XYPEX AUSTRALIA

CHLORIDE PENETRATION TESTS ON XYPEX ADMIX C-1000NF MODIFIED COMMERCIAL CONCRETES

AUSINDUSTRY START RESEARCH PROJECT

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1. <u>INTRODUCTION</u>

A substantial research program was undertaken at the The Australian Centre for Construction Innovation of the University of New South Wales with financial support from AUSINDUSTRY under a START Graduate Research Grant. The primary aim of this research was to determine the benefits resulting from the use of Xypex Admix C-1000NF as an integral component of concrete required to demonstrate superior durability in aggressive environments. This program used commercial concretes which contained conventional water reducing admixture, different supplementary cementitious materials and Xypex Admix C-1000NF at various dose rates,

This report outlines test results obtained for **<u>chloride resistance</u>** using test methods **<u>ASTM C1202 (modified)</u>**, and **<u>NT BUILD 443</u>**. Assessment of these test results indicates that, whilst concrete performance was influenced by cement type, Xypex Admix C-1000NF can also significantly improve the durability of concrete in aggressive environments.

2. <u>MATERIALS AND TESTING METHODS</u>

To minimise the difference in performance between “lab concrete” and “site concrete”, and to ensure relevance for construction applications, commercial concrete batches were used in this research. One of three types of cement was used in each concrete mixes, i.e. AS3972 Type-GP (SL) Portland cement only, or AS3972 Type-GB fly ash blend with 20% fine fly ash (Type F) or AS3972 Type-GB slag blend with about 38% slag.

All concrete batches were supplied by a ready-mix plant based on 32 MPa grade commercial concrete mixes. AS1478.1 Type-WR admixture was added as required to achieve a target slump of 80mm. Xypex Admix C-1000NF was dosed at 0.8% or 1.2% in accordance with manufacturer’s directions. Description of selected test methods for chloride resistance is shown in the Table 2-A.

Table 2-A Description of Chloride Resistance Test Methods

Test Method	Source	Objectives
Rapid Chloride Ion Test	CSIRO Modified ASTM C1202 (1)	Electrical indication of concrete’s ability to resist chloride ion penetration
NordTest	NT BUILD 443, 1995 (2)	Determination of chloride penetration depth and chloride diffusion coefficients of concrete after immersed in 16.5% sodium chloride solution for 35 days

3. TEST RESULTS AND DISCUSSIONS

Test results are summarised and shown in Table 3-A.

Table 3-A Summary of Test Results

Mix Code	W/C Ratio	Cement Type and Content (kg)	Xypex Admix C-1000NF (% of Cement Content)	Compressive Strength		CSIRO Modified ASTM C1202	NT BUILD 443 (Chloride Penetration Depth)
				3 days	28 days		
GPC	0.55	GP (330)	Nil	24.1	43.8	Control	Control
GPX1	0.55	GP (330)	0.8%	26.1	46.0	- 7%	- 10%
GPX2	0.55	GP (330)	1.2%	27.2	46.8	-16%	- 32%
FAC	0.50	20% Fly Ash (360)	Nil	25.4	42.0	Control	Control
FAX1	0.50	20% Fly Ash (360)	0.8%	25.4	44.6	- 27%	- 38%
FAX2	0.50	20% Fly Ash (360)	1.2%	26.1	44.9	- 41%	-
FAX3	0.48	40% Fly Ash (380)	0.8%	21.1	39.3	-	-
SC	0.55	38% Slag (330)	Nil	17.4	40.2	-	Control
SX1	0.55	38% Slag (330)	0.8%	17.8	42.7	-	- 3%

3.1 Rapid Chloride Ion Test (CSIRO Modified ASTM C1202)

Fig 3.1-A shows the total charge difference in CSIRO modified CSIRO ASTM C1202 test of the concrete mixes. Reductions in total charge difference were found with the Xypex Admix C-1000NF modified Type-GP cement concretes (Mix-GPX1 & Mix-GPX2) compared with control Mix-GPC. At dosage rate of 0.8% Xypex Admix C-1000NF by weight of cement, Mix-GPX1 recorded an average of 7% lower charge difference than control concrete. At a higher dosage rate of 1.2% Xypex Admix C-1000NF Mix-GPX2 recorded 16% lower charge difference than the control.

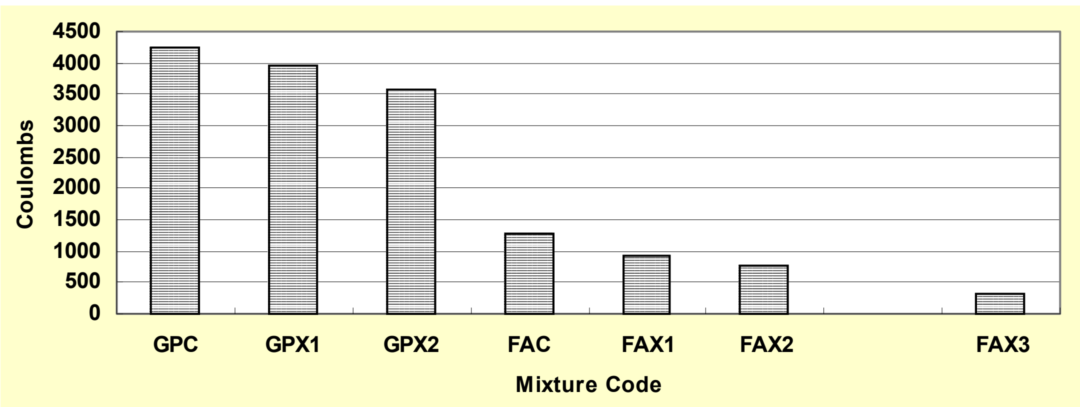


Fig 3.1-A Total Charge Difference in CSIRO Modified ASTM C1202 Test

Xypex Admix modified fly ash concretes (Mix-FAX1 & Mix-FAX2) showed further reduction in coulomb values by 27% and 41% compared with the already low charge of the control Mix-FAC. Mix-FAX3 40% fly ash (Type F), with addition of 0.8% Xypex Admix C-1000NF is the most recent update from the project extension and It has shown significant lower in overall coulomb values to below 500 coulombs. Based on the CSIRO modified ASTM C1202 test, a proposed classification of concrete quality is shown in Table 3.1-A.

Table 3.1-A CSIRO Modified ASTM-C1202 Concrete Classification

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

Blended cements are dominantly used for marine structures in contemporary concrete applications, since Type-GP cement concretes are usually not considered to have sufficient resistance to sulphate attack and chloride penetration. It is then not surprising that most of the Type-GP concrete mixes tested in this program would be classified as “Poor” with the total charge exceeding 3000 coulombs in the CSIRO modified ASTM C1202 test. Whilst the control fly ash concrete Mix-FAC would be classified as “Good”, the Xypex Admix modified concretes (Mix-FAX1 & Mix-FAX2) would be classified as “Very Good” in terms of resistance to chloride penetration. In addition to that, Mix-FAX3 would be classified as “Excellent”.

Results obtained from the modified test have demonstrated that Xypex Admix has substantial ability to reduce chloride ion penetration. Overall, test results indicated excellent performance for grade 32 concrete.

3.2 CHLORIDE PENETRATION BY NORDTEST METHOD

Fig 3.2-A shows chloride penetration depth of concretes in the test. For each of the three types of concrete, Xypex Admix modified mixes had lower chloride penetration depth than the respective control concrete. For Type-GP cement concrete, chloride penetration depths in Xypex Admix modified Mix-GPX1 and Mix-GPX2 were 10% and 32% lower than that in control Mix-GPC. Chloride penetration depth in Xypex Admix modified fly ash concrete Mix-FAX1 was significantly lower (by 38%) than that in control Mix-FAC. Xypex Admix modified slag concrete Mix-SX1 had a marginally lower chloride penetration than control Mix-SC.

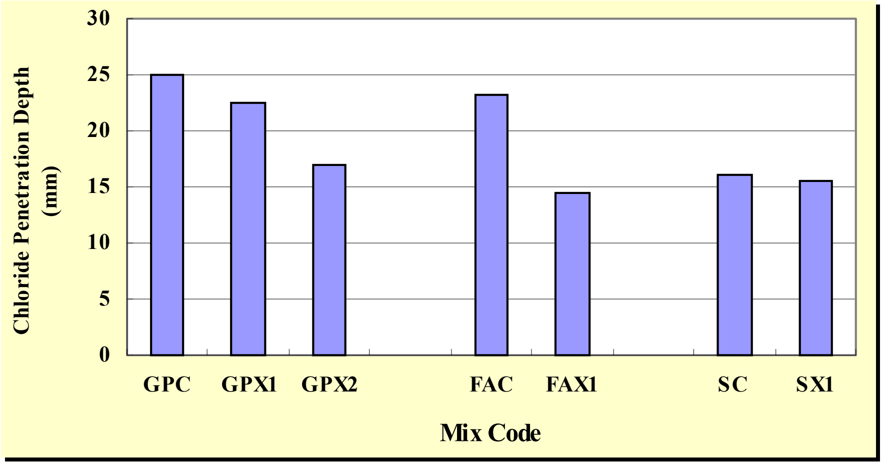
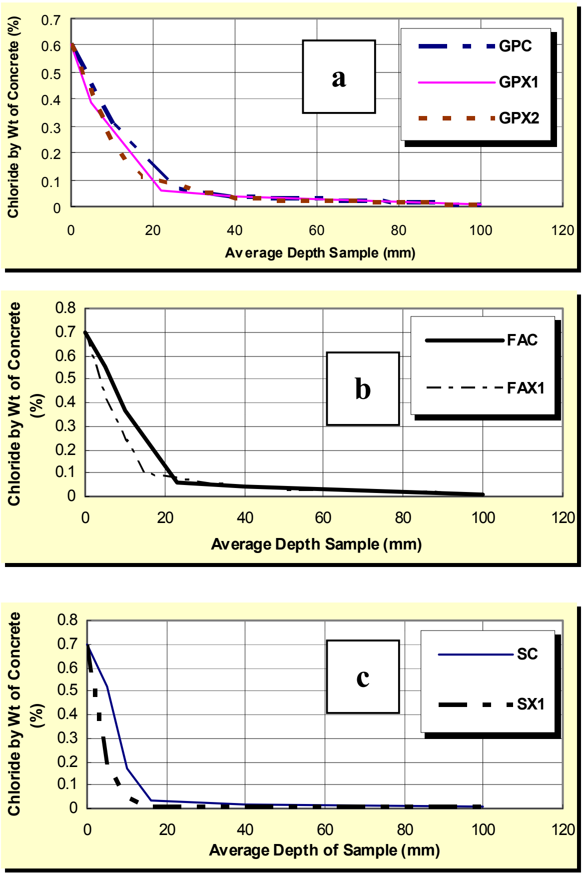


Fig 3.2-A Chloride Penetration Depth in NordTest after 35 Days Immersion

In Fig 3.2-B (d), the chloride ion diffusion coefficients were calculated according to Fick's second law and based on the chloride content profile in the concrete samples, Fig 3.2-B (a), (b) & (c).



d	Chloride Ion Diffusion Coefficient ($10^{-12} m^2/s$)
GPC	35
GPX1	25
GPX2	24
FAC	30
FAX1	15
SC	12
SX1	4

Fig. 3.2-B a), b) and c) Chloride Penetration Profiles in Nordtest; d) Chloride Ion Diffusion Coefficients for All Mixes

The chloride ion diffusion coefficients showed similar trends as the chloride profiles. For the Type-GP cement concretes, Xypex Admix modified, Mix-GPX1 & Mix-GPX2, each had 30% lower in chloride ion diffusion coefficient than the control Mix-GPC. The fly ash concrete Mix-FAX1 had 50% lower in diffusion coefficient than its control Mix-FAC, while slag concrete Mix-SX1 had 67% lower in diffusion coefficient than its control Mix-SC.

3.2.1 SERVICE LIFE ESTIMATION **

There are some methods and models proposed in literature (3,4) for making estimations of the service life of concrete structures exposed in marine environments. In general, the time to initiation of corrosion of reinforcement steel in concrete is affected by some major parameters:

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

Where a concrete structure is placed in a marine environment, the chloride ion diffusion coefficient is a time-dependent variable as is the concrete surface chloride ion concentration. To simplify these analyses, the concrete surface chloride ion concentration is normally assumed to be a constant. A model for estimation of time-dependent chloride diffusion coefficients was proposed by Toronto University (4). The following is an example using a mathematical model** to estimate the time elapsed before initiation of reinforcement corrosion based on chloride diffusion coefficients of the Type-GB (38% slag) concrete Mix-SC (Fig 3.2.1-A) and Mix-SX1 (Fig 3.2.1-B) in this research program.

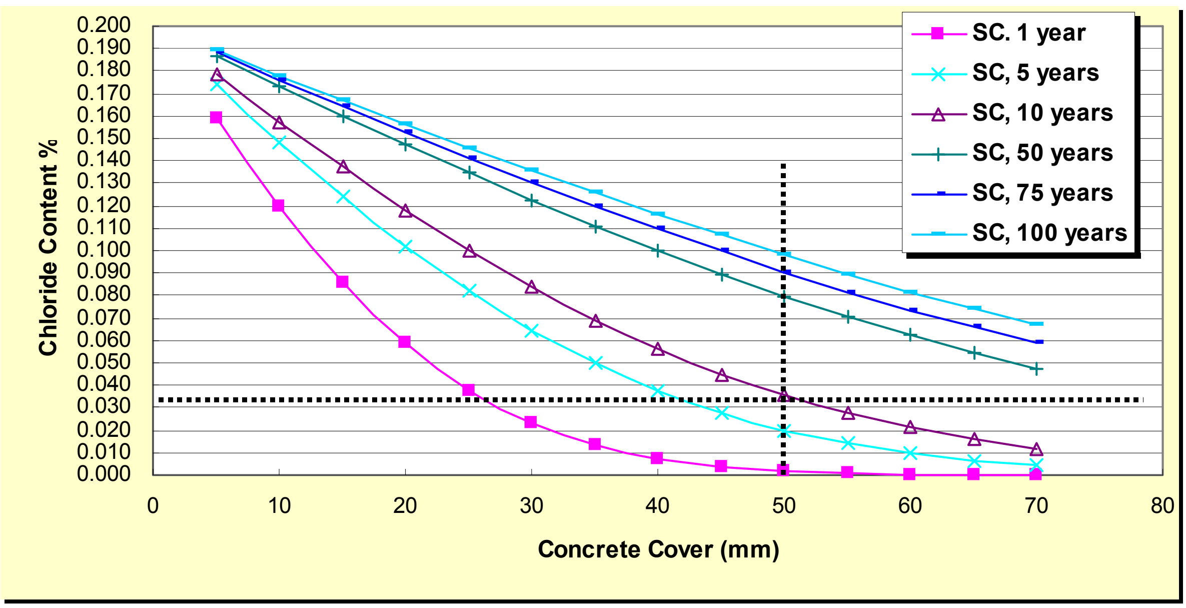


Fig 3.2.1-A Chloride Content vs. Cover Depth Model in Control Mix-SC

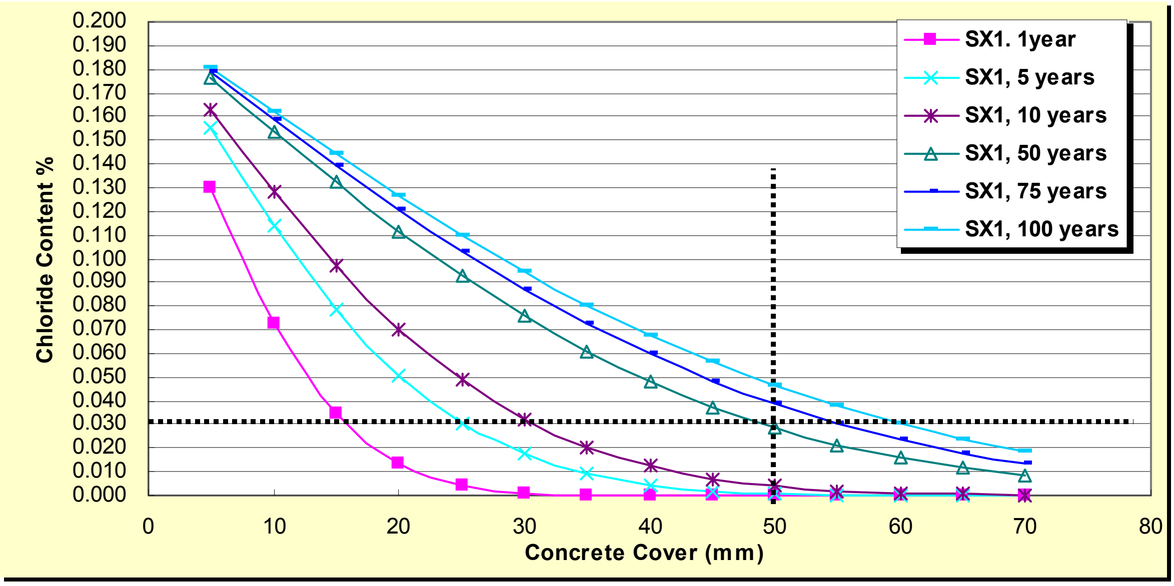


Fig 3.1.2- B Chloride Content vs. Cover Depth Model in Xypex Modified Concrete Mix-SX1

If the concrete cover is assumed to be 50mm in depth and the critical chloride threshold is taken as 0.033% by weight of concrete as limited by AS 1379, the time to initiation of corrosion of reinforcement steel in the control concrete Mix-SC would be estimated to be around 10 years (see Fig 3.1.2-A) when the chloride content in this concrete reaches the critical threshold at the reinforcement level. However, under the same assumptions as shown in Fig 3.1.2-B, the time for initiation of corrosion of reinforcement steel in the Xypex Admix modified concrete Mix-SX1 would be estimated to be more than 50 years. The model analysis demonstrates the impact of using Xypex Admix on the service life of concrete structures exposed in aggressive chloride environments.

Disclaimer (**): Service life estimations and references in this section are only intended for comparison between control concrete and Xypex Admix modified concrete in this research project. Performance data included in the figures are derived from both publications in concrete literature and research test results. Certain major criteria and boundary conditions were set prior to the estimations. Readers are urged to read the publications and seek further details on this research project to understand the limitations on using this service life estimation.

4. CONCLUSION

This report outlines test results obtained for chloride resistance using test methods ASTM C1202 (modified) and NT BUILD 443. Xypex Admix C-1000NF with two dosage rates, 0.8% and 1.2%, were used with three types of cement in commercial concretes with nominal strength of 32MPa.

Overall from the test results, concretes with the addition of Xypex Admix C-1000NF have demonstrated excellent performance by showing significant resistance to chloride penetration on the following tests:

1) Significant reduction in coulomb values in the CSIRO modified ASTM C1202 by up to 41% compared to control mix;
2) Significant reduction in chloride ion penetration depth in the NordTest by up to 38% compared to control mix;
3) Significant reduction in Chloride diffusion rates in the NordTest by up to 67% compared to control mix;
4) When the model of service life estimation (Section 3.2.1) is applied to Xypex modified concrete Mix-SX1 (32 MPa) the initiation to corrosion of reinforcement steel is fifty (50) years (Fig 3.1.2-B) compared to ten (10) years (Fig 3.1.2-A) for the control Mix-SC which demonstrates the superior performance of the Xypex Admix modified concrete exposed to aggressive chloride environments.

5. REFERENCE

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