CONFIDENTIAL

Final Report

of

Xypex Australia Research Program – Stage III

on

PERFORMANCE OF XYPEX ADMIX C-5000 MODIFIED 40MPa COMMERICAL CONCRETES

For

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EXECUTIVE SUMMARY

This research project was undertaken at the Australian Centre for Construction Innovation (ACCI) of the University of New South Wales. The primary aim of this research was to evaluate the performance of 40MPa commercial concretes modified with the permeability-reducing admixture Xypex Admix C-5000.

Four commercial 40MPa concretes were investigated in this project using two Type-GB cements, a fly ash (25%) blended cement and a slag (38%) blended cement. For each type of cement, two concrete mixes were investigated including a control mix and a concrete mix dosed with 0.5% Xypex Admix C-5000 by weight of the total cementitious materials. A comprehensive test program was implemented to study the effects of Xypex Admix C-5000 on a broad range of concrete properties especially those relating to durability performance.

In general, the test results showed a significant improvement in the overall performance of both types of concretes after modification with Xypex Admix C-5000. Compared to the control concretes, the Xypex Admix C-5000 modified concretes recorded significantly higher early age strength, lower drying shrinkage, lower sulphate expansion, and greatly reduced chloride penetration, chloride diffusion rate, and water permeability. The test results indicated the benefits of using Xypex Admix C-5000 to improve durability performance of concretes in aggressive environments.

Slight retardation in setting time was found for the 40MPa concretes dosed with Xypex Admix C-5000 together with the water reducer (Pozz 370).

1. INTRODUCTION

Most major cities in Australia are located in coastal climate zones where corrosion of steel reinforcement is a major factor affecting the durability of concrete structures. Concrete is inherently a porous material containing capillary pores, gel pores and weak cement-aggregate interface zones. Chloride ions in seawater or in marine atmosphere can diffuse into concrete through the concrete pore system. Once the chloride concentration at the reinforcing steel level reaches a threshold value, corrosion of steel reinforcement will initiate.

The use of low permeability concrete and control of cracking in concrete are among the key techniques to achieve durable concrete in marine environments. The traditional means to improve concrete durability are through reduction of water to cement ratio and increase of moist curing period. More recently, partial replacement of Portland cement with supplementary cementitious materials (SCMs), such as fly ash or ground granulated blast furnace (GGBF) slag, has become popular for concrete to be used in aggressive environments. The use of SCMs in concrete has been discussed extensively in the literature (1,2).

The Australian Standard AS 3600 (Concrete Structures) requires a minimum strength grade of 40MPa for concrete structures in the exposure classification B2, which includes those permanently submerged in seawater and above ground in coastal areas (up to 1km from the coastline, but excluding tidal and splash zones). The requirement of a minimum concrete strength provides only one basic guideline for concrete to be used in marine environments. It has been found that durability performance of concrete in marine environments is not simply related to concrete strength but affected by a number of concrete properties, including porosity and pore structures, concrete permeability and resistance to chloride penetration and diffusion. All the relevant properties must be considered in design of durable concrete structures in marine environments.

Permeability-reducing admixtures form a new class of chemical admixtures that can reduce the rate of transmission of moisture either in a liquid or vapour form through concrete. It is the moisture transportation that plays an important role as a vehicle carrying chlorides and other aggressive ions into concrete through its pore system. Several types of permeability-reducing admixture are commercially available. Some of these are classified as hydrophobic admixtures due to presence of long chained fatty acids or vegetable oils (3), whereas some others are classified as microstructure modifiers which reduce concrete permeability through crystallisation activity in concrete pores (4). Most of these admixtures claim to have the ability to greatly reduce water penetration and also impart good resistance to chemical attack in concrete.

Xypex Admix C-5000 is a permeability-reducing admixture characterised by crystallisation reactivity. According to the manufacturer's technical information, Xypex Admix C-5000 is an inorganic admixture and its active ingredients react with a broad range of hydration by-products which include various metal oxides and salts, un-hydrated and partially hydrated cement particulates, regardless of the portland or blended cement types. The reaction products of Xypex Admix C-5000 are in mineral crystal forms and grow in residual vacancies (pores and cracks) in concrete. Research work in Canada and Japan has demonstrated that Xypex Admix C-5000 has the ability to seal leaking cracks and to improve chemical resistance of concrete through reduction of permeability. Xypex Admix C-5000 complies with AS 1478.1 as a Type SN, Special purpose chemical admixture.

The test results obtained in the previous ACCI-Xypex research projects, (Stage-I and Stage II) (5,6), indicated improved concrete properties for concretes modified with Xypex Admix C-Series (C-1000NF) at the dosage rate of 0.8% and 1.2% by weight of total cement.

Xypex Admix C-5000 is a new product developed specifically to achieve optimal durability performance and cost effectiveness using a lower dose rate of 0.5% by weight of cement. The aim of this investigation is to evaluate the potential of Xypex Admix C-5000 to enhance the durability performance of 40 MPa concretes with regard to marine applications. Further detailed objectives of this research are as follows:

1. To investigate the effects of Xypex Admix C-5000 on the plastic state properties of 40MPa commercial concretes using two different Type GB blended cements. The plastic concrete properties to be measured include slump and setting time.

2. To investigate the effects of Xypex Admix C-5000 on the hardened state properties of 40MPa commercial concretes using two Type GB blended cements. A broad range of hardened concrete properties, including major durability properties, investigated in this project include:
    a. Compressive strength
    b. Drying shrinkage
    c. Water absorption and AVPV (Apparent volume of permeable voids)
    d. Chloride ion penetration and diffusion under all major test procedures
    e. Length change in sulphate solution
    f. Water permeability under the pressure of 10 bars

3. To evaluate the effectiveness of Xypex Admix C-5000 to enhance concrete durability performance based on analysis of the test results.

This report summarises the experimental program, the test results, the interpretation and discussion of the results and the conclusions of this research work.

2. MATERIALS AND EXPERIMENTAL PROGRAM

2.1 CONCRETE MIXTURE DESIGNS AND MATERIAL PROPERTIES

A total of four commercial concretes (Grade 40MPa) were investigated in this research program. The four concretes were classified into two groups according to the cement types. Two cements used were Type-GB (AS3972) blended cement with 25% fly ash (AS3582.1 or ASTM C618 Class F) and Type GB blended cements with approximately 38% slag (AS3582.2) respectively. Of each of the two groups, a control concrete mix without Xypex Admix C-5000 was produced and the other concrete mix was modified with Xypex Admix C-5000 at the dose rate of 0.5% by weight of total cementitious materials.

To minimise the differences in the performance between "laboratory mixed concrete" and commercial "site received concrete", all concretes (one cubic metre each) were produced in a Boral premix concrete plant and delivered to the ACCI laboratory where testing of fresh concrete properties were carried out and concrete samples were cast and cured for testing hardened properties. All the concrete mixes were commercial concretes of 40MPa strength grade.

Table 2.1-1 summarises the mix proportions of four concrete mixes using different cements and admixtures. Table 2.1-2 presents the properties of two cement products and the fly ash used in the concrete mixes. Table 2.1-3 gives the mix code names of the two groups according to the cement type, and the dosage of Xypex Admix C-5000.

AS1478.1 Type-WR water reducing admixture, Pozzolith 370 (Pozz370) from MBT, was used to achieve a target slump of 80±10mm for all the concrete mixes. Xypex Admix C-5000 was added into the selected concrete batches at the ready-mix plant according to the manufacturer's recommendations.

The copies of Boral concrete delivery dockets and the material test certificates are included in the APPENDICES of this report.

Table 2.1-1 CONCRETE MIX PROPORTIONS

		Type GB (Fly Ash, Type F)		Type GB (38% Slag)	
Date of Concrete Delivery		19/01/04	21/01/04	27/01/04	29/01/04
Mix Designation		1	2	4	5
Total Cement Binder Content (kg/m^3)		435	435	435	435
Water to Cement ratio (W/C)		0.4	0.4	0.4	0.4
Cement Proportion	Portland Cement -Type GP (SL) (%)	75	75	62	62
	Fly Ash (%)	25	25		
	Slag (%)			38	38
Coarse Aggregates		20mm Dunmore Basalt			
		10mm Dunmore Basalt			
Fine Aggregates		Emu Plains Coarse Sand			
		Kurnell Fine Sand			
Aggregate / Cement Ratio		3.93	3.93	3.96	3.96
Water Reducer - Pozz 370 (300ml/100kg cement)		$1.35L/m^3$	$1.35L/m^3$	$1.35L/m^3$	$1.35L/m^3$
Xypex Admix C-5000	Dosage (%/cement)	0	0.5%	0	0.5%
	Mass (kg/m^3)	0	2.175	0	2.175
Target Slump (mm)		80	80	80	80
Quantity of Concrete Per Mix (m^3)		1	1	1	1

Table 2.1-2 Properties of Cements and Fly ash

Cement Type	**Type GP (SL)**	**Type GB Slag Blend**	**Fly ash**
Cement Name	Shrinkage Limited	Slagment	Fly Ash
Source	Blue Circle Southern Cement LTD,	Blue Circle Southern Cement LTD,	Eraring
Certificate No	3481	3500	42410
Setting Time			
Initial	2h / 00m	2h / 00m	
Final	3h / 15m	3h / 30m	
Soundness	1mm	1mm	
SO3 Content %	2.6	2.7	
Compressive Strength MPa			
3 days	33.0	26.2	
7 days	46.3	38.9	
28 days	62.7	64.2	
Mortar Shrinkage			
28 weeks	550	-	
Chemical Properties %			
L.O.I	-	-	1.00
C_3S	60	-	-
C_2S	14	-	-
C_3A	4.5	-	-
C_4AF	14	-	-
K_2O	0.50	-	1.85
Na_2O	0.00	-	0.49
MgO	1.30	-	0.54
Al_2O_3	4.60	-	22.50
Physical			
Fineness Index	335 m^2/kg	410 m^2/kg	
Normal Consistency	27.0%	30.7%	
Autoclave Expansion	<0.01%	-	

Table 2.1-3 Mix Codes and Types of Cement and Admixture

Mix Code	Cement Type	Xypex Admix / Dose Rate	Water Reducer
3F1	Type-GB (25% Fly Ash)	Nil	Pozz 370
3F2	Type-GB (25% Fly Ash)	C-5000NF / 0.5%	Pozz 370
3LS1	Type-GB (38% Slag)	Nil	Pozz 370
3LS2	Type-GB (38% Slag)	C-5000NF / 0.5%	Pozz 370

2.2. EXPERIMENTAL TEST PROGRAM

Table 2.2-1 shows the experimental test program for investigation of a broad range of properties of the four concretes. As shown in Table 2.2-1, most of the tests were carried out according to the relevant Australian Standards. Where the Australian standard methods are not available, such as the tests for chloride diffusion and water permeability, other standard methods (e.g. ASTM C1202 and NORDTEST) and non-standard test methods (e.g. ACCI test method) were adopted. The methods for testing plastic and hardened concrete are described as follows.

2.2.1. Plastic Concrete Tests

Slump:

Slump of each concrete was tested when received at the ACCI laboratory in accordance with the Australian Standard AS1012.3.

Setting Time:

The initial and final setting time of each concrete was determined in accordance with the Australian Standard AS1012.18.

Table-2.2-1. Concrete Test Program of ACCI-Xypex Research Project Stage III

Cement Type			**Type GB (25% Fly Ash)**		**Type GB (38% Slag)**	
Total Cement Content (kg/m^3)			**435**	**435**	**435**	**435**
W/C Ratio		0.40	**0.4**	**0.4**	**0.4**	**0.4**
Cement Proportions		Portland Cement (%)	75%	75%	62%	62%
		Fly Ash (%)	25%	25%		
		Slag (%)			38%	38%
Xypex Admix		**Xypex C-5000 by weight of Cement (%)**	**0**	**0.5%**	**0**	**0.5%**
Chemical Admixture		Water Reducer - Pozz 370 (300ml/100kg cement)	**Y**	**Y**	**Y**	**Y**
Experimental Tests	1	Slump (AS1012)	**80 mm**	**80**	**80**	**80**
	2	Setting Time (AS1012)	Y	Y	Y	Y
	3	Drying Shrinkage (AS 1012)	Y	Y	Y	Y
	5	3, 28 & 91 day Compressive Strength (AS1012.9)	Y	Y	Y	Y
	6	CSIRO modified ASTM C1202 - at 28 days	Y	Y	Y	Y
	7	ACCI Cl Diffusion/Nordtest (3% NaCl at 28d over 35d & 105d / 15%NaCl at 28d for 35d)	Y	Y	Y	Y
	8	ACCI Cyclic Cl penetration (15%NaCl, 28d curing; wet/dry at 28d over 14 d)	Y	Y	Y	Y
	9	ACCI Cyclic Cl penetration (15%NaCl, 28d curing; wet/dry at 28d over 28 d)	Y	Y	Y	Y
	10	Water Absorption & AVPV (14d curing & 42days air dry; 56d curing, AS 1012.21)	Y	Y	Y	Y
	11	Water Sorptivity (RTA T362, 14d curing, 35 air dry)-Class C	Y	Y	Y	Y
	12	Length Change in Sulphate Solution (AS 2350.14)	Y	Y	Y	Y
	13	ACCI Water Permeability at 91d (14d curing + 77 air dry)	Y	Y	Y	Y
		Concrete Mix Number	**3F1**	**3F2**	**3LS1**	**3LS2**

2.2.2. Hardened Concrete Tests

Compressive Strength:

Compressive strength was tested with 100mm diameter cylinder samples after standard curing for 3,7,28, and 91 days in accordance with AS1012.9.

Drying Shrinkage:

Drying shrinkage samples were cast, cured and exposed to standard drying conditions according to AS1012.13. Drying shrinkage was measured every 7 days until 56 days of drying.

Length Change in Sulphate Solution:

Prism samples were cast, cured and immersed in the standard sulphate solution according to AS2350.14. Expansions of prisms were measured using a comparator every 2 weeks after immersion in refreshed sulphate solution. Final readings were taken after 16 weeks of immersion.

CSIRO Modified ASTM C1202 Rapid Chloride Ion Penetration:

In this investigation, testing was undertaken based on the CSIRO modified ASTM C1202 method (7,8). The CSIRO modified test procedures involve performing of two parallel tests. One test is performed according to the standard ASTM C1202 procedures to measure electrical charge under a DC voltage of 60 V passed through a concrete specimen located between two chambers filled with a sodium hydroxide solution and a sodium chloride solution. The additional test is performed in a similar way but with the two chambers filled with specimen curing water (i.e. saturated limewater). The difference between the total passed charges of the two parallel tests is taken as the indicator for the concrete's resistance to chloride ingress in the CSIRO Modified ASTM C1202 test.

ACCI Cyclic Chloride Penetration Test:

The ACCI wetting-and-drying cyclic chloride penetration test is described in the "Performance Criteria for Concrete in Marine Environments" (9) published by the Concrete Institute of Australia. Prism samples (100x100x200mm) were cast and cured according to AS1012. This method essentially involves testing of chloride penetration into concrete under accelerated cyclic exposure conditions (12 hours drying under heating lamps and 12 hours immersion in 15% NaCl solution). The chloride penetration depth in concrete is determined with a silver nitrate indicator sprayed on the freshly fractured cross section of the samples after cyclic exposure for 14 and 28 days respectively.

Nordtest (NT BUILD 443, 1995):

The Nordtest (NT BUILD 443, 1995) is an accelerated test method for assessment of chloride diffusion into hardened concrete. It is based on immersion of cylinder samples in 16.5% NaCl solution for at least 35 days. A longer immersion time should be used with low permeable concrete samples. A 35 days immersion period was adopted in this test program. The cylinder samples are coated with epoxy or polyurethane on all surfaces except for the top surface. After the immersion period, powder samples are extracted at different depths from the exposed surface for analysis of chloride contents. The chloride content profile in the concrete is plotted and used to determine the chloride diffusion coefficient by analysis against the Fick's Second Law.

ACCI Chloride Diffusion Test in 3% NaCl Solution (ACCI):

ACCI chloride diffusion test is based on the modified Nordtest (NT BUILD 443, 1995) and is a non-accelerated test method for assessment of chloride diffusion into hardened concrete. It is based on immersion of cylinder samples in 3% NaCl (similar to the chloride concentration in natural seawater) solution for at least 35 days. A longer immersion time is necessary with low permeable concrete samples. Both 35 days and 105 days immersion periods were adopted in this test program. The preparation of cylinder samples, extraction of powder samples, analysis of chloride contents and analysis of chloride content profiles for chloride diffusion coefficients are exactly the same as those in the Nordtest

Water Absorption and AVPV:

Immersion water absorption, boiled water absorption, and apparent volume of permeable voids (AVPV) of concrete samples were measured in accordance with AS1012.21. Two different curing conditions were included in this investigation. These were 7 days limewater curing followed by air-drying until age of 56 days, and 56 days continuous limewater curing.

Water Sorptivity (RTA-NSW Test Method T362):

Water sorptivity of hardened concrete prisms was tested according to the procedures of the RTA (NSW) test method T362. For this investigation, two concrete prisms (100 x 100 x 350mm) were cured in limewater for 14 days followed by drying for 35 days (required by RTA-T362 for concrete in marine exposure Classification C of AS 3600) at 23 ºC and 50% relative humidity. The prisms were then soaked in a water bath for 24 hours. At the end of the soaking period, the prisms were broken transversely in the central zone and the cross sections were dusted with a moist indicator "methylene blue" and the water penetration depths were measured at three locations for each prism sample.

ACCI Water Permeability Test:

The ACCI test apparatus was modified from the Taywood water permeability test apparatus. Concrete samples were cured in limewater for 14 days followed by 77 days of air-drying and were tested at the age of 91 days. An epoxy resin (Sikadur 52) was used for sealing the side of concrete sample during sample preparation. Water pressures of 6 bars and 10 bars (60 metres and 100 metres water head) were applied to one surface of the 50mm thick samples (100mm in diameter) during the test period. The amount of water flow through the samples under the pressure was measured. The water permeability coefficient was calculated using Darcy's equation and shown in the unit of m/s.

$$k = \frac{Q}{A} \times \frac{L}{H}$$

where k = water permeability coefficient (m/s)

Q = flow rate (m^3/s);

L = depth (thickness) of specimen (m)

A = specimen area under pressure (m^2);

H = head of water (m)

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental test results of this research are described and discussed in the following two parts, the plastic concrete properties and the hardened concrete properties.

3.1 PLASTIC CONCRETE PROPERTIES

Table 3.1-1 summarises the test results of plastic concrete of all the four concrete mixes in this research work. These results are discussed in the following sections.

Table 3.1-1. SUMMARY OF PLASTIC CONCRETE PROPERTIES

Mix Code	Ambient Temperature (°C)	Concrete Temperature (°C)	Relative Humidity (%)	Slump (mm)	Setting Time (Hr:min)	
					Initial	Final
3F1	24.0	27.5	49.0	90.0	3:40	4:50
3F2	25.2	31.2	66.7	100.0	4:40	5:50
3LS1	23.3	28.8	62.5	70.0	3:20	5:10
3LS2	24.4	30.0	52.8	65.0	4:50	6:30

3.1.1 Slump (AS1012.3)

All concrete mixes were ordered to have the target slump of 80±10mm. However, the actual slump of the concrete mixes when received and tested at the ACCI laboratory was in the range of 65mm to 100mm as shown in Table 3.1-1. No additional water was added into any of these concrete mixes.

It was found by the slump testing and by observation during the preparation of concrete samples that the Xypex Admix C-5000 modified concretes had similar workability to the control concrete mixes.

3.1.2 Setting Time (AS1012.18)

The initial and final setting times of all the concrete mixes are summarised in Table 3.1-1 and also shown in the bar chart in Fig 3.1.2-1. In general, the Xypex Admix C-5000 modified concrete mixes had slightly longer initial and final setting times than their corresponding control concretes, when used in combination with Pozz 370.

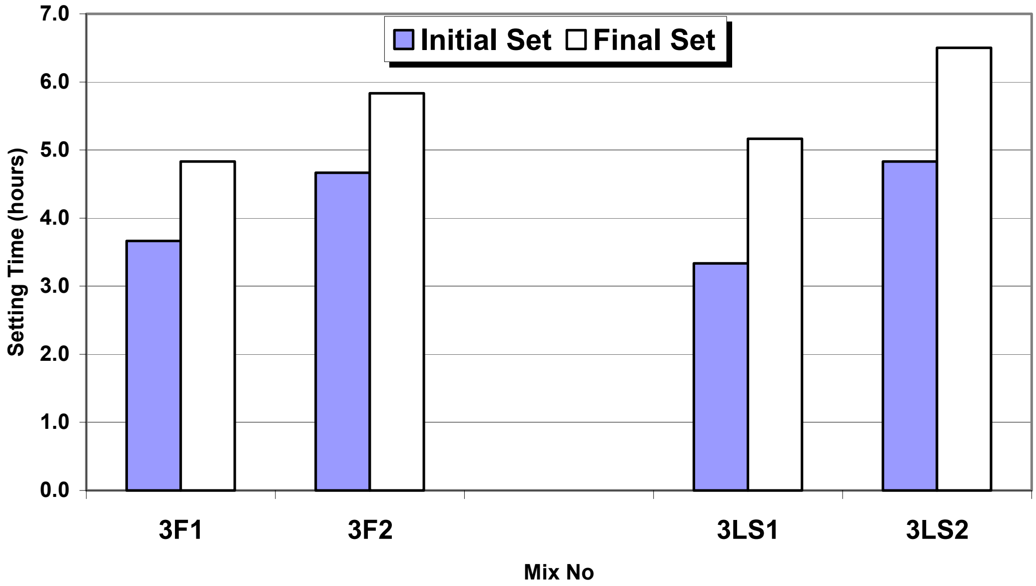

Fig 3.1.2-1 Comparison of Results of Initial and Final Setting Time

When compared with the Type-GB fly ash control concrete Mix-3F1, addition of 0.5% Xypex Admix C-5000 (Mix-3F2) increased both the initial setting time and final setting time by 60 minutes. The low slag concrete (38% slag) of Mix-3LS2 with 0.5% Xypex Admix C-5000 experienced an increase of initial and final setting times by 90 minutes and 80 minutes respectively compared with the control Mix-3LS1.

However, the initial setting times of the 40MPa control concretes were found to be relatively short being 200 minutes (3h: 20m) and 220 minutes (3h: 40m) respectively. The delaying setting time of 60 to 80 minutes for the Xypex Admix C-5000 modified concretes may be advantage for casting and compacting concrete in hot weather and in massive structural elements, by preventing formation of cold joints.

In summary, the results indicated that initial and final setting times were slightly retarded when Xypex Admix C-5000 was used together with the water reducer, Pozz 370. At 0.5% dose rate the Xypex Admix C-5000 modified concretes had slightly delayed initial setting times in the range of 60 to 90 minutes.

3.2 HARDENED CONCRETE PROPERTIES

3.2.1 Compressive Strength (AS1012.9)

The compressive strength test results are shown in Table 3.2.1-1 for all the concrete mixes at the ages of 3, 7, 28, and 91 days after standard curing in limewater. The compressive strengths of the Xypex Admix C-5000 modified concretes are also expressed as ratios to that of their control concretes tested at the same age.

Table 3.2.1-1 Results of Compressive Strength at All Ages

Compressive Strength (MPa)								
	3 days	Ratio to Control	**7 days**	Ratio to Control	**28 days**	Ratio to Control	**91 days**	Ratio to Control
Type-GB (25% Fly Ash)								
3F1	25.27	1	36.20	1	48.89	1	59.50	1
3F2	30.15	1.19	40.50	1.12	51.60	1.06	62.56	1.05
Type-GB (38% Slag)								
3LS1	21.70	1	27.73	1	49.56	1	58.38	1
3LS2	24.27	1.12	31.34	1.13	50.89	1.03	59.55	1.02

The influence of Xypex Admix C-5000 on compressive strength of the two types of concretes is also shown in Fig 3.2.1-1.

In general, the Xypex Admix C-5000 modified concretes of both types had higher compressive strengths than the control concrete mixes at all ages. In particular, the effect of Xypex Admix C-5000 on strength increase was more significant at the early ages. The Xypex Admix C-5000 modified fly ash concrete Mix-3F2 had significantly higher 3 days strength than the control Mix-3F1 by 19%. The slag concrete Mix-3LS2 modified with Xypex Admix C-5000 also recorded significantly higher strength at 3 days than the control Mix-3LS1 by 12%.

The test results indicated that concrete modified with Xypex Admix C-5000 benefited, with enhanced compressive strength especially at early ages, which would enable earlier stripping of formwork and acceleration of construction processes.

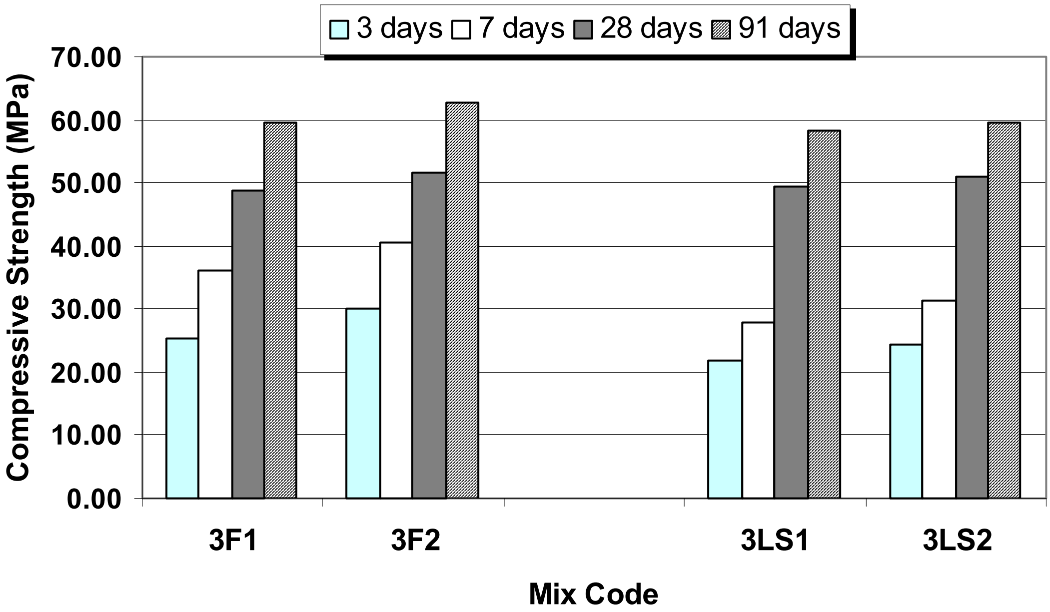

Fig 3.2.1-1 Comparison of Compressive Strengths of All Concretes

3.2.2 Drying Shrinkage (AS1012.13)

Table 3.2.2-1 presents the drying shrinkage results of all the concrete mixes measured after 28 days and 56 days of standard drying according to AS1012.13.

Table 3.2.2-1 Shrinkage after 28 Days and 56 Days of Standard Drying

Mix No	28 Days Drying Shrinkage (10^{-6})	Ratio to Control	56 Days Drying Shrinkage (10^{-6})	Ratio to Control
Type-GB (25% Fly Ash)				
3F1	534	1.00	644	1.00
3F2	497	0.93	618	0.96
Type-GB (38% Slag)				
3LS1	682	1.00	796	1.00
3LS2	605	0.89	723	0.91

The drying shrinkage results of two Type-GB fly ash (25%) cement concretes are shown in Fig 3.2.2-1. The concretes modified with Xypex Admix C-5000 (Mix-3F2) had lower shrinkage by 7% compared to the control Mix-3F1. Fig 3.2.2-2 shows the drying shrinkage of Type-GB slag (38%) cement concrete Mix-3LS1 and Mix-3LS2. The Xypex Admix C-5000 modified concrete Mix-3LS2 had significantly lower shrinkage than the control concrete Mix-3LS1 by up to 11%.

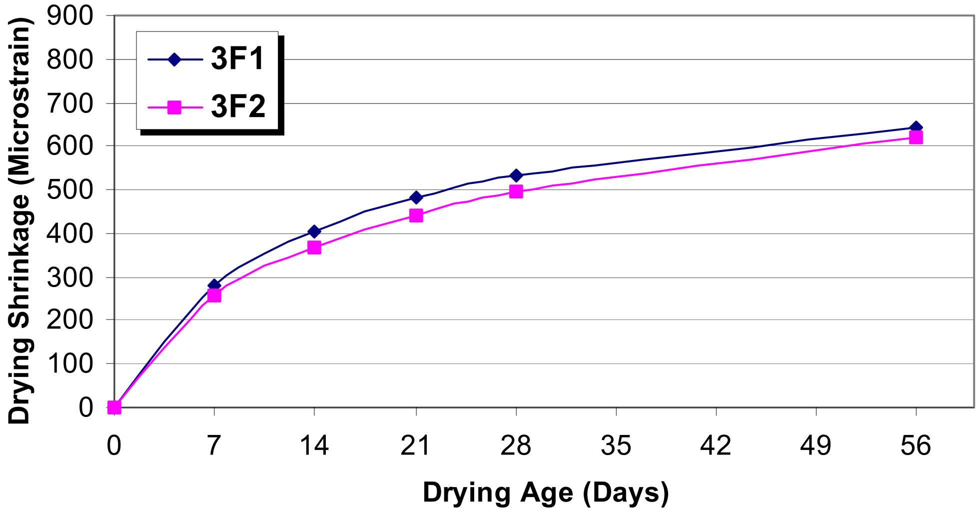

Fig 3.2.2-1 Drying Shrinkage of Type-GB Fly Ash (25%) Cement Concretes

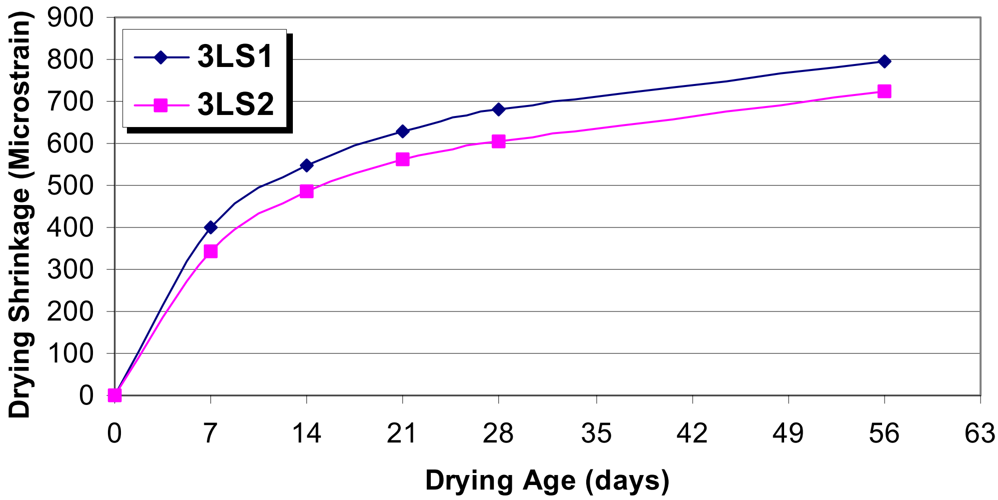

Fig 3.2.2-2 Drying Shrinkage of Type-GB Slag (38%) Cement Concretes

Overall, the Xypex Admix C-5000 modified concrete mixes were found to have lower drying shrinkage compared to the control mixes using either Type-GB (25% fly ash) cement or Type-GB (38% slag) cement.

3.2.3 Water Absorption and AVPV (AS1012.21)

The water absorption and AVPV (Apparent Volume of Permeable Voids) of concrete were determined in accordance with the Australian Standard AS1012.21. The tests were conducted under two different curing regimes in order to study the influence of curing method (in air or limewater) and curing time on water absorption and AVPV. The curing regimes used in this test were:

1. 7 days limewater curing followed by air curing at 23°C to 56 days
2. 56 days continuous limewater curing

Table 3.2.3-1 summarises the water absorption test results for all the concretes under the two curing regimes. In general, the Xypex Admix C-5000 modified concretes had lower water absorptions than the control concretes under both curing regimes. The most significant reduction in water absorption of 13% was found with the Xypex Admix C-5000 modified 38% slag concrete Mix-3LS2 compared with the control Mix-3LS1.

All the concretes recorded lower water absorption values under continuous limewater curing to 56 days compared to that under the curing regime of 7 days in limewater followed by air curing to 56 days. Table 3.2.3-2 shows the reduction in water absorption of the concrete samples continuously cured in limewater compared to those only cured in limewater for 7 days.

Table 3.2.3-1 Summary of Water Absorption Test Results

Mix No	Sample Curing Methods – Immersion Absorption (%)			
	7 days limewater + 49 days air dry	Ratio to Control	56 days limewater	Ratio to Control
Type-GB (25% Fly Ash)				
3F1	5.16	1.00	4.26	1.00
3F2	4.81	0.93	3.84	0.90
Type-GB (38% Slag)				
3LS1	5.35	1.00	4.10	1.00
3LS2	4.64	0.87	3.85	0.94

Table 3.2.3-2 Influence of Curing Regime on Water Absorption Results

Mix No	Sample Curing Methods – Immersion Absorption (%)		
	7 days limewater + 49 days air dry	56 days limewater	Reduction (%) due to longer curing time in limewater
Type-GB (25% Fly Ash)			
2F1	5.16	4.26	-17%
2F2	4.81	3.84	-20%
Type-GB (38% Slag)			
2LS1	5.35	4.10	-23%
2LS2	4.64	3.85	-17%

Table 3.2.3-3 summarises the test results on AVPV (Apparent Volume of Permeable Voids). In general, the AVPV results showed similar trends to the water absorption results. The Xypex Admix C-5000 modified concrete mixes had lower AVPV values than their control mixes under both curing regimes.

Table 3.2.3-3 Influence of Curing Regime on AVPV Test Results

Mix No	Sample Curing Methods – AVPV (%)				
	7 days limewater + 49 days air dry	Ratio To Control	56 days limewater	Ratio To Control	Reduction (%) due to longer curing time in limewater
Type-GB (25% Fly Ash)					
3F1	11.85	1.00	9.78	1.00	-17%
3F2	11.30	0.95	9.20	0.94	-18%
Type-GB (38% Slag)					
3LS1	12.28	1.00	9.48	1.00	-22%
3LS2	11.34	0.92	8.95	0.94	-21%

Table 3.2.3-4 presents the concrete assessment criteria of VicRoad Section 610 (Structural Concrete) based on AVPV results. It is shown that maximum VPV (another term for AVPV) values at 28 days is limited to be 13% for grade VR440/40 concrete cylinders compacted by vibration. All the concrete mixes in this investigation (see Table 3.2.3-3) had VPV values well below the maximum values specified in VicRoad Section 610. The Xypex Admix C-5000

modified concretes Mix-3F2 and Mix-3LS2 had shown even lower AVPV values compared to their control concretes.

Table 3.2.3-4 Vic Road Section 610, Structural Concrete, VPV Requirements

Concrete Grade	Maximum VPV Values at 28 days (%)		
	Test Cylinders (compaction by vibration)	Test Cylinders (compacted by rodding)	Test Cores
VR330/32	14	15	17
VR440/40	13	14	16
VR450/50	12	13	15
VR470/55	11	12	14

3.2.4 Water Permeability Test (ACCI Method)

All the concretes in this investigation were tested for water permeability by the ACCI method under water pressure up to 10 bars (100 metres water head). The concrete samples were cured in limewater for 14 days followed by 77 days of air curing at 23 °C and tested for water permeability at concrete age of 91 days.

Table 3.2.4-1 presents the water permeability test results expressed in terms of the permeability coefficient. The Xypex Admix C-5000 modified Type-GB 25% fly ash cement concrete Mix-3F2 showed a significant reduction by 39% in water permeability than the control concrete Mix-3F1. The Xypex Admix C-5000 modified Type-GB (38% slag) concrete Mix-3LS2 recorded a very significant reduction in water permeability by 81% compared to the control concrete Mix-3LS1.

Table 3.2.4-1 Water Permeability Coefficients or Water Penetration Depths

Mix No	Water Permeability Coefficient (m/s) @ 91 days	Ratio to Control
	Type-GB (25% Fly Ash)	
3F1	1.15×10^{-12}	1.00
3F2	6.20×10^{-13}	0.61
	Type-GB (38% Slag)	
3LS1	2.36×10^{-13}	1.00
3LS2	4.59×10^{-14}	0.19

In general, it was also found that water permeability in the Type-GB slag (38%) cement concretes was lower by approximate one order of magnitude lower than in the concretes made with Type-GB fly ash (25%) cement.

Taywood Engineering proposed criteria for assessment of concrete quality based on water permeability coefficients, which were adopted by the British Concrete Society Committee on In-situ Permeability of Concrete. It was proposed that concretes with water permeability coefficients in the range of $1x10^{-10}$ to $1x10^{-12}$ m/s have acceptable quality, while concretes with permeability coefficient greater than $1x10^{-10}$ m/s have poor quality. Concretes with permeability coefficients less than of $1x10^{-12}$ m/s are regarded as very good concretes for use in severe environments. According to these criteria, all the Xypex Admix C-5000 modified flyash (25%) and slag (38%) concretes are ranked as having very good quality and suitable for severe environments.

3.2.5 RTA Water Sorptivity (RTA Test Method T362)

RTA (NSW) water sorptivity test (RTA test method T362) was carried with samples of all the concretes in this research program. Concrete prism samples were initially cured in limewater for 14 days followed by drying in a drying shrinkage room at 23 °C and 50% relative humidity. The drying period was taken as 35 days in accordance with the requirement of RTA-T362 for testing concretes for the exposure classification C, which includes marine tidal and splash zones, according to AS 3600.

Table 3.2.5-1 summarises the RTA water sorptivity test results. As shown in the table, the Xypex Admix C-5000 modified 25% fly ash concrete Mix-3F2 recorded water sorptivity depth 14% lower compared to the control concrete Mix-3F1.

Table 3.2.5-2 reproduce the Table B80.6 in the RTA (NSW) QA Specification-B80 “Concrete Work for Bridges”, which specifies durability requirements based on water sorptivity for concretes under various exposure conditions classified by AS 3600.

It is shown that the maximum sorptivity penetration depth is limited to 8mm for concrete applications in the exposure classification C. All the concrete mixes in this research have not met this durability requirement. It is not surprising that concrete mixes in this investigation did not meet this strict requirement, because the “exposure classification C” includes the tidal and splash zones in marine environments and it is the most severe exposure classification in

AS 3600. For concrete to be used in tidal and splash zones, the compressive strength grade usually needs to be 50MPa plus to meet durability criteria required for such severe exposure environments.

Table 3.2.5-1 Summary of RTA Sorptivity Test Results

Mix No	RTA Sorptivity (mm) – Exposure Classification C	Ratio to Control
Type-GB (25% Fly Ash)		
3F1	18.60	1.00
3F2	16.00	0.86
Type-GB (38% Slag)		
3LS1	9.5	1.00
3LS2	9.5	1.00

Table 3.2.5-2 Durability Requirement for Concrete in RTA-B80

Exposure Classification	Minimum Cement Content (kg/m^3)	Maximum water/cement ratio (by mass)	Maximum Sorptivity Penetration Depth (mm)	
			Portland Cement	Blended Cement
A	320	0.56	35	35
B1	320	0.50	25	25
B2	370	0.46	17	20
C	420	0.40	N/A	8
U	In accordance with Annexure B80/A1			

However, all concrete mixes in this research program satisfied the durability requirement for exposure classification B2 based on the water sorptivity test results. The classification B2 (AS 3600) includes the exposure conditions of permanently immersed in seawater and those in the coastal areas (within 1 km from the coast) except the tidal and splash zones.

3.2.6 Length Change in Sulphate Solution (AS2350.14)

Potential expansion of concrete in sulphate environments was assessed in accordance with AS2350.14 by immersing mortar (sieved out of each concrete) samples in a sulphate solution over 16 weeks. The assessment criterion of the AS 2350.14 test for acceptable sulphate resistance is that the sample expansion should be no more than 900 microstrains after 16 weeks immersion in the sulphate solution. Table 3.2.6-1 summarises the test results of samples of all concretes included in this investigation.

Table 3.2.6-1 Sample Expansions after 16 Weeks in Sulphate Solution

Mix No	Length Change in Sulphate Solution (microstrain)	Ratio to Control
Type-GB (25% Fly Ash)		
3F1	341	1.00
3F2	251	0.74
Type-GB (38% Slag)		
3LS1	441	1.00
3LS2	371	0.84

Fig 3.2.6-1 shows the length change of mortar samples from the 25% fly ash cement concretes. The samples of the Xypex Admix C-5000 modified concrete 3F2 recorded excellent sulphate resistance with the expansion of only 251 microstrains after 16 weeks immersion in sulphate solution. The expansion of the samples of the Xypex Admix C-5000 modified concrete Mix-3F2 was also 26% lower than that of the control concrete Mix-3F1. The outstanding sulphate resistance of Mix-3F2 together with its high early strength characteristic indicated significant benefits of using Xypex admix C-5000 to enhance performance of fly ash concrete.

Fig 3.2.6-2 shows the length changes of mortar samples of two Type-GB slag (38%) cement concretes. The Xypex Admix C-5000 modified concrete Mix-3LS2 recorded expansion up to 16% lower than compared to the control concrete Mix-3LS1.

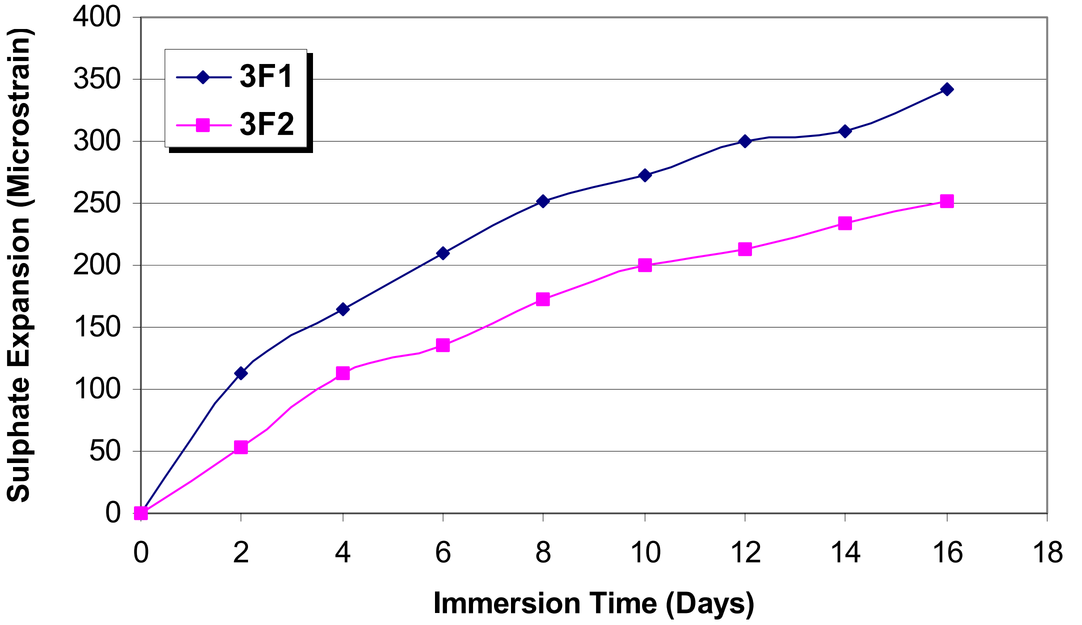

Fig 3.2.6-1 Expansion in Sulphate Solution of Samples of Fly Ash Concretes

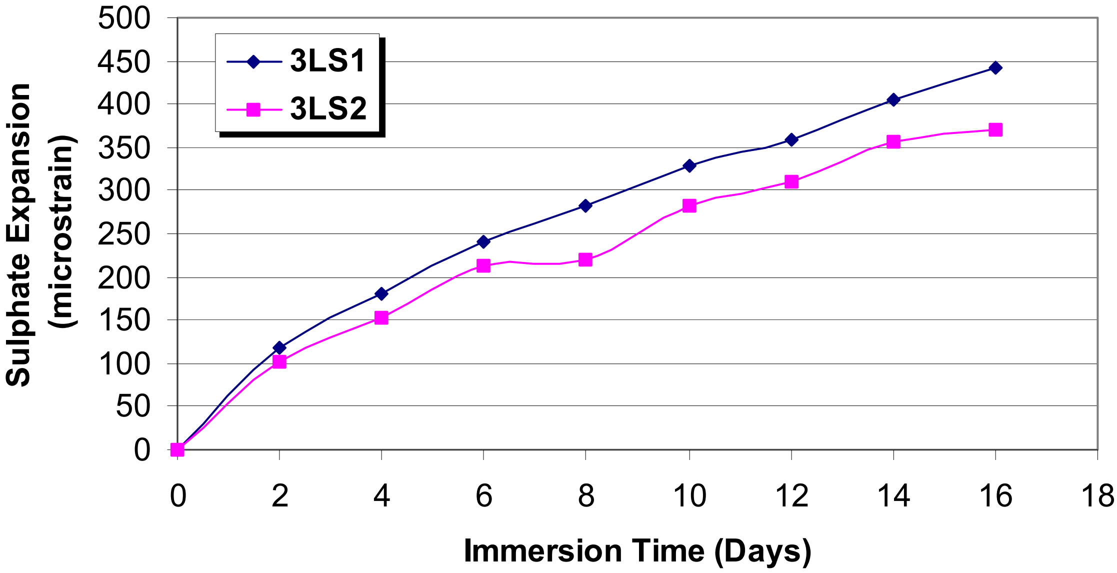

Fig 3.2.6-2 Expansion in Sulphate Solution of Samples of Slag (38%) Concretes

In general, the use of Xypex Admix C-5000 demonstrated significant improvement in sulphate resistance of the concretes using Type-GB fly ash (25%) cement and slag (38%) cement.

3.2.7 Rapid Chloride Ion Penetration (CSIRO Modified ASTM C-1202 Method)

The rapid chloride ion penetration test was undertaken in accordance with the CSIRO modified ASTM-C1202 method. Table 3.2.7-1 summarises the CSIRO modified ASTM C1202 test results which are the differences between two tests: the electrical charge passed in the ASTM-C1202 test and the electrical charge passed in the CSIRO parallel test using saturated limewater.

The highest charge difference of 1799 coulombs was recorded with the samples of the fly ash (25%) control concrete Mix-3F1. The Xypex Admix C-5000 modified fly ash concrete Mix-3F2 recorded a reduction in the charge difference of 12% compared with the control concrete Mix-3F1.

Table 3.2.7-1 Test Results of CSIRO Modified ASTM C1202 Method

Mix No	Electrical Charge			
	ASTM C1202 (Coulomb)	CSIRO-Lime water (Coulomb)	Charge Difference (CSIRO Modified ASTM C1202) (Coulomb)	Ratio to Control Mix
Type-GB (25% Fly Ash)				
3F1	7322	5523	**1799**	**1.00**
3F2	6750	5166	**1584**	**0.88**
Type-GB (38% Slag)				
3LS1	4347	3700	**647**	**1.00**
3LS2	3564	2969	**594**	**0.92**

Of the two Type-GB 38% slag cement concretes, the Xypex Admix C-5000 modified concrete Mix-3SL2 recorded an electrical charge difference of only 594 coulombs, which was 8% lower than that recorded from the control concrete Mix-3LS1.

The following acceptance criteria in Table 3.2.7-2 were proposed by CSIRO for assessment of concrete quality for marine applications based on the CSIRO modified ASTM C1202 test result.

Table 3.2.7-2 Classification Criteria for CSIRO Modified ASTM C1202 Test

Modified Total Charge Passed (Coulomb)	Concrete Quality
> 3000	Poor
2000-3000	Reasonable
1000-2000	Good
500-1000	Very good
< 500	Excellent

According to the criteria, both of the fly ash (25%) concrete Mixes-3F1 and 3F2 fall into the category of "Good" concrete. The two 38% slag concretes Mix-3LS1 and Mix-3LS2 are classified as "Very Good" in terms of their resistance to chloride penetration.

Overall, the Xypex Admix C-5000 modified concrete mixes using the two types of blended cements (25% fly ash and 38% slag) recorded lower charge differences by 8% to 12% compared to the control mixes in the CSIRO modified ASTM C1202 test. The results indicated that these Xypex Admix C-5000 modified 40MPa concretes are suitable for marine applications.

3.2.8 Cyclic Chloride Penetration Test (ACCI Method)

The ACCI cyclic chloride penetration test uses a high chloride concentration (15% NaCl solution) and cyclic wetting-and-drying procedures to accelerate chloride penetration into concrete prisms in a laboratory test period. While the normal test period is 14 days, tests were also conducted over 28 days for all concretes in this investigation.

Table 3.2.8-1 summarises the results of chloride penetration depths after 14 and 28 days cyclic exposure. The chloride penetration depths from the trowel-finished surface and from the moulded surface of prism samples are compared in each of the two types of concretes. The chloride penetration from trowel -finished concrete surface was usually higher than that from moulded surface, because the trowel -finished surface layer was usually more porous due to bleeding.

Table 3.2.8-1 Summary of ACCI Cyclic Chloride Penetration Test Results

Mix No	Finished Surface – Chloride Penetration Depth (mm)				Moulded Surface – Chloride Penetration Depth (mm)			
	14 Cycles	Ratio to Control	28 Cycles	Ratio to Control	14 Cycles	Ratio to Control	28 Cycles	Ratio to Control
Type-GB (25% Fly Ash)								
3F1	10.5	1.00	13.4	1.00	9.2	1.00	12.4	1.00
3F2	5.9	0.56	10.9	0.81	6.0	0.65	9.9	0.80
Type-GB (38% Slag)								
3LS1	13.0	1.00	15.5	1.00	11.0	1.00	15.5	1.00
3LS2	10.9	0.84	13.0	0.84	9.7	0.88	12.7	0.82

Fig 3.2.8-1 shows the results of chloride penetration depths from the moulded concrete surface of all concrete mixes after 14 and 28 cyclic exposures. For the Type-GB 25% fly ash cement concrete, the chloride penetration depth in the Xypex Admix C-5000 modified concrete Mix-3F2 was lower than that in the control concrete Mix-3F1 by up to 44% measured from the trowel-finished surface.

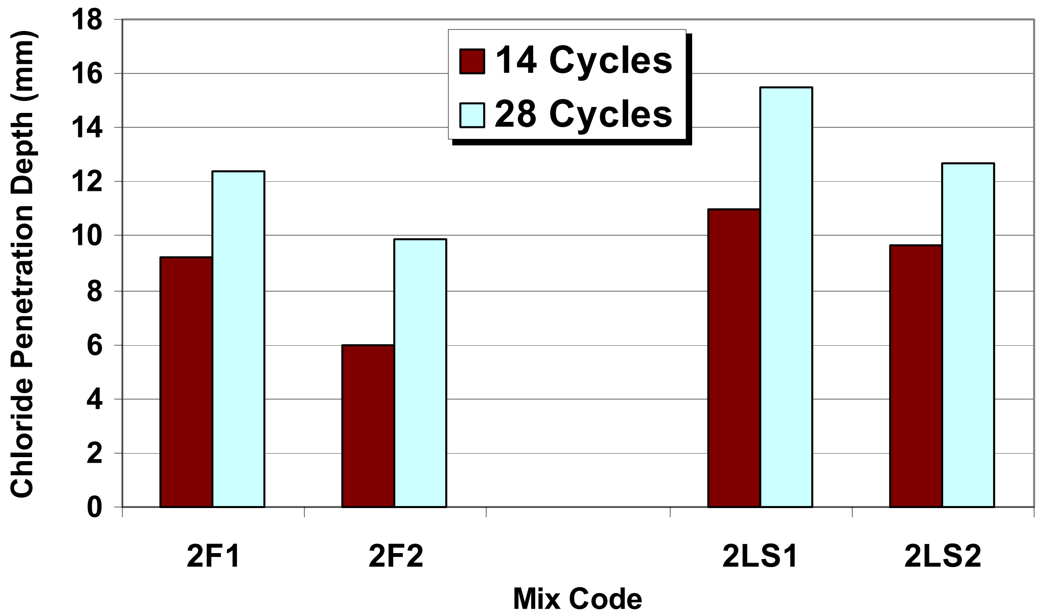

Fig 3.2.8-1 Chloride Penetration Depths after 14 and 28 Days Cyclic Testing

The normal test duration of the ACCI cyclic chloride penetration test is 14 days wetting-and-drying period as described in the "Performance Criteria for Concrete in Marine Environments" (9) published by the Concrete Institute of Australia. Table 3.2.8-2 shows the proposed criteria for assessing chloride penetrability in concrete based on the 14 days ACCI cyclic chloride penetration depth measured from the trowel-finished surface.

Table 3.2.8-2 Criteria for Chloride Penetrability in Concrete

Chloride Penetration Depth (mm)	Chloride Penetrability
> 20	High
15 to 20	Moderate
10 to 15	Low
5 to 10	Very Low
< 5	Negligible

The test results after 14 days cyclic exposure and measured from the trowel-finished surface in Table 3.2.8-1 show that the chloride penetrability in the Xypex Admix C-5000 modified fly ash (25%) concrete Mix-3F2 falls into the "Very Low" category compared to the control concrete 3F1 falling into the "low" category. Both slag (38%) cement concrete mixes had the chloride penetrability in the "Low" category, however, the Xypex Admix C-5000 modified Mix-3LS2 was measured a 16% lower chloride penetration depth than the control Mix-3LS1. The test results indicated good resistance of the Xypex Admix C-5000 modified concretes against chloride penetration under the cyclic wet and dry exposure condition.

3.2.9 Chloride Diffusion by NordTest Method (NT BUILD 443)

The Nordtest NT BUILD 443, 1995 is a standard method of the nodic countries for evaluation of the chloride diffusion coefficient of concrete by accelerated laboratory test. All concrete mixes in this investigation were tested according to the NordTest procedures. Fig 3.2.9-1 to

Fig 3.2.9-2 show the chloride content profiles in the two types of concretes obtained from the NordTest. Lower chloride contents were measured in both types of the Xypex Admix C-5000 modified concretes than in the control concretes at the same depth.

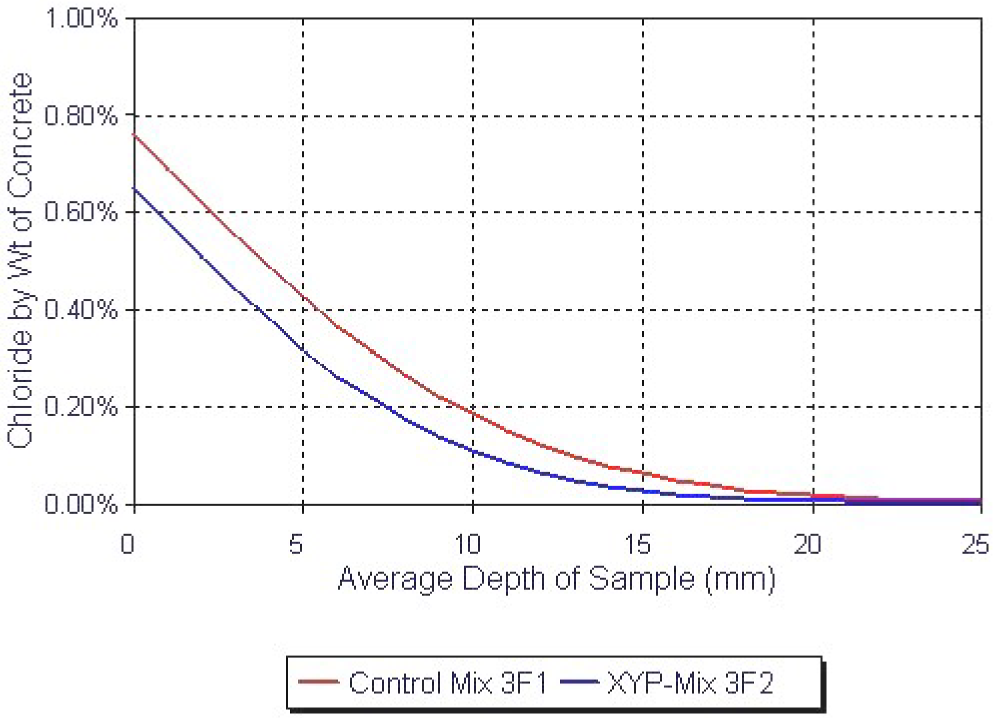

Fig 3.2.9-1 Chloride Diffusion Profiles of Fly Ash (25%) Concretes from NordTest

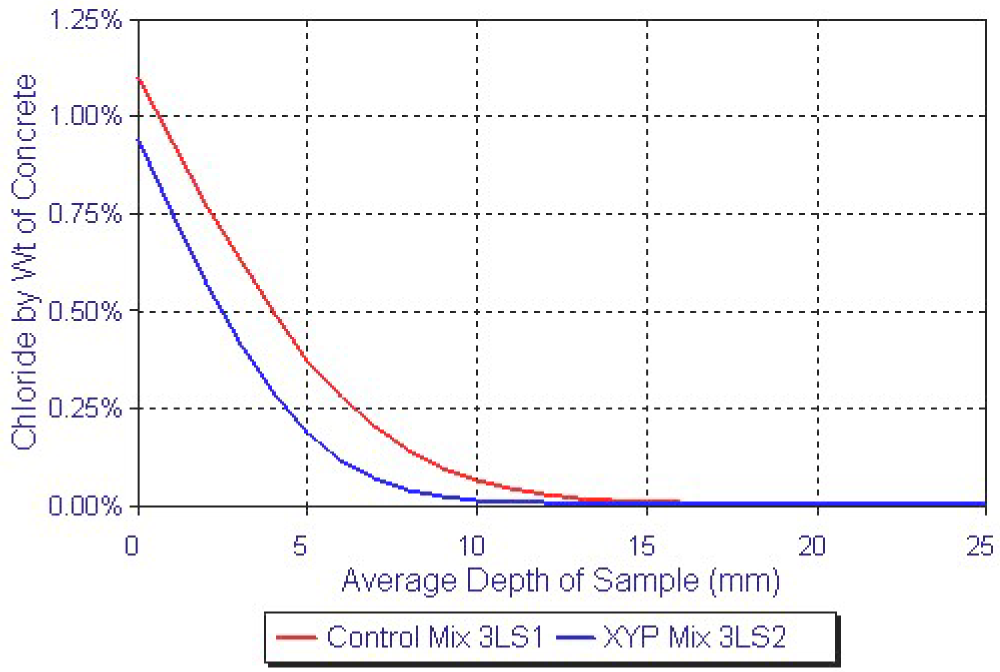

Fig 3.2.9-2 Chloride Diffusion Profiles of Slag (38%) Concretes from NordTest

Table 3.2.9-1 summarises the chloride diffusion coefficients as the results of the NordTest. The chloride diffusion coefficients were calculated according to Fick's second law and based on the chloride content profile in the concrete samples after 35 days immersion in 16.5% sodium chloride solution.

Table 3.2.9-1 Results of Chloride Diffusion Coefficients from NordTest

Mix No	NordTest – Chloride Diffusion Coefficient ($10^{-12}m^2/s$)	Ratio to Control
Type-GB (25% Fly Ash)		
3F1	12.0	1.00
3F2	8.5	0.70
Type-GB (38% Slag)		
3LS1	4.5	1.00
3LS2	2.5	0.55

Significantly lower chloride diffusion coefficients were found with Xypex Admix C-5000 modified concrete made of the two types of blended cements. The Xypex Admix C-5000 modified Type-GB fly ash (25%) cement concrete Mix-3F2 had the chloride diffusion coefficient 30% lower than the control concrete Mix-3F1. The chloride diffusion coefficient of the Xypex Admix C-5000 modified slag (38%) concrete Mix-3LS2 was 45% lower than that of the control concrete Mix-3LS1.

3.2.10 ACCI Chloride Diffusion Test in 3% NaCl Solution

ACCI 3% chloride diffusion test has similar test procedures as the NordTest (NT BUILD 443). However, instead of using 16.5% sodium chloride solution as in NordTest, the ACCI modified Nordtest uses a 3% sodium chloride solution, which is similar to the chloride concentration in natural seawater. The test procedures and sample preparations were the same as in the Nordtest. The duration of immersion of concrete cylinder samples in 3% sodium chloride solution was set at 35 days, 105 days and 365 days respectively. At the end of each immersion period, the concrete samples are analysed for chloride content at the specified depths, the chloride diffusion profiles are plotted and the chloride diffusion coefficients are calculated.

Table 3.2.10-1 summarises the calculated chloride diffusion coefficients of all the concretes after 35 days and 105 days immersion in 3% sodium chloride solution in the ACCI chloride diffusion test. Chloride diffusion coefficients after 365 days immersion are not available at present; these results will be reported after completion of the tests and attached as an appendix to this report. Fig 3.2.10-1 to Fig 3.2.10-2 show the chloride content profiles in the two types of concrete after 105 days of immersion in 3% sodium chloride solution.

Table 3.2.10-1 Chloride Diffusion Coefficients from ACCI 3% Chloride Diffusion Test

Mix No	ACCI 3% Chloride Diffusion Test			
	Chloride Diffusion Coefficient ($10^{-12} m^2/s$)			
	35 days	Ratio to Control	105 days	Ratio to Control
Type-GB (25% Fly Ash)				
3F1	15.0	1.00	4.6	1.00
3F2	10.0	0.60	2.8	0.61
Type-GB (38% Slag)				
3LS1	5.0	1.00	1.6	1.00
3LS2	2.5	0.50	1.0	0.63

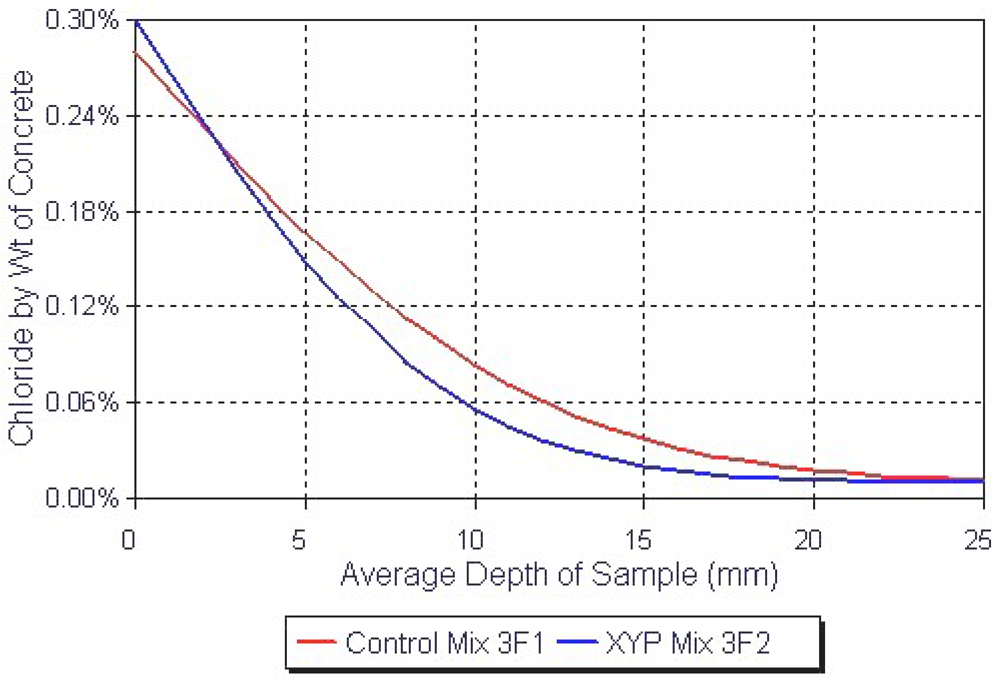

Fig 3.2.10-1 Chloride Diffusion Profiles of Fly Ash (25%) Concretes after 105 days

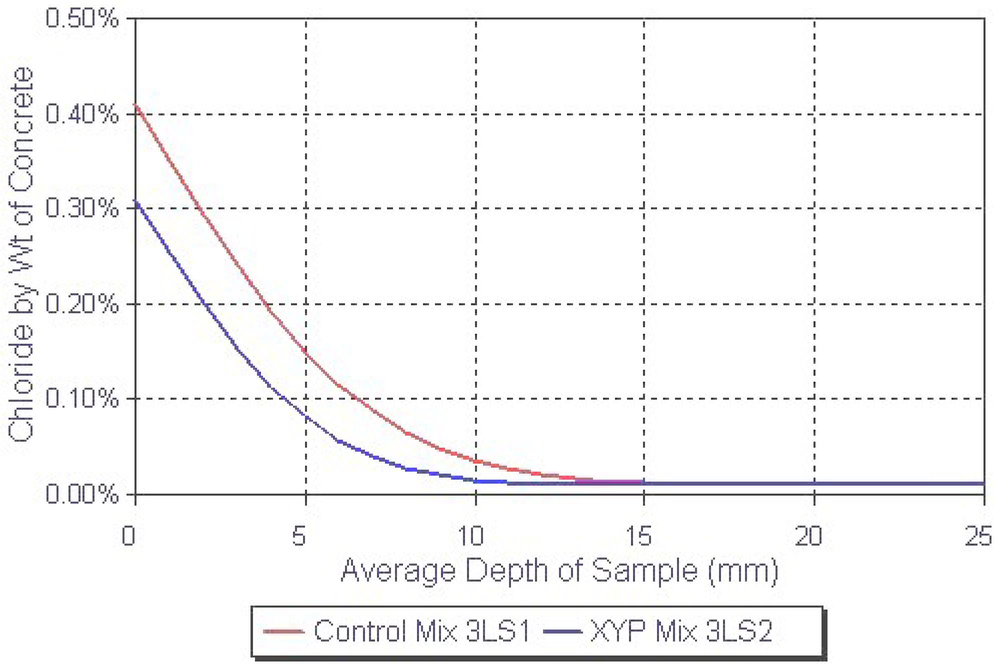

Fig 3.2.10-2 Chloride Diffusion Profiles of Slag (38%) Concretes after 105 days

Generally, significantly lower chloride diffusion coefficients were found for the Xypex Admix C-5000 modified concretes compared to the control concretes using the two types of blended cements. After 35 days immersion, the chloride diffusion coefficients of the Xypex Admix C-5000 modified concretes were 40% to 50% lower than those of the control concretes. After 105 days immersion, the Xypex Admix C-5000 modified concretes had the chloride diffusion coefficients 37% to 39% lower than the control concretes.

3.2.11 Predicted Corrosion Initiation Time based on Chloride Diffusion Coefficient

There are several methods and models proposed in the literature for estimating the service life of concrete structures exposed in marine environments (11,12,13,14). In general, the time to corrosion initiation of steel reinforcement in concrete is affected by several factors including:

1) Concrete cover depth;
2) Chloride diffusion coefficient of concrete;
3) Threshold chloride concentration at reinforcement level;
4) Exposure environments

In the real world chloride diffusion rate in concrete of marine structures is a time-dependent process of a number of variables. A model for estimation of the time-dependent chloride diffusion process was developed by Toronto University (12,14) and a computer software "LIFE 365" was written by Evan Bentz and Michael Thomas (12,13) based on the Toronto model. This software LIFE 365 was used for estimation of the corrosion initiation time of the concrete mixes in this investigation. The predictions are based on the following assumptions and formulas:

i. One dimensional chloride diffusion
ii. Structure overall thickness: 450mm
iii. Clear concrete cover depth: 45mm
iv. Water to cement ratio (W/C): 0.40
v. The influences of Class-F fly ash of 25%, or GGBF slag content of 38% in the total cement are considered according to an American database of site investigation results
vi. Exposure condition: Marine spray or coastal zone
vii. Surface chloride concentration is assumed to be 2% by weight of concrete
viii. Concrete age at first exposure to the marine environment: 28 days
ix. Chloride threshold value at reinforcement level to cause corrosion initiation: 0.03% by weight of concrete
x. Chloride Diffusion Coefficients: the ACCI chloride diffusion test results (as shown in the Table 3.2.10-1) in 3% NaCl solution over 105 days are used in the analyses.
xi. Basic parameters such as the rebar type and its percentage, exposure temperature and so on are set as the default values.
xii. Chloride ion penetration into concrete is assumed to follow the Fick's second law of diffusion:

$$\frac{(C_{cr} - C_0)}{(C_s - C_0)} = erfc\left(\frac{x}{2\sqrt{Dt}}\right) \quad \text{..........................(1)}$$

where **C_{cr}** = Chloride threshold
(assumed to be **0.03%** by weight of concrete)
C_0 = Background chloride ion concentration inside concrete
(assumed to be **0.005%** by weight of concrete)
C_s = Concrete surface chloride concentration

(assumed to be a constant **2%** by weight of concrete)

Erf = error function

x = concrete cover depth (mm)

D = chloride ion diffusion coefficient (m^2/s)

t = time of exposure (second)

xiii. The corrosion initiation time, T_{corr}, is the time elapsed when the calculated chloride concentration at the reinforcement level equals to the threshold value C_{cr}. T_{corr} is then calculated by Equation (2), which is based on Equation (1) but uses a time-dependent diffusion coefficient D_t rather than a constant diffusion coefficient D:

$$T_{Corr} = \frac{x^2}{4D_t}\left[erfc^{-1}\left(\frac{C_{cr} - C_0}{C_S - C_0}\right)\right]^{-2} \quad \text{..............................(2)}$$

Where:

The time-dependent reduction of diffusion coefficient D_t and is calculated with Equation (3)

$$D_t = D_{ave} \times \left(\frac{t_{ave}}{t}\right)^m \quad \text{...(3)}$$

where **D_t** = Diffusion coefficient at time t

D_{ave} = diffusion coefficient at time t_{ave}

t_{ave} = Concrete age to obtain D_{ave}

m = time-dependant parameter

The current Australian Standard AS 3600 requires a minimum concrete strength of 40 MPa and minimum cover depth of 45mm for concrete under the exposure classification B2, which includes permanent immersion in seawater and coastal areas up to 1 km from coastline but excluding tidal and splash zone (classification C). The analyses using LIFE365 for corrosion initiation time simulated the performance of the concretes of this investigation under the exposure environments of the classification B2 of AS 3600.

Table 3.2.11-1 and Fig 3.2.11-1 and Fig 3.2.11-2 present the results of analyses using the software LIFE 365 on prediction of corrosion initiation time for all the four concrete mixes in this research. It should be pointed out that the absolute corrosion initiation time values in Table 3.2.11-1 might be very different if a database of the long term performance of Australian concretes are available for the analyses. For example, it appears that Australian 25% flyash concrete with w/c ratio of 0.4 should have much longer corrosion initiation time that that of only 11 years based on local materials and practice in Australia. For this reason, the comparison of relative performances between concrete mixes of the same type, but with and without Xypex Admix C-5000, makes more sense because they were analysed on the basis of the same model.

Table 3.2.11-1 Predicted Time of Corrosion Initiation due to Chloride Diffusion

Concrete Mix	3F1	3F2	3LS1	3LS2
Corrosion Initiation Time (Year)	8.9	15.5	33.3	55.8
Ratio to Control	1.00	1.74	1.00	1.68

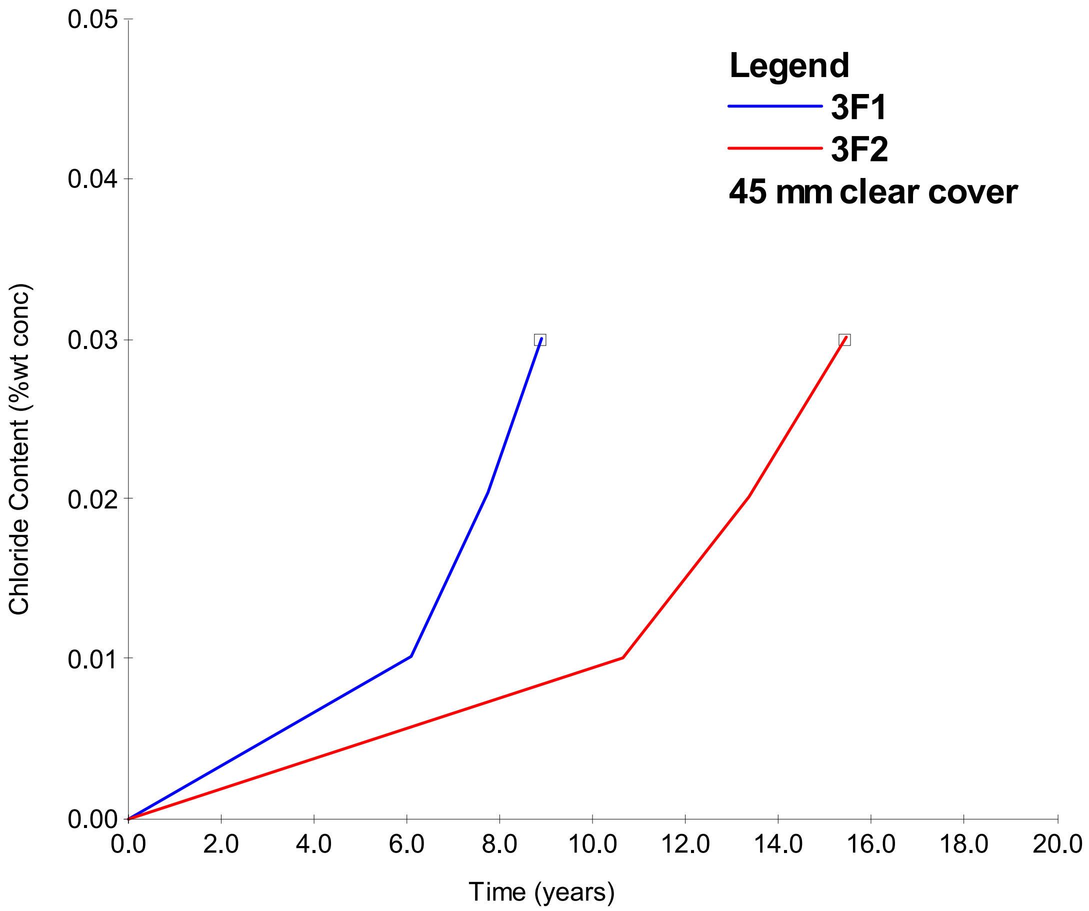

Fig 3.2.11- 1 Predicted Corrosion Initiation Time for Fly Ash (25%) Concretes

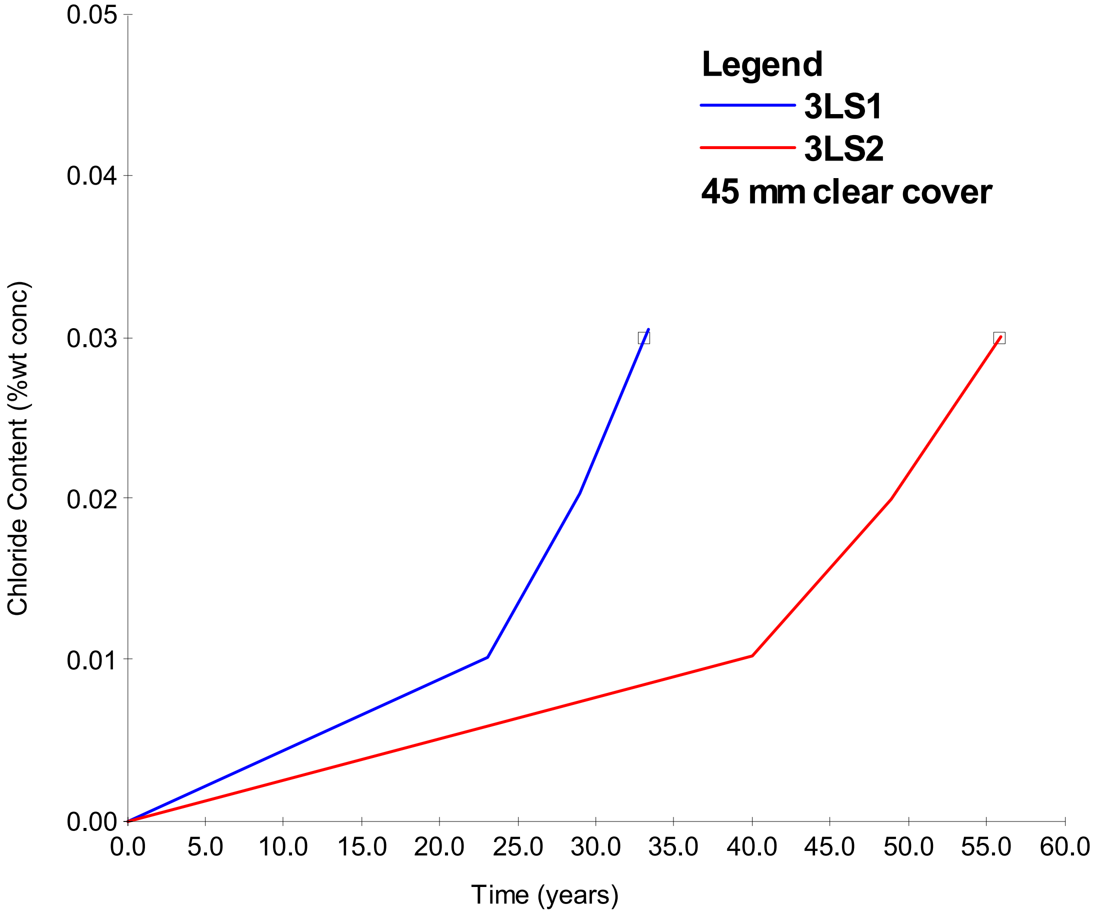

Fig 3.2.11- 2 Predicted Corrosion Initiation Time for Low Slag (38%) Concretes

As shown in Table 3.2.11-1, significant increase in the corrosion initiation time and the service life can be achieved by using Xypex Admix C-5000 in concretes exposed to environments of classification B2 of AS 3600. The corrosion initiation time in the Xypex Admix C-5000 modified concrete Mix-3F2 and Mix-3LS2 is 1.68 to 1.74 times those of the control concretes. The results demonstrated the benefits of using Xypex Admix C-5000 in concrete to prolong service life of concrete structures in costal areas.

4. SUMMARY AND CONCLUSIONS

Four commercial 40MPa concretes were investigated in this project to evaluate the performance of two types of concrete modified with the permeability reducing admixture Xypex Admix C-5000. Two Type GB cements, a fly ash (25%) blended cement and a slag (38%) blended cement, were used in the two types of concrete. For each type of concrete, two concrete mixes were investigated including a control mix and a mix dosed with 0.5% of Xypex Admix C-5000 by weight of the total cement. A broad range of plastic and hardened concrete properties were tested and comparisons were made between the properties of the control concretes and the Xypex Admix C-5000 modified concretes.

The plastic properties of Xypex Admix C-5000 modified concretes were generally similar to those of respective control concretes. One variant property identified was that when Xypex Admix C-5000 was used together with Pozz370 water reducing admixture concrete setting time was slightly retarded.

The major test results and conclusions for hardened state properties are summarised as follows:

1. For Type GB (25% fly ash) cement concrete, moderate to significant improvements in the strength and durability performance were achieved by using 0.5% of Xypex Admix C-5000 in concrete. The major improvements in relation to the control mix included:

- Early age strength at 3 days Increased by 19%;
- Drying shrinkage reduced by 7%;
- Sulphate expansion reduced by 26%;
- Significantly lower chloride penetration or diffusion in four recognised test methods
    - Up to 12% reduction in CSIRO modified ASTM C1202 test;
    - Up to 44% reduction in ACCI cyclic (wet-and-dry) chloride penetration test;
    - 30% lower in chloride diffusion coefficient in NordTest and
    - Up to 40% lower in chloride diffusion coefficient in ACCI chloride diffusion test.
- Lower water absorption and AVPV by up to 10%;
- Significantly lower water sorptivity (RTA-T362) by up to 14%;
- Significantly lower water permeability coefficient by 39% under 100m water head.

The overall performance of Xypex Admix C-5000 modified Type-GB fly ash (25%) cement concrete mix is significantly better than the control concrete.

2. For Type-GB 38% slag cement concrete, the Xypex Admix C-5000 modified mix also achieved moderate to significant improvements in the early strength and the durability performance compared to the control mix. These major improvements include:

- Early strength at 3 days Increased by 12%
- Drying shrinkage reduced by up to 12%;
- Sulphate expansion reduced by up to 16%;
- Significantly lower chloride penetration or diffusion in four recognised test method
    - Up to 8% reduction in CSIRO modified ASTM C1202 test;
    - Up to 18% reduction in ACCI cyclic (wet-and-dry) chloride penetration test;
    - 45% lower in chloride diffusion coefficient in NordTest and
    - Up to 50% lower in chloride diffusion coefficient in ACCI chloride diffusion test.
- Lower water absorption and AVPV by up to 16%;
- Significantly lower water permeability coefficient by 81% under 100m water head;

The overall performance of Xypex Admix modified Type-GB slag (38%) cement concrete mix is significantly better than the control concrete.

Overall, the two types of concrete modified with Xypex Admix C-5000 were found to have greatly improved properties compared to control concretes. Whilst drying shrinkage and sulphate expansion were reduced, the resistance against chloride penetration and diffusion was significantly enhanced in both Xypex Admix C-5000 modified concretes. The results of this investigation indicated the benefits of using this Xypex Admix for improving concrete durability performance in aggressive environments.

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6. APPENDICES