Ash Development Association of Australia

FLY ASH CONCRETE IN MARINE ENVIRONMENTS

FLY ASH TECHNICAL NOTE No. 4

November 2009

INTRODUCTION

Marine environments can be highly aggressive to reinforced concrete. High concentrations of various types of dissolved salts mainly chlorides, can seriously impact on the long term durability of concrete. If not adequately designed and specified, the durability of reinforced concrete structural elements exposed to marine conditions can be severely compromised. Corrosion of the reinforcement within the concrete is usually the main cause of deterioration.

Corrosion of steel reinforcement in concrete is an electrochemical process. Concrete is typically highly alkaline. Under such conditions, embedded steel develops a protective passive film on its surface. Seawater is rich in chloride ions which can penetrate through the cover concrete. With time, and in sufficient concentration, the chloride ions tend to disrupt the passive film on the steel surface and initiate corrosion. This corrosion will cause conversion of the steel into rust which has a higher volume than the original metal. This expansion can cause cracking and spalling of the concrete which impacts the load carrying capacity, serviceability and design life of the structure.

Image 1 - *Sea Cliff Bridge*. Concretes used in marine environments must be adequately designed to minimise destruction by corrosion

There has been extensive research done into corrosion of steel reinforcement in concrete in high chloride conditions in Australia and overseas involving fly ash concretes (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11). The Ash Development Association of Australia has summaries of major R&D work undertaken specifically on issues relating to the use of fly ash concretes within current specifications (12, 13).

This technical note provides details of basic mechanisms of corrosion initiation and propagation in concrete. Chloride diffusion characteristics of typical fly ash concretes are described. Typical mix parameters that are specified for marine concrete and the beneficial role of fly ash in concrete are also discussed.

AUSTRALIAN STANDARDS COVERING MARINE CONCRETES

Australian Standard, AS3600 (14), has a section devoted to design for durability (Section 4) where exposure classifications are detailed for different concrete exposure conditions. Concrete exposed to marine environments is designated in one of three Exposure Classifications, B2, C1 or C2.

A range of other standards also reference concrete for marine environments, these include:-

- AS5100 – Bridge Design
- AS2159 – Piling
- AS3735 – Liquid Retaining Structures
- AS4997 – Guidelines for the Design of Maritime Structures (this is not a full standard, rather a guide as stated)

The method of specification of marine concretes within these standards can vary and users should seek information specific to individual applications prior to putting forward solutions.

CHLORIDE DIFFUSION, SERVICE LIFE AND FLY ASH

There is no one agreed method in Australia to obtain a measure of the ‘durability’ of a concrete structure in aggressive marine conditions. A commonly used model to describe the corrosion of steel in concrete is presented in Figure 1 (3). There are three key elements in this model, which are:

- The initiation stage
- The threshold level of chloride needed to depassivate steel, and
- The propagation stage

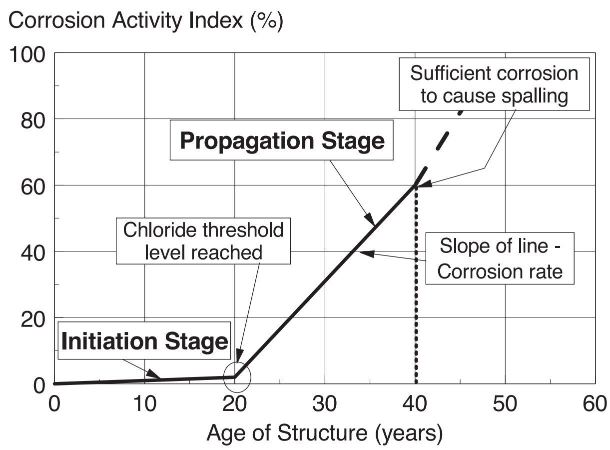


Figure 1 - Commonly used Model Describing Corrosion of Steel Reinforcement in Concrete (following Ref. 3)

In the initiation stage, chloride ions diffuse through the cover concrete towards the steel. During the propagation stage the steel corrodes and the concrete will eventually crack and spall. The design life of a structure is generally described by the timeframe presented in this model, usually taken at the time at which corrosion is initiated. There are other models that can be applied to determine the initiation and propagation time for corrosion, although there is significant debate as to their accuracy (7, 12). The most commonly used model for design purposes is the chloride diffusion model (3).

A number of different test methods are currently used to assess the durability of concretes in marine environments. The most commonly used methods in Australia (3) are:

- Minimum strength (40 MPa or 50 MPa depending on exposure classification) and cover (as defined in AS3600)
- Rapid chloride ion penetrability, and
- Chloride diffusion

Methods used to assess chloride diffusion characteristics of concrete have become popular in design of marine structures. As indicated previously, there is still great conjecture as to the accuracy with which design lives can be estimated for reinforced concrete. The methods used to derive such design lives are based on Fick's second law of diffusion and are described extensively in the literature (12).

In summary, to estimate a service life, a chloride diffusion coefficient is derived for a particular concrete using a sample exposed to salt water conditions for a period of time. The coefficient is derived by taking chloride ion concentrations at various depths from salt water exposed powdered concrete samples. A threshold chloride ion concentration for steel depassivation is assumed as is a surface chloride ion concentration. From these assumptions, a time is derived for steel within concrete to go from a passive state to an active corrosion state (Figure 1).

Fly ash is known to enhance the ability of concrete to resist penetration of chloride ions (7, 13). Typical data on chloride diffusion coefficient versus concrete strength for fly ash concretes is provided in Figure 2. The Nordtest Build 443 method has been used to derive the data shown in this Figure (3).

The Ash Development Association of Australia stresses that the information given in this Figure is indicative only for one set of fly ash concretes investigated. It is recommended that chloride diffusion data be verified for individual fly ash and other component material combinations in concretes.

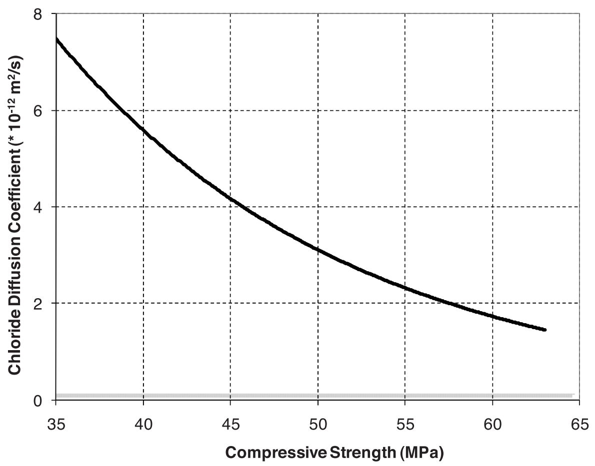
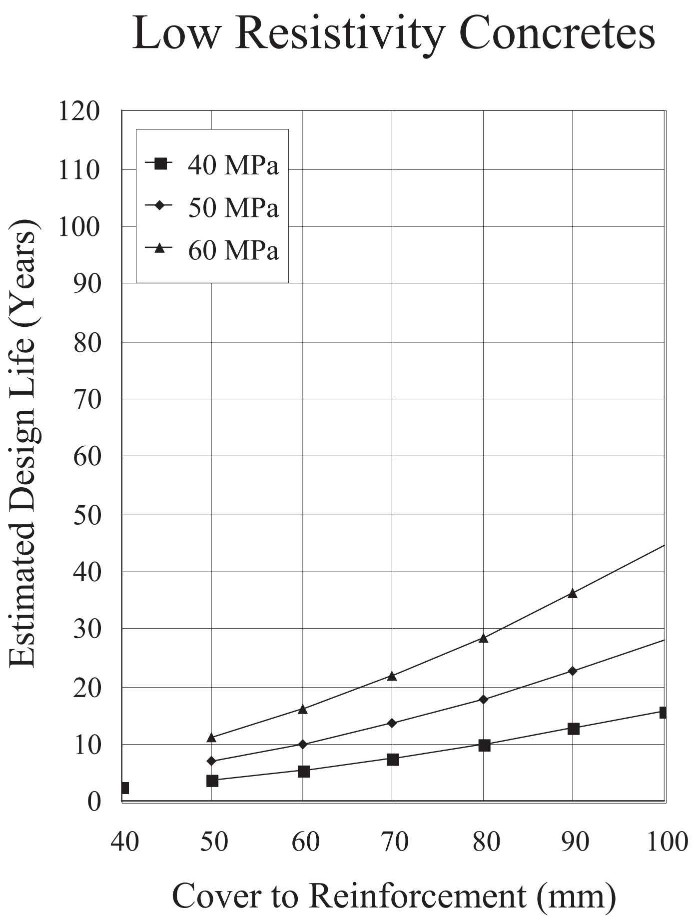


Figure 2 – Typical Data for Chloride Diffusion Coefficient versus Fly Ash Concrete Compressive Strength (Note: Fly ash contents range between 25% to 35% by mass of binder)

FLY ASH IN MARINE CONCRETE

The role of fly ash and other supplementary cementitious materials in limiting steel corrosion in concrete was extensively studied some years ago in long-term studies (4, 5, 6, 7). In these studies, a range of concretes were tested that included concretes having 20% to 25% fly ash by mass of binder. The fly ash concretes were found to have high resistivity characteristics when exposed to high chloride conditions when compared with plain Portland cement concretes that were found to have low resistivity characteristics (1).

Models were developed for both low resistivity and high resistivity concretes to relate cover to reinforcement with an estimated design life in years. This was based on a time to corrosion potential jump as measured on reinforced concrete samples exposed to high chloride conditions for long periods (1, 4, 5, 6, 7, 8). The interrelationships between these parameters and concrete strength grade were derived. A set of nomographs summarising these test results is presented in Figure 3. Importantly, these relationships are thought to be more reliable than those for normal chloride diffusion based models as there is no need for estimating a threshold chloride level for steel depassivation as stated earlier (7). The clear benefits of using fly ash concretes in aggressive marine environments can be seen from the data in Figure 3, where the high resistivity concretes made with fly ash take significantly longer to reach an active corrosion state when compared with plain Portland cement concretes equivalent in strength. It must be noted, however, that a low water:binder ratio concrete is needed and guides provided in relevant Australian Standards for minimum strength and cover to steel should be followed. In addition, specialist advice should be sought for critical structures requiring long design lives.



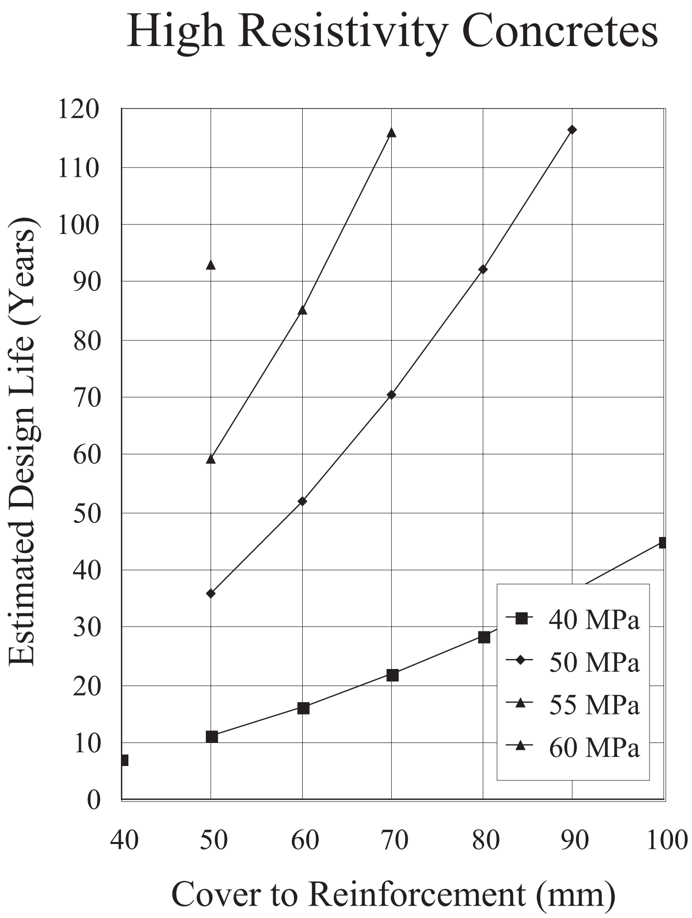


Figure 3 - Estimated Design Life (Years) versus Cover to Reinforcement for Low and High Resistivity Concretes (4)

CONCLUSIONS

A suggested specification outline for a typical high performance concrete for marine or high chloride environment (Classification C per AS 3600) is as follows:

- The concrete strength grade shall not be less than 50 MPa.
- The binder shall consist of Portland cement, fly ash, and one or a combination of additional supplementary cementitious materials conforming to AS3582 to provide the high concrete resistivity characteristics that will ensure improved resistance to chloride induced corrosion of steel.
- Cover to reinforcement shall be appropriate for the design life (described in Figure 3), and as per the requirements of AS3600, or other relevant standard or specification.
- The curing treatment shall be equivalent to at least seven days of wet curing at 23°C without loss of moisture from the concrete.

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