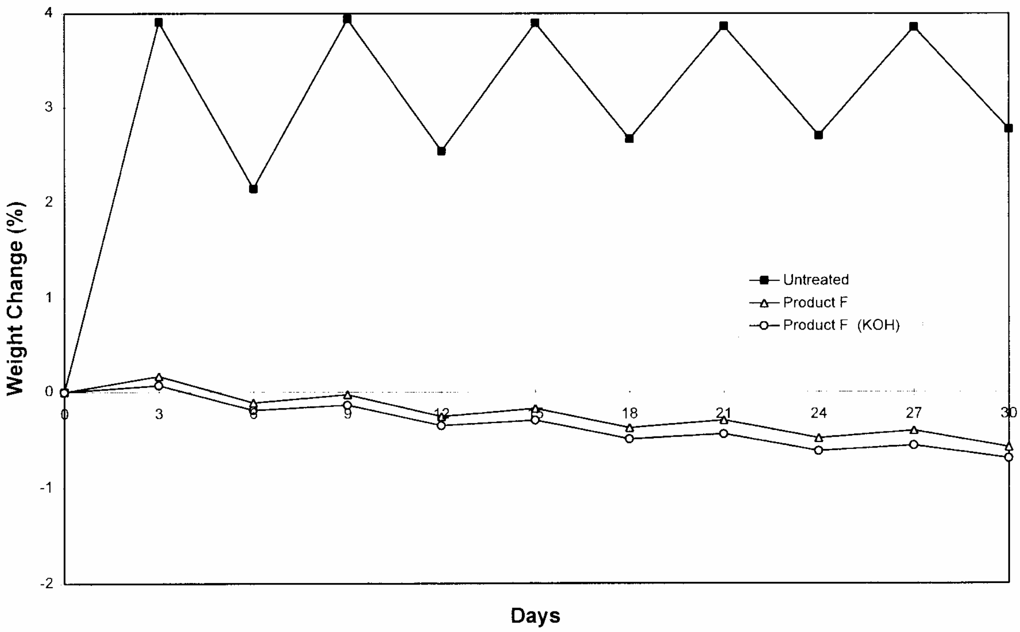
PRODUCT NO.: F   36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		%
	Product F	Untreated	Reduction
0-5	0.440	5.896	92.54
10-15	0.006	3.913	99.85
20-25	0.000	1.036	100.00

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

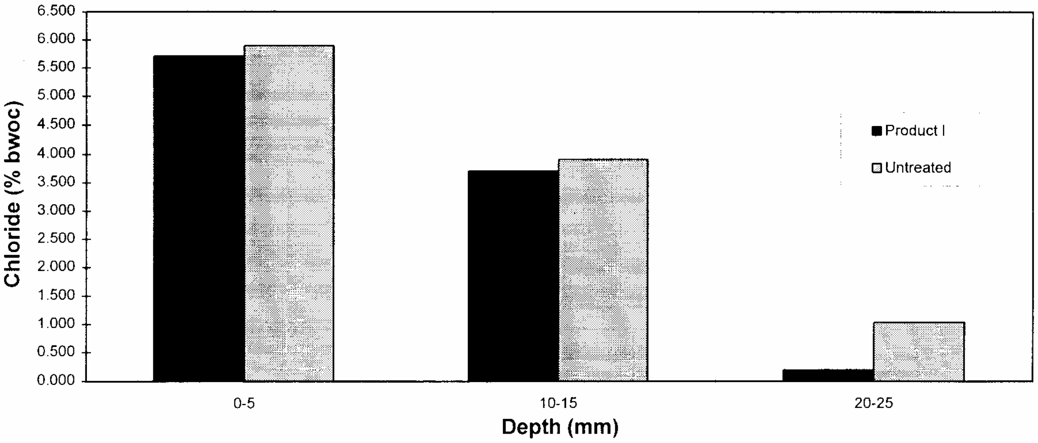
Figure B18. Performance Data for Product F: 36MPa Concrete

CTI

PRODUCT NO.: I 36 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product I	Untreated	
0-5	5.711	5.896	3.14
10-15	3.713	3.913	5.11
20-25	0.197	1.036	80.98

‡ increase over background
* bwoc = by weight of cement



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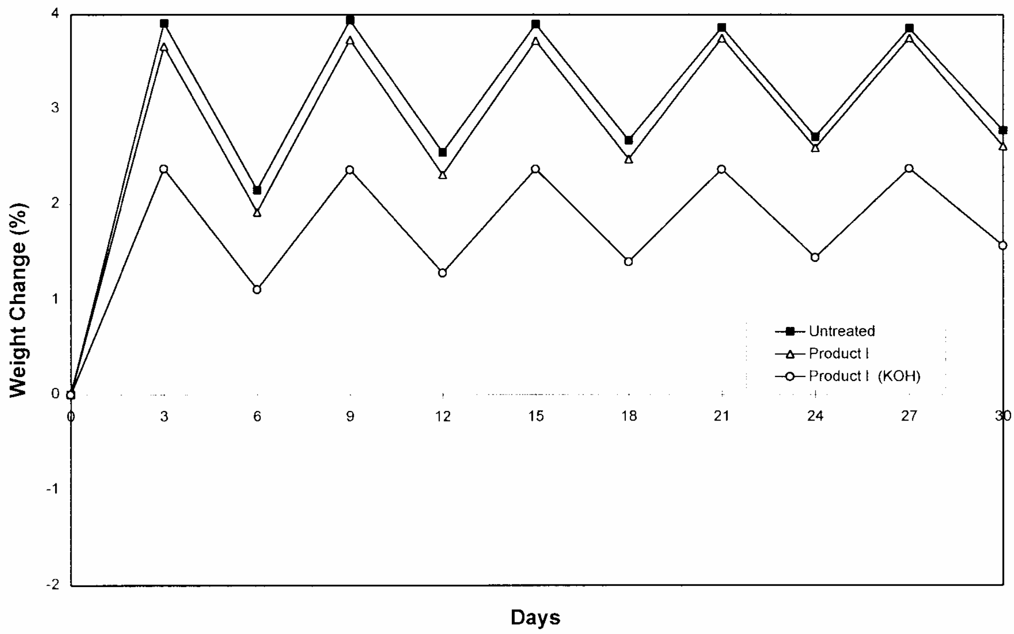


CYCLIC IMMERSION TESTING

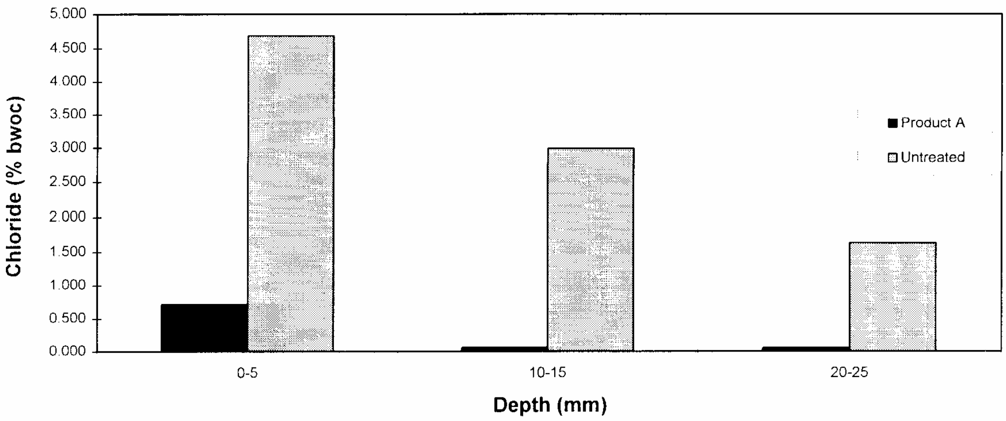
Figure B19. Performance Data for Product I: 36MPa Concrete

CTI

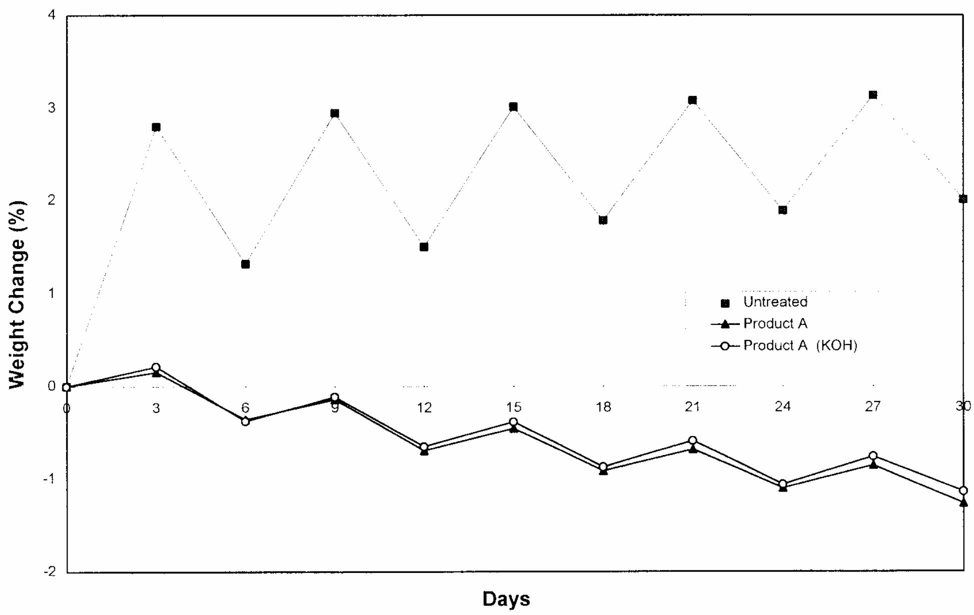
PRODUCT NO.: A 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product A	Untreated	
0-5	0.718	4.691	84.69
10-15	0.059	2.992	98.03
20-25	0.052	1.637	96.82

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

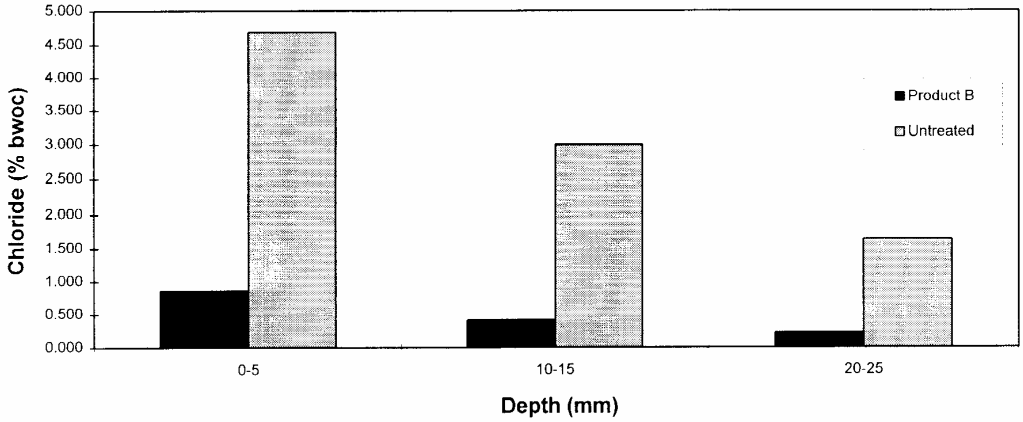
Figure B1. Performance Data for Product A: 50MPa Concrete

CTI

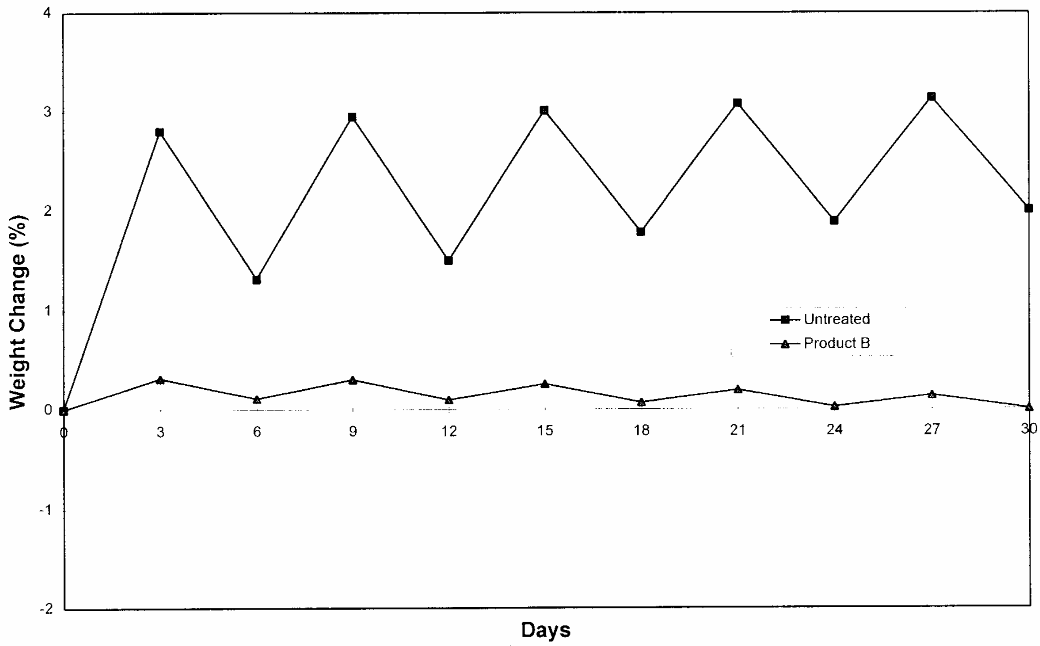
PRODUCT NO.: B   50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product B	Untreated	
0-5	0.862	4.691	81.62
10-15	0.419	2.992	86.00
20-25	0.225	1.637	86.26

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

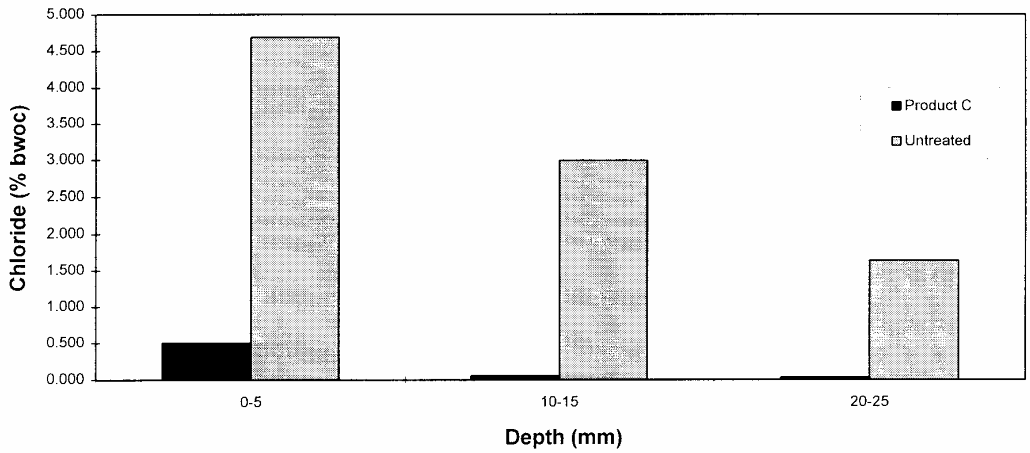
Figure B2. Performance Data for Product B: 50MPa Concrete

CTI

PRODUCT NO.: C 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product C	Untreated	
0-5	0.503	4.691	89.28
10-15	0.057	2.992	98.09
20-25	0.032	1.637	98.05

‡ increase over background
* bwoc = by weight of cement



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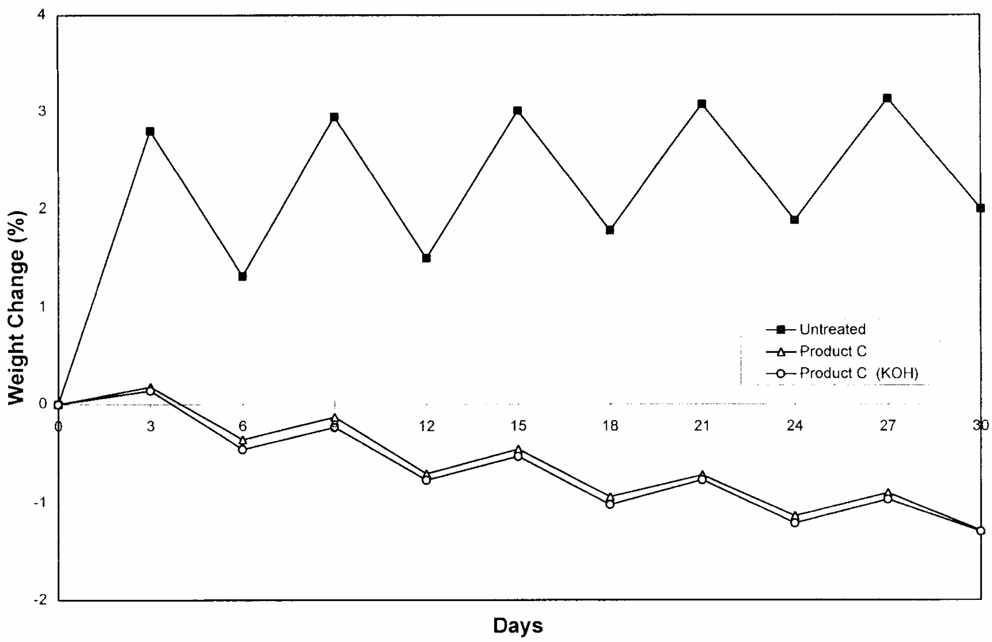


CYCLIC IMMERSION TESTING

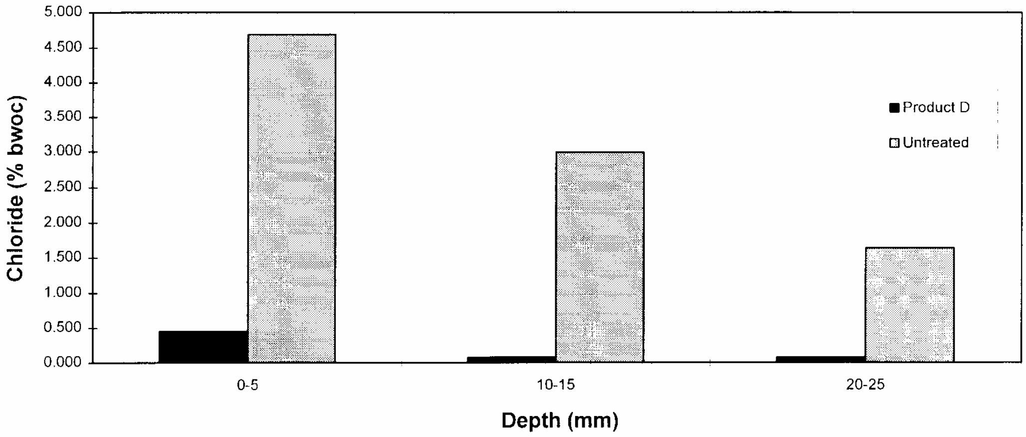
Figure B3. Performance Data for Product C: 50MPa Concrete

CTI

PRODUCT NO.: D 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product D	Untreated	
0-5	0.454	4.691	90.32
10-15	0.081	2.992	97.29
20-25	0.079	1.637	95.17

‡ increase over background
* bwoc = by weight of cement



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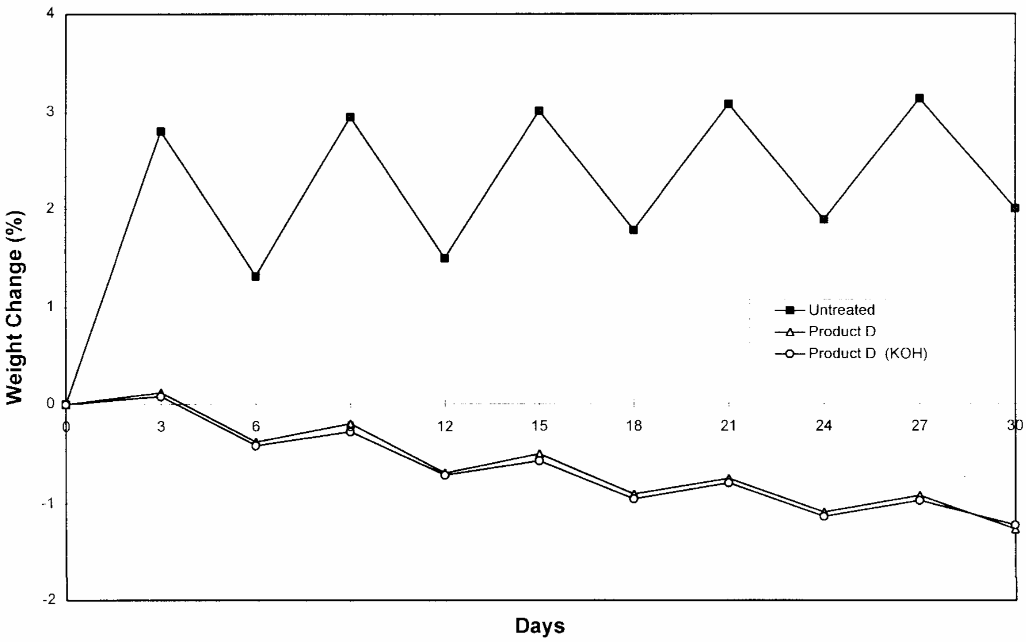


CYCLIC IMMERSION TESTING

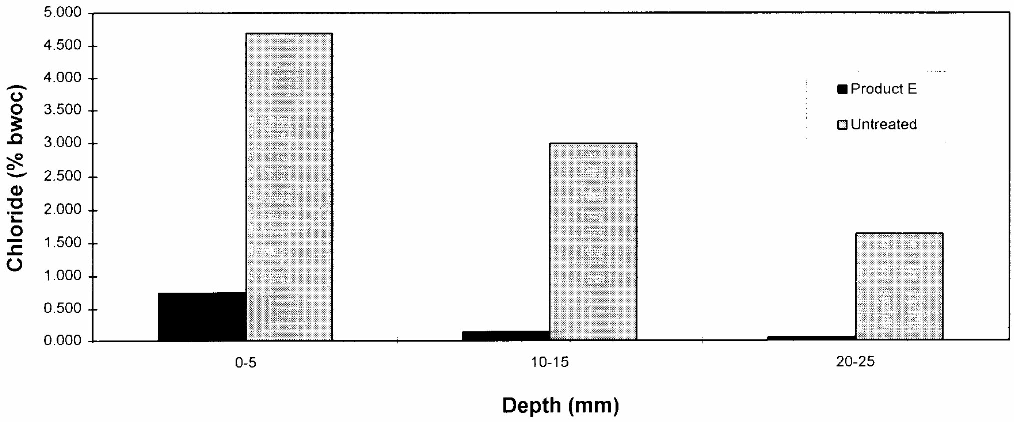
Figure B4. Performance Data for Product D: 50MPa Concrete

CTI

PRODUCT NO.: E 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product E	Untreated	
0-5	0.751	4.691	83.99
10-15	0.145	2.992	95.15
20-25	0.059	1.637	96.40

‡ increase over background
* bwoc = by weight of cement



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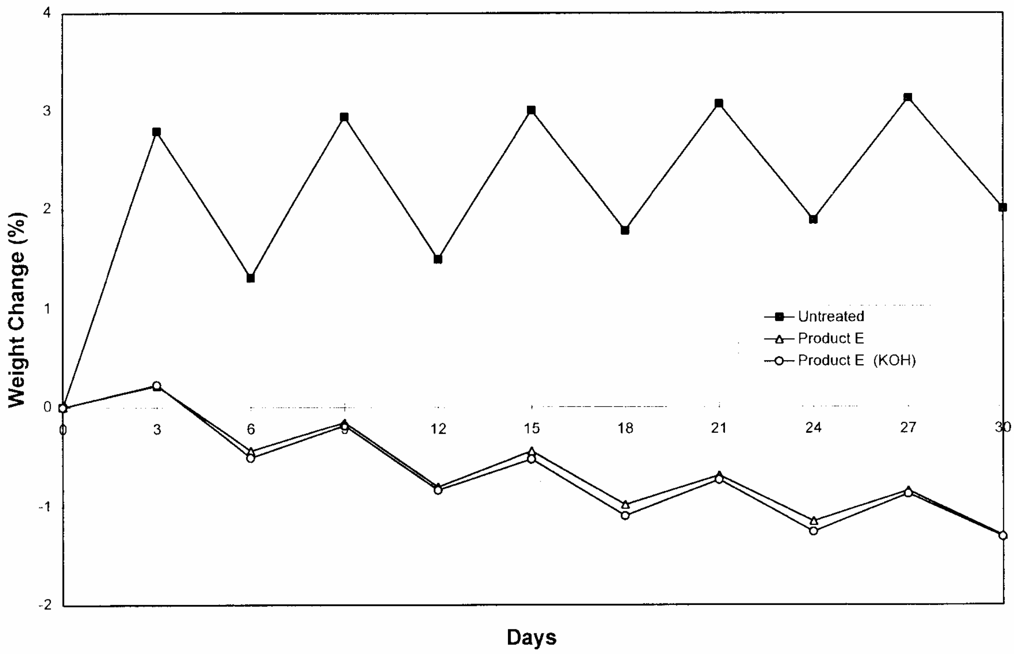


CYCLIC IMMERSION TESTING

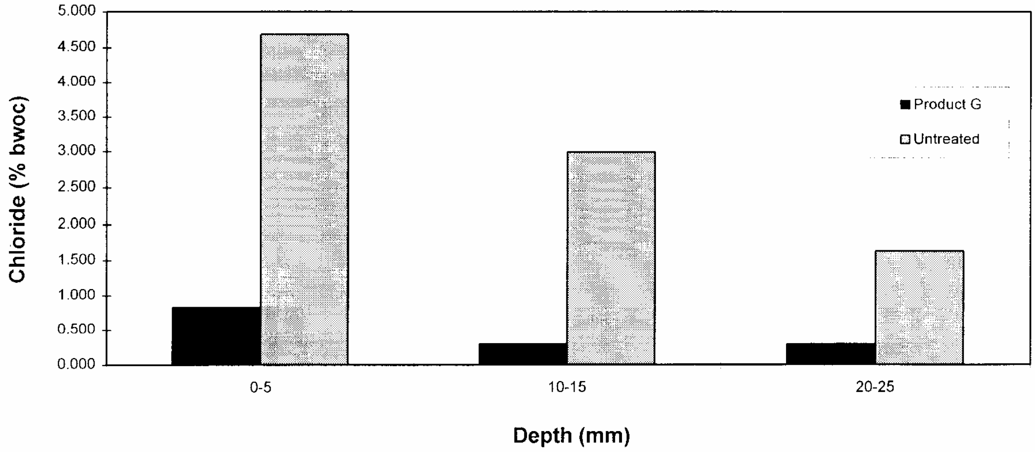
Figure B5. Performance Data for Product E: 50MPa Concrete

CTI

PRODUCT NO.: G 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product G	Untreated	
0-5	0.829	4.691	82.33
10-15	0.297	2.992	90.07
20-25	0.295	1.637	81.98

‡ increase over background
* bwoc = by weight of cement



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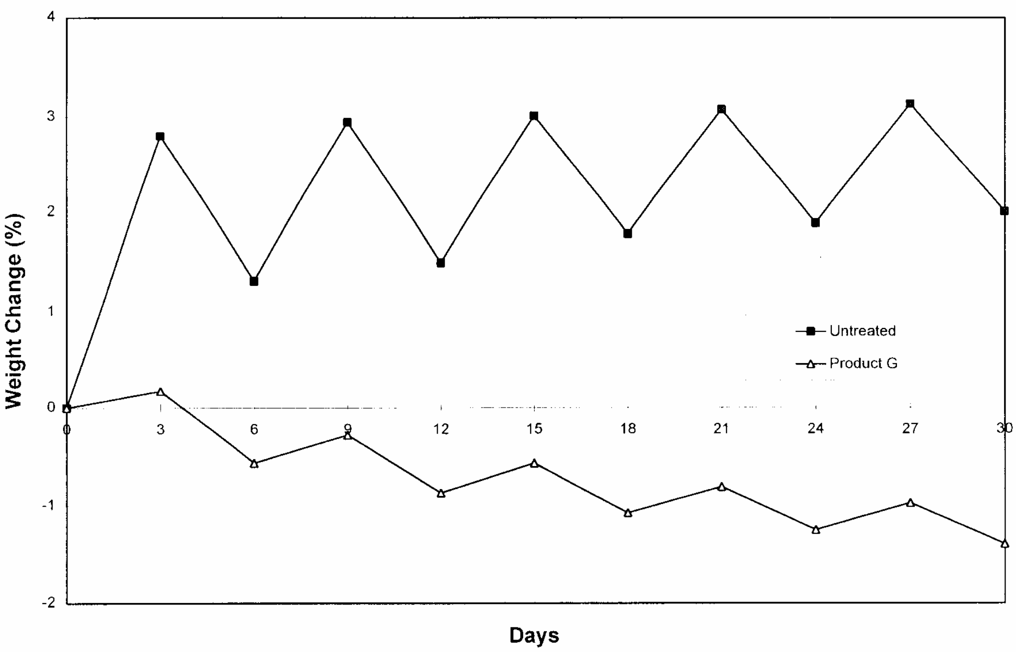


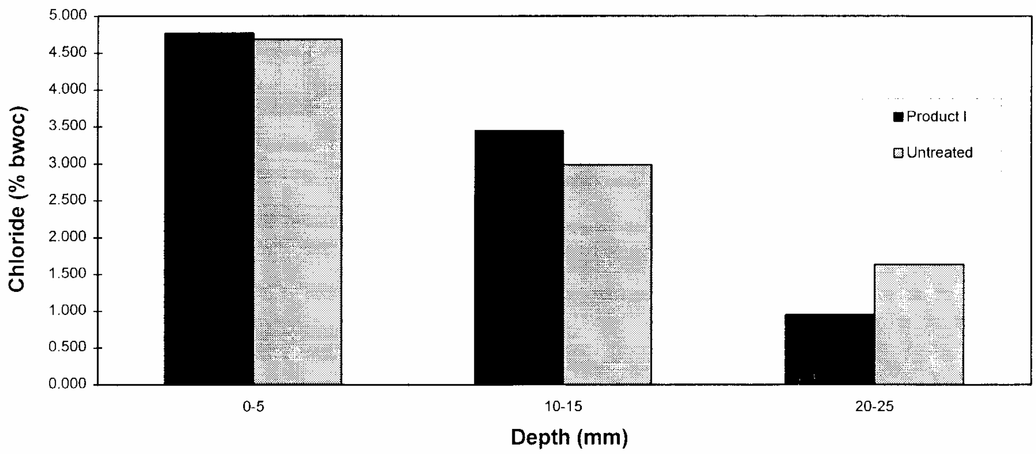
CYCLIC IMMERSION TESTING

Figure B7. Performance Data for Product G: 50MPa Concrete

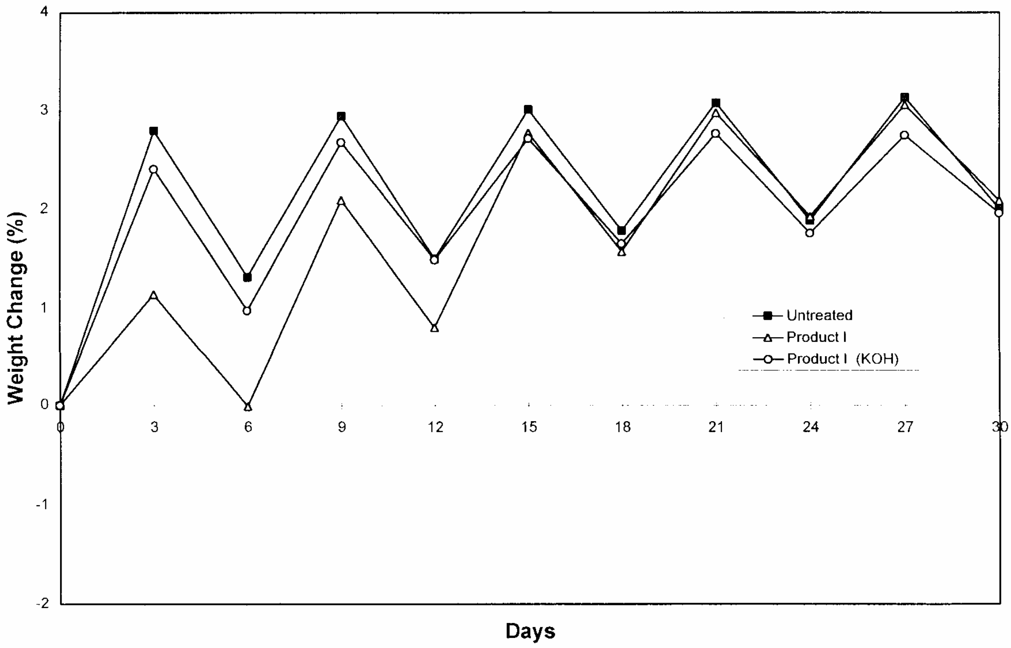
PRODUCT NO.: I 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product I	Untreated	
0-5	4.773	4.691	-1.75
10-15	3.445	2.992	-15.14
20-25	0.952	1.637	41.84

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

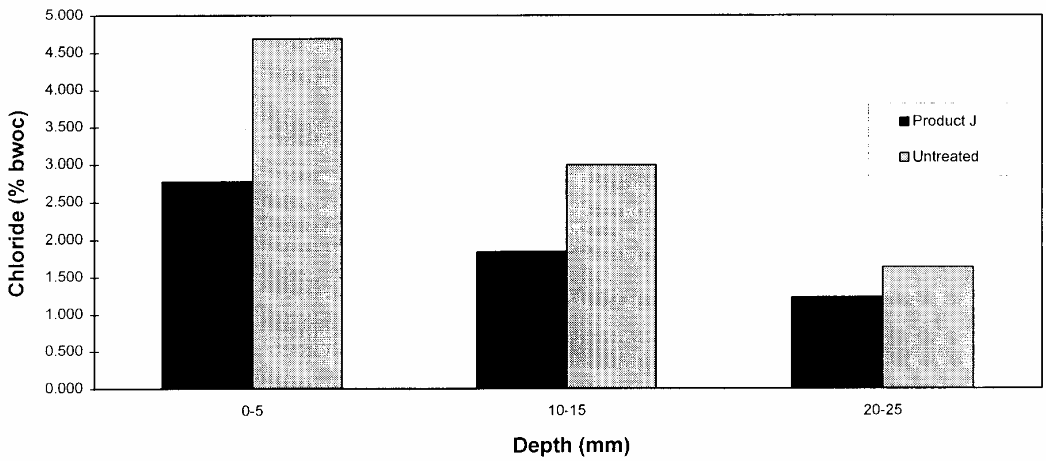
Figure B9. Performance Data for Product I: 50MPa Concrete

CTI

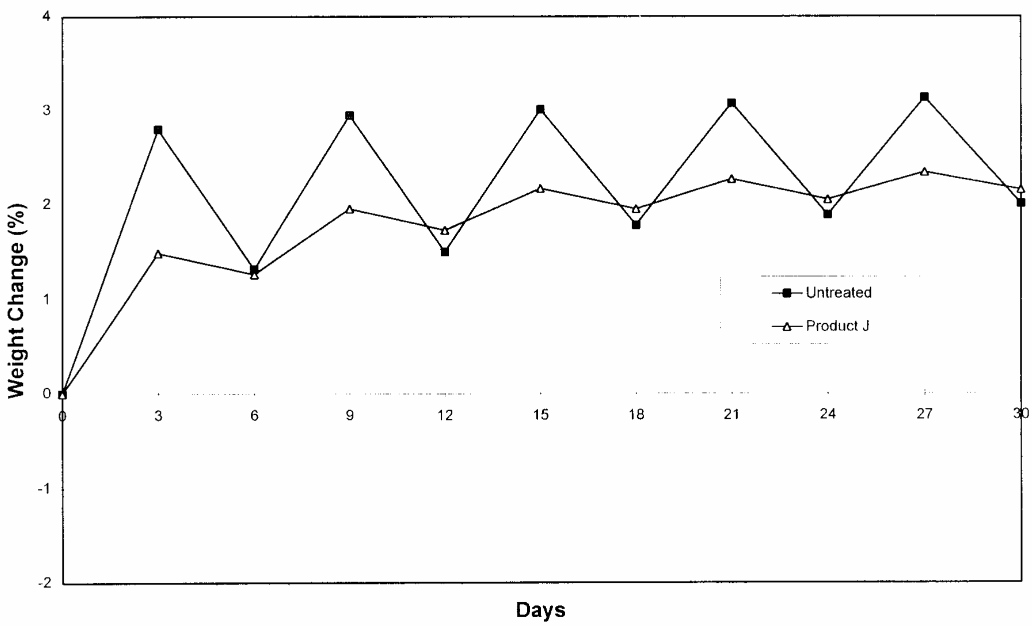
PRODUCT NO.: J 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product J	Untreated	
0-5	2.778	4.691	40.78
10-15	1.847	2.992	38.27
20-25	1.229	1.637	24.92

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

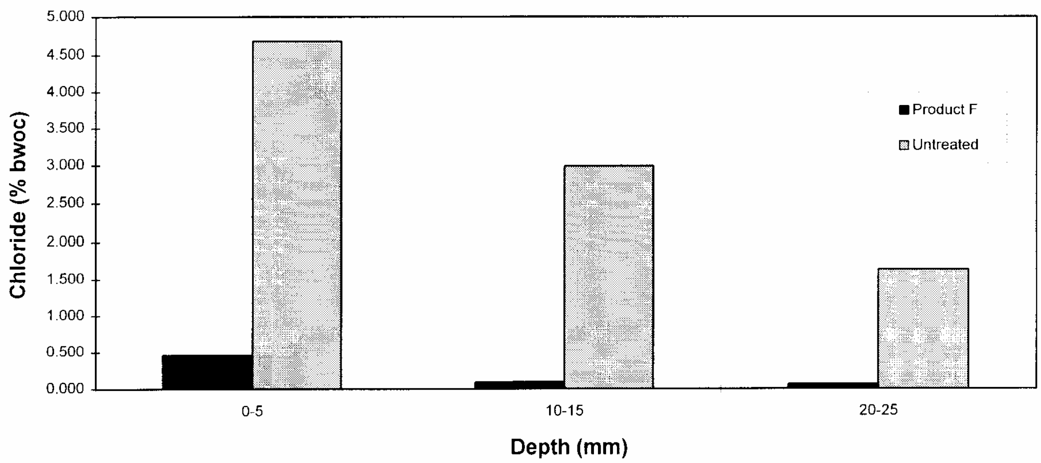
Figure B10. Performance Data for Product J: 50MPa Concrete

CTI

PRODUCT NO.: F 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product F	Untreated	
0-5	0.463	4.691	90.13
10-15	0.090	2.992	96.99
20-25	0.060	1.637	96.33

‡ increase over background
* bwoc = by weight of cement



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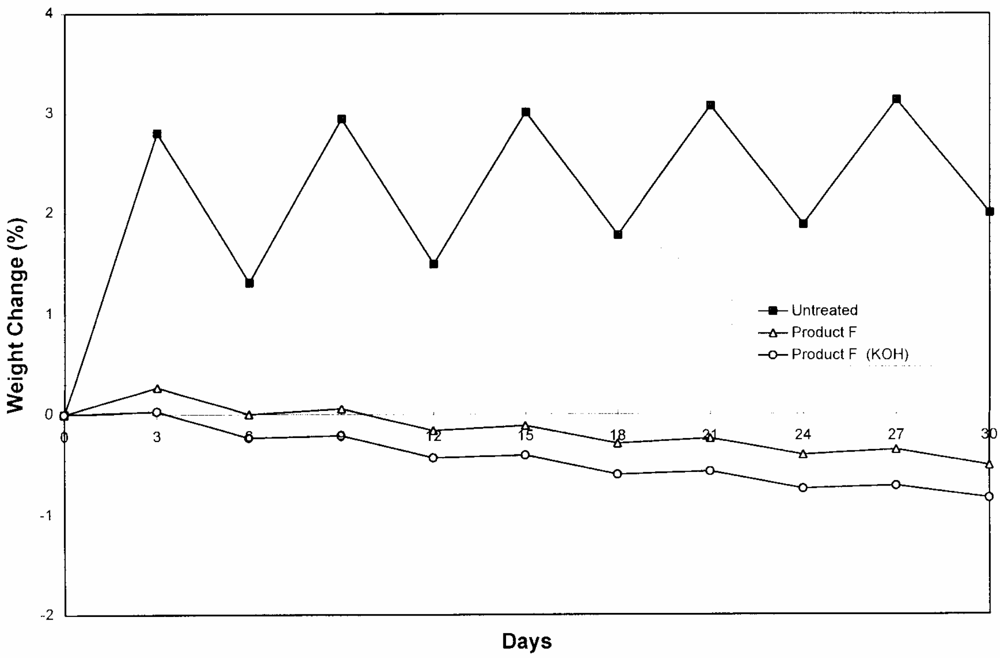


CYCLIC IMMERSION TESTING

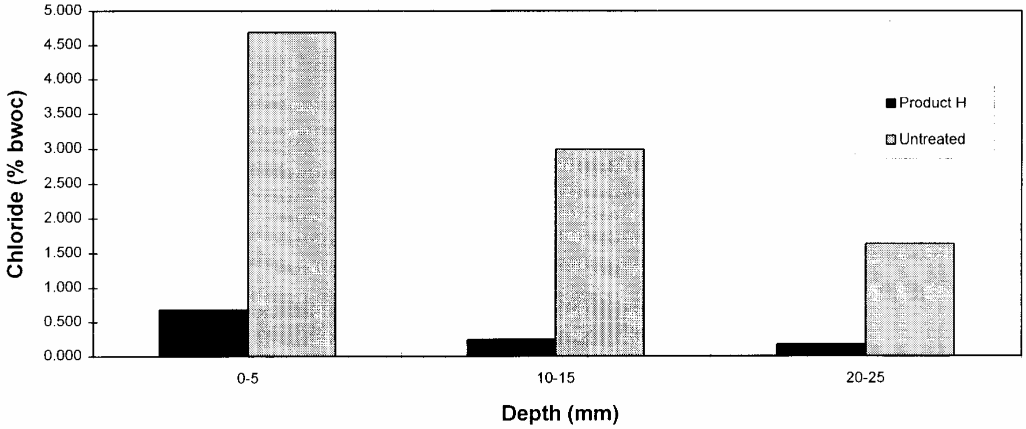
Figure B6. Performance Data for Product F: 50MPa Concrete

CTI

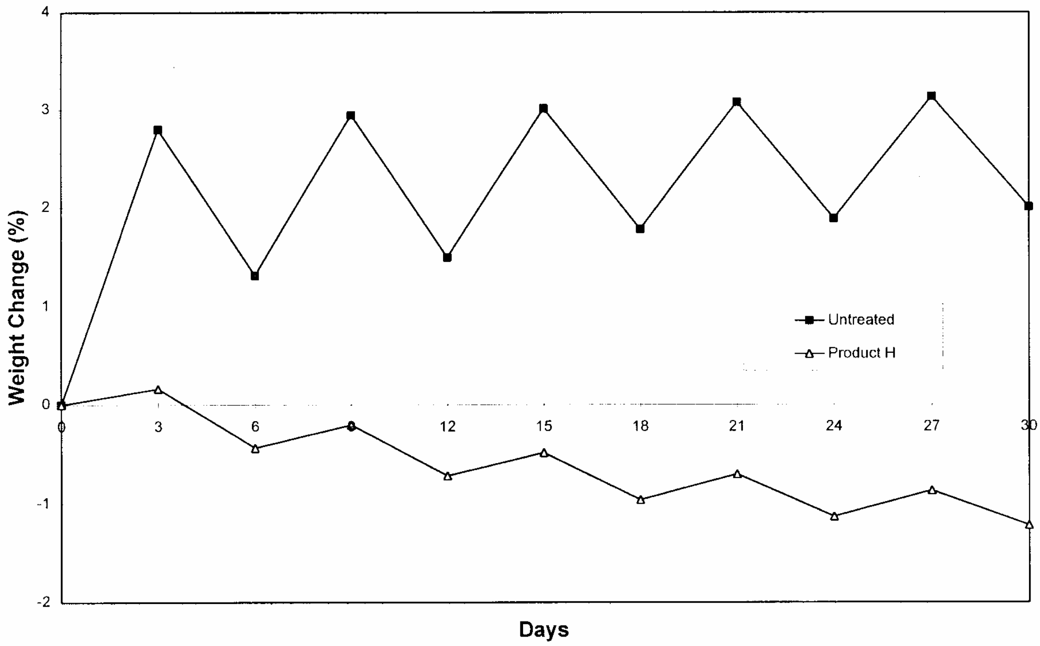
PRODUCT NO.: H 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product H	Untreated	
0-5	0.681	4.691	85.48
10-15	0.247	2.992	91.74
20-25	0.169	1.637	89.68

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

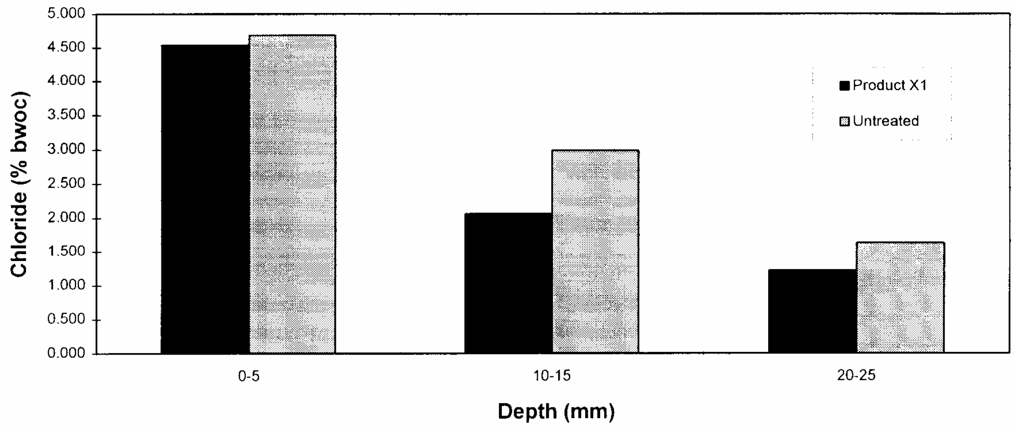
Figure B8. Performance Data for Product H: 50MPa Concrete

CTI

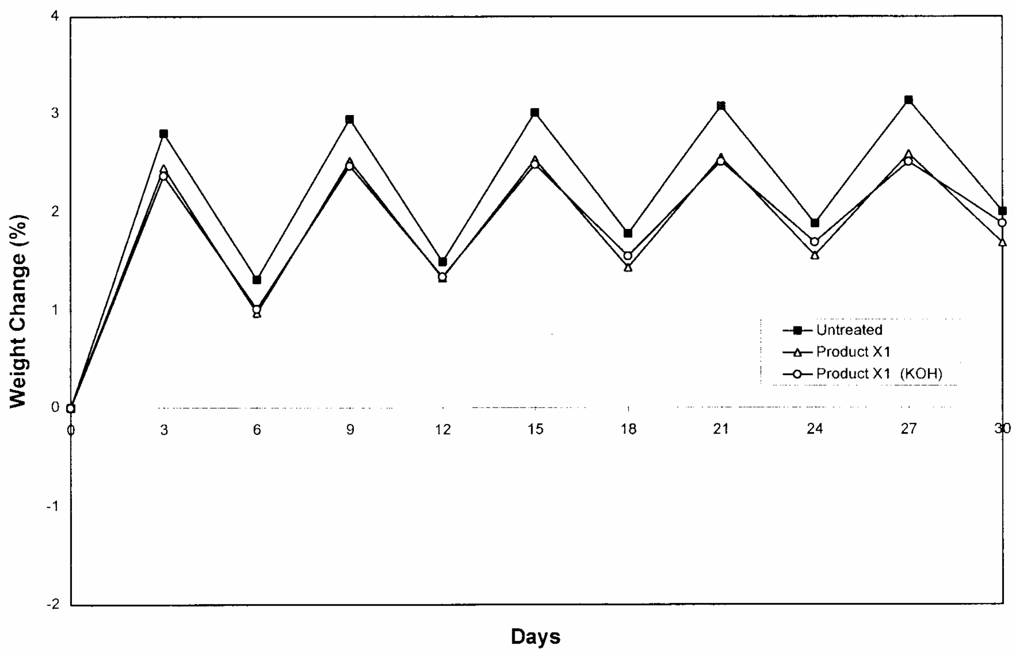
PRODUCT NO.: X1 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product X1	Untreated	
0-5	4.543	4.691	3.15
10-15	2.065	2.992	30.98
20-25	1.222	1.637	25.35

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

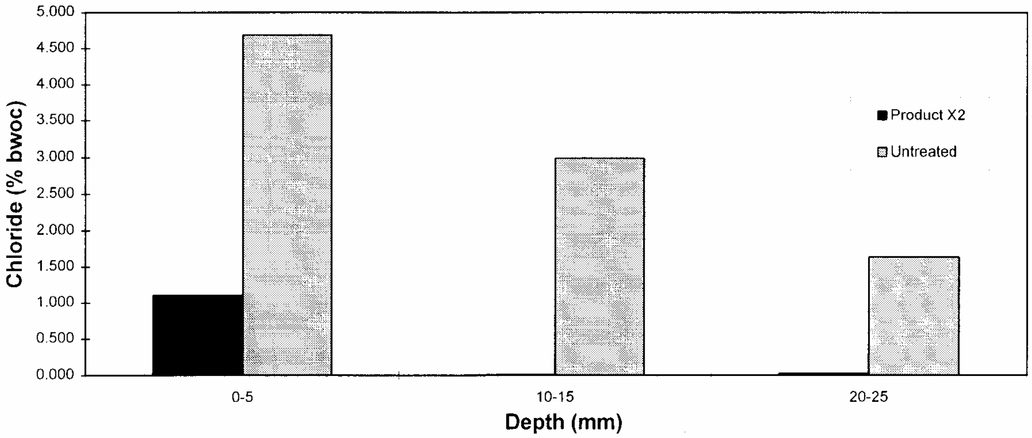
Figure B11. Performance Data for Product X1: 50MPa Concrete

CTI

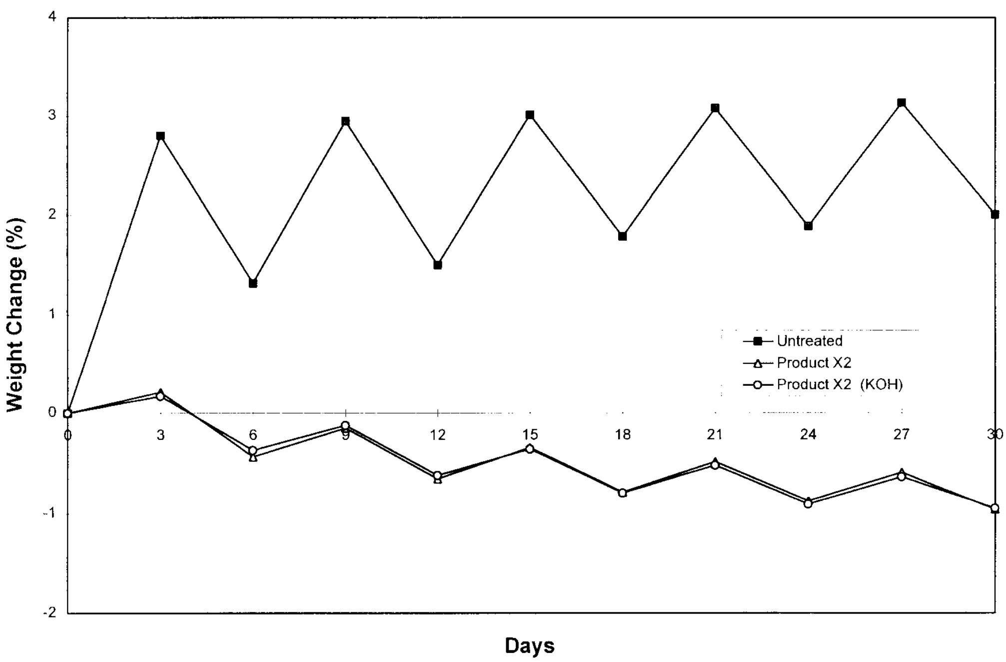
PRODUCT NO.: X2 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product X2	Untreated	
0-5	1.106	4.691	76.42
10-15	0.007	2.992	99.77
20-25	0.026	1.637	98.41

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

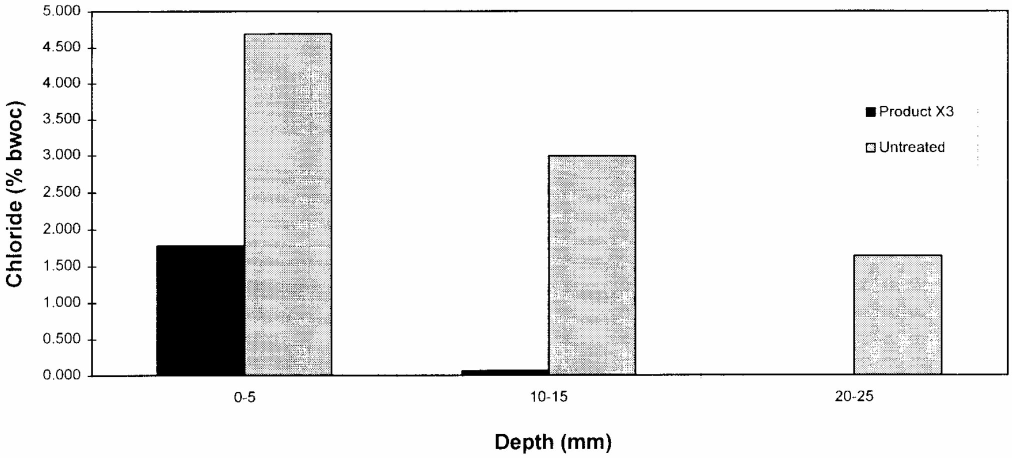
Figure B12. Performance Data for Product X2: 50MPa Concrete

CTI

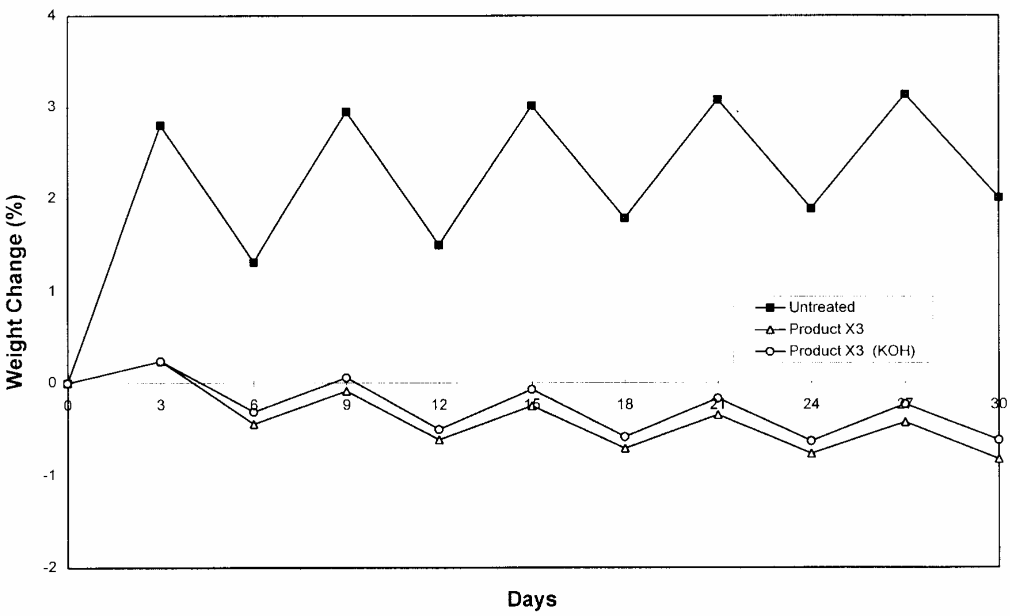
PRODUCT NO.: X3 50 MPa Concrete

Depth (mm)	Chloride Concentration‡ (% bwoc*)		% Reduction
	Product X3	Untreated	
0-5	1.780	4.691	62.05
10-15	0.064	2.992	97.86
20-25	0.000	1.637	100.00

‡ increase over background
* bwoc = by weight of cement



CHLORIDE PROFILES



CYCLIC IMMERSION TESTING

Figure B13. Performance Data for Product X3: 50MPa Concrete

CTI