Ash Development Association

FLY ASH CONCRETE IN MARINE ENVIRONMENTS

FROM CSIRO RESEARCH REPORT BRE NO. 062

FLY ASH REFERENCE DATA SHEET

NO. 6. 2000

1. INTRODUCTION

In marine environments, disintegration of concrete and corrosion of steel are the two main forms of deterioration. Although, corrosion of steel reinforcement has been acknowledged as the principal cause of deterioration of marine concrete structures, disintegration of concrete usually accelerate the process of steel corrosion.

1.1 DISINTEGRATION OF CONCRETE

Disintegration of concretes in marine environments is mostly caused by chemical deterioration such as sulfate attack, magnesium attack and leaching. Physical deterioration from crystallisation of soluble hydrated salts in pores of the concrete, erosion and abrasion promotes further disintegration.

The overall results of these attacks on concrete are softening, cracking and partial removal of cover concrete. This in turn exposes a fresh surface for further attack.

1.2 CORROSION OF STEEL REINFORCEMENT

The ingress of chlorides from seawater into concrete will eventually lead to corrosion of steel reinforcement.

1.3 DURABLE CONCRETE IN MARINE ENVIRONMENTS

Preventive measures, which can be adopted to obtain durable reinforced concrete in a marine environment, can be summarised as follow:

Selection of concrete raw materials suitable for resisting marine attack. Mix design to minimise water and air voids. Provision of adequate cover over reinforcement. Structural design and detailing to avoid cracking, congestion of reinforcement, sharp corners, and moisture collection. Construction techniques which ensure proper mixing and placing, thorough compaction of concrete; free from defects with a minimum of joints. Quality control is an important aspect of producing durable concrete structures.

Dam Wall

2. CHLORIDE ATTACK ON CONCRETE CONTAINING PORTLAND CEMENT AND FLY ASH

Chloride attack on concrete differs from the other modes of environmental attack. It is the chloride-induced corrosion of steel reinforcement that causes damage to the concrete. The presence of chloride ions in the pore solution of concrete by itself does not lead to damage[1]. The extent of chloride attack on reinforced concrete is therefore dependent on the rate of chloride penetration and the corrosion rate of steel reinforcement. Comparing cementitious materials in terms of resistance to chloride attack involves evaluating these two factors. Although both factors affect service life, resistance to chloride ion penetration is often considered the most significant property for reinforced concrete in structures in a marine environment.

2.1 RESISTANCE TO CHLORIDE ION PENETRATION INTO CONCRETE

Fly ash concretes have been known to have higher resistance to chloride ion penetration than portland cement concretes [2,3,4]. This beneficial characteristic of concrete containing fly ash is influenced by the source of the fly ash, its rate of addition and the portland cement type. The pore refinement effect of fly ash in concrete[5,6,7] is the main contributor to this characteristic. The better chloride binding capacity of fly ash blended cement may also contribute [8,9].

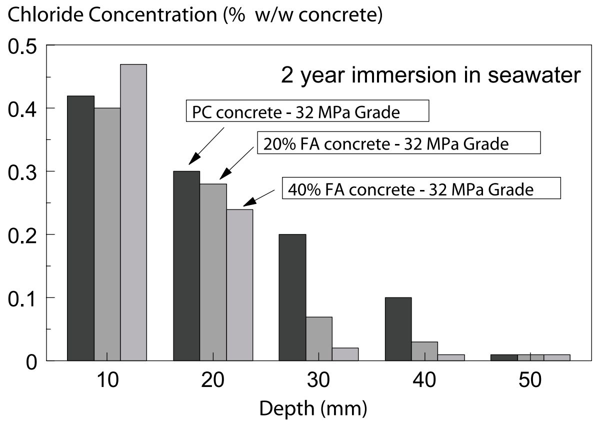

Figure 1: Chloride penetration into equivalent 32 MPa concretes made with and without Australian fly ash.

Overseas[10] and locally generated data confirm this fact.

When equivalent concretes (similar slump, 28 day strength and 7 day initial curing) are immersed in seawater, the resistance to chloride penetration of fly ash concrete is much better than that of portland cement concrete as shown in Figure 1.

In a corroding situation, while everything else is similar, the corrosion rate of steel will be less in concrete having high resistivity and resistance to ionic movement. Concretes containing fly ash are known to have higher resistivity and higher resistance to ionic movement than equivalent portland cement concretes[11,12]. Figure 2 demonstrates this beneficial effect of fly ash. In conjunction with the higher resistance to chloride ion penetration, the corrosion rate of steel at a given level of chloride contamination is likely to be less in fly ash concrete in comparison with portland cement concrete. The service life of fly ash concrete is likely to be longer than that of equivalent portland cement concrete in marine environment.

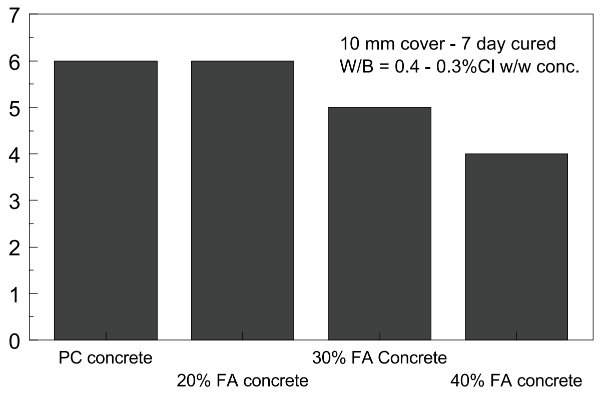

Figure 2: Corrosion rate of steel in concretes with and without fly ash at similiar chloride contamination at the steel surface.

3. SEAWATER ATTACK ON PORTLAND CEMENT AND FLY ASH BLENDED CEMENT CONCRETE

Studies on mortar bars in isolated aggressive environments such as sodium sulfate and sodium/magnesium sulfate solutions show that fly ash blended cement will perform equal to or better than portland cements (Figure 3).

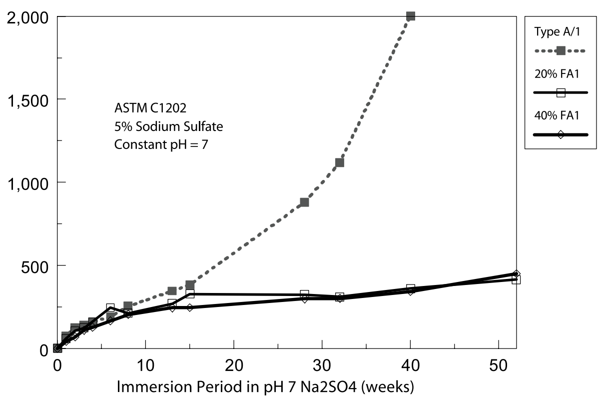

Figure 3: Expansion of mortar bars made with and without fly ash in pH 7 Na2SO4 solution.

GRADE 32 CONCRETE

Immersion Period (y)	40	60	80	100
Binder Type	Diffusion Coefficient (10^{-12} m^2/s)			
GP	2.10	1.70	1.50	1.40
20% FA	0.65	0.55	0.45	0.40
30% FA	0.51	0.40	0.35	0.30

GRADE 40 CONCRETE

Immersion Period (y)	40	60	80	100
Binder Type	Diffusion Coefficient (10^{-12} m^2/s)			
GP	1.00	0.80	0.70	0.60
20% FA	0.60	0.45	0.40	0.36
30% FA	0.40	0.35	0.32	0.29

GRADE 50 CONCRETE

Immersion Period (y)	40	60	80	100
Binder Type	Diffusion Coefficient (10^{-12} m^2/s)			
GP	0.65	0.50	0.46	0.40
20% FA	0.45	0.35	0.32	0.30
30% FA	0.40	0.32	0.27	0.25

GRADE 60 CONCRETE

Immersion Period (y)	40	60	80	100
Binder Type	Diffusion Coefficient (10^{-12} m^2/s)			
GP	0.45	0.40	0.33	0.30
20% FA	0.35	0.31	0.27	0.25
30% FA	0.35	0.29	0.25	0.23

Table 1: Estimated Values of *D* at different times for concretes made with portland cement and fly ash blended cements – 7 day wet cured – fully immersed condition (B2 exposure)

The results shown in Table 1 denote the following trends:

- D reduce with higher grade concrete as expected;
- D is lower with fly ash concretes;
- The difference between fly ash concrete and portland cement concrete is more apparent with lower grade concrete.

The overall consequence of these results is that for a given grade, fly ash concrete will provide higher resistance to chloride penetration and hence longer service life.

3.1 AS 3600 AND FLY ASH BLENDED CEMENT CONCRETES

For concrete subject to a marine environment, AS 3600 provides the following requirements for design life of 40 to 60 years (Table 4.10.3.4 – AS 3600 – 1994 – p.32).

Exposure Class	Required Cover, mm*		
	Characteristics Strength (fc)		
	32 MPa	40 MPa	50 MPa
B2	(65)	45	(35)
C	–	(70)	50

Table 2: AS 3600 requirements for exposure classification B2 (submerged zone) and C (splash zone)

*AS 3600 makes special provision (5 to10 mm reduced cover) where rigid formwork and intense compaction are used.

When the procedures for estimating service life given previously are applied to fly ash concrete and portland cement concrete requiring a design life of 40 years, the required covers are given in Table 3.

Exposure Class B2 Charac. Strength (fc), MPa	Required Cover, mm*, for 40 year design life			
	32	40	50	60
Cement	100	70	50	40
20% Fly Ash	60	55	45	35
30% Fly Ash	50	45	40	35

Table 3: Required covers estimated for 40 year design life

Exposure Class C	Required Cover, mm*, for 40 year design life Characteristic Strength (fc)			
	32MPa	40MPa	50MPa	60MPa
Cement	(>100)	(>100)	60	60
20% Fly Ash	95	90	70	55
30% Fly Ash	85	70	65	55

Comparing these results and those provided by AS 3600, it can be seen that:

- AS 3600 requirements are quite reasonable. However, they appear to be applicable only for fly ash blended cement concrete (and blended cement in general).
- AS 3600 requirements, at best, would provide a design life at the lower end of the expected range, ie. about 40 years and perhaps lower.
- The required covers for portland cement concrete are much higher than those indicated by AS 3600. For a given required cover, portland cement concrete needs to be increased by one strength grade to achieve the minimum design life.
- CSIRO research data and field data are not sufficient at this stage to assess the cover concessions where rigid formwork and intense vibration are used.

While binder type is not emphasised in AS 3600, it appears that fly ash concrete meets AS 3600 durability requirements would be likely to achieve a design life of 40 years. The same can not be said with any certainty for reinforced portland-cement concrete subjected to chloride attack. In regard to this aspect, the RTA QA Specification B80 – Concrete Work for Bridges is more advanced since blended cement is required to be used in a marine environment.

3.2 DESIGN CHARTS

The following charts provide levels of required cover suggested for different design lives. They were generated based on the above procedures suggested for estimating service life and on an extrapolated *D* obtained from tests on a range of fine-grade Australian fly ashes. 'Average' *D* is used to estimate mean service life.

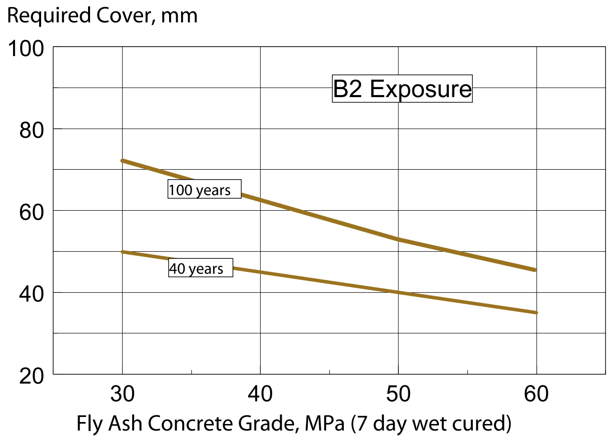

Figure 4: Suggested covers for fly ash concrete in B 2 exposure

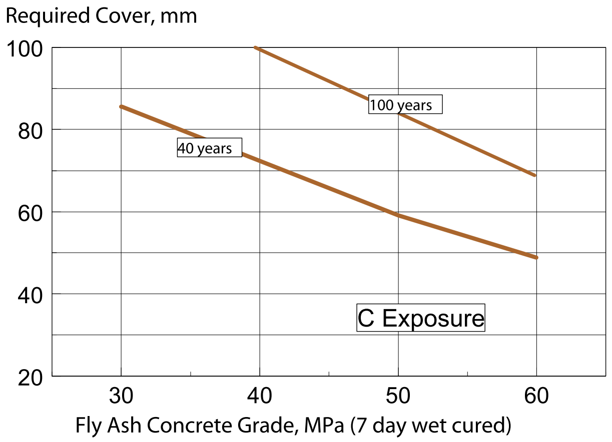

Figure 5: Suggested covers for fly ash concrete in C exposure

It should be emphasised that these 'design charts' are based on chloride induced corrosion of steel reinforcement with assumptions to simplify marine attack on concrete. Therefore they should be used as initial guides. Since concrete is an inhomogeneous material and environmental actions on concrete are case specific, a performance characteristic of concrete is generally connected to a distribution function. This aspect will need to be addressed in the overall approach to design for durability.

4. SUMMARY

Fly ash blended cements are more suitable as binders for marine concrete structures than portland cements. The use of fly ash blended cement in marine concrete will lead to higher resistance to chloride attack and good resistance to seawater damage. The overall results are longer service life in marine exposure.

A procedure for estimating the service life of reinforced, marine concrete structures is suggested in Fly Ash Reference Data Sheet No. 5. With the data generated using fly ash concrete and portland cement concrete, it can be demonstrated that for a given grade of concrete and cover thickness, fly ash concrete can provide longer service life under AS 3600, B2 and C exposures.

Required cover thicknesses for different design lives are suggested for fly ash blended cement concretes in marine environments.

5. LIMITATIONS

The work presented in this report, particularly in aspects related to service life, is limited to normal cast in situ concrete wet cured for 7 days. The 'average' behaviours of portland and fine grade fly ash concretes were reported. The translation of the suggested requirements to specific concrete mixes with and without the use of a specific fly ash, under different curing regimes or made with different processes should NOT be done without relevant data.

It should be noted further that to ensure the achievement of service life of marine concrete structures, it might be necessary to consider the consequence of concrete damages by other physical/chemical/biological degradations relevant to the specific marine environment. The evaluation of risk of failure at different stages during the design service life is advisable. This is critical for marine structures where the risk of failure is linked to safety and/or substantial economic lost.

6. REFERENCES

The full text of CSIRO Research Report BRE 062, Guidelines for the Use of Fly Ash Concrete in Marine Environments, prepared by H.Trinh Cao and Liana Bucea is available on the Ash Development Association website www.adaa.asn.au

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