Available online at www.sciencedirect.com
ScienceDirect
Construction and Building Materials 22 (2008) 829–836
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Prediction of long term chloride diffusion of concrete in harsh environment

A.K. Tamimi [a], J.A. Abdalla [b,*], Z.I. Sakka [c]

[a] *Civil Engineering, Institute of Material System, American University of Sharjah, Sharjah, United Arab Emirates*
[b] *Civil Engineering Department, American University of Sharjah, Sharjah, United Arab Emirates*
[c] *School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia*

Received 31 December 2005; received in revised form 8 January 2007; accepted 10 January 2007
Available online 27 February 2007

Abstract

A harsh environment of temperature (20–54 °C [68–129 °F]) and humidity (80–95%) with the presence of chloride and sulfate make concrete structures vulnerable to deterioration and as a result shorten their service life span. This research has evaluated the durability of normal concrete (NC) and high performance concrete (HPC) made with two aggregates, types AA and AD. Concrete specimens were exposed to saline water in a controlled temperature and humidity environment and tested for initial surface absorption and chloride diffusion. It is observed that the NC and HPC made of type AA aggregates showed lower permeability and lower chlorides diffusion as compared to that made of type AD aggregates. HPC samples produced by the two types of aggregate have consistently shown better durability performance compared to that of NC. The results collected within 21 months period allowed the prediction of chloride diffusion with time for NC. A long term prediction of the chloride diffusion was made to estimate the service life of structures. Experimental observations of s diffusion of NC correlated better with Fick's Second Law prediction than those of HPC.

Keywords: Prediction model; Concrete durability; Chloride diffusion; Initial surface absorption test (ISAT); High performance concrete; Normal concrete

1. Introduction

Extending service life of buildings is an important challenge facing structural engineers and building materials professionals everywhere. This is particularly important in harsh environment such as that of the Arabian Gulf region including United Arab Emirates (UAE) where buildings have been characterized by short service life spans compared to their counter parts elsewhere. The harsh environment of high temperatures (20–54 °C [68–129 °F]) accompanied by high humidity (80–95%), together with the presence of chloride and sulfate make concrete structures vulnerable to deterioration and as a result shorten their life expectancy.

Chloride diffusion is one of the main factors that affect concrete durability and therefore shorten the life span of the buildings. The diffusion of chloride is influenced by many factors including the composition of the concrete and its porosity. Since aggregates represent around 75% of the volume of concrete in a typical concrete mix, aggregate properties play a significant role in chloride diffusion and durability of concrete structures. Over the years, several researchers [1–4] have investigated the issue of chloride diffusion and come up with different chloride prediction and service life models to estimate the service life of given structures with known mixes and materials. Bamforth [5] has established a predictive model that is a useful basis for designing reinforced concrete structures in salt-contaminated environments. Smith [6] showed that addition of silica fume (SF) and other durability enhancing materials such as fly ash (FA) and GGBS in certain percentages can increase the durability of concrete drastically. For the

* Corresponding author. Fax: +97 165152979.
E-mail address: jabdalla@aus.edu (J.A. Abdalla).

0950-0618/$ - see front matter
doi:10.1016/j.conbuildmat.2007.01.001

model to work, quantitative information is needed to define the boundary condition at the exposed surface, the effective chloride transport coefficient, and the corrosion initiation threshold level of chloride as required by the relevant code. Mangat and Molloy [7] have presented a wide range of experimental results on acid soluble chloride diffusion in different mixes of concrete. They have shown that the effective chloride transport coefficient is strongly dependent on the period of exposure of concrete to chloride environment. Xi et al. [8] have devised a mathematical model for chloride penetration in saturated concrete taking into consideration w/c ratio, cement type, aggregate content, curing time, temperature and surface chloride iron concentration. Permeation properties of the near surface concrete and the various transport mechanisms which govern the ingress of chloride into concrete are the major factors that influence concrete durability as assessed by Basheer et al. [9]. Basheer and Bai [10] studied the effect of ash on concrete durability and Basheer et al. [11] studied the influence of mix parameters, specifically the effect of size and grading of the coarse aggregate on durability of concrete, among other concrete characteristics. They carried out air permeability, freeze–thaw/salt scaling resistance and an accelerated carbonation test for testing the durability of concrete. They concluded that the increase of proportion of larger size aggregate decreases durability.

Azari et al. [12] carried out a study to investigate the interaction of cement, water, curing conditions and microsilica content on chloride diffusion characteristics. They found that a relationship exists between chloride diffusion and w/c ratio, where the relationship varies with the various microsilica contents. They concluded that the effect of high w/c ratios in chloride ingress is much more evident in low microsilica content mixes and the chloride ingress is also sensitive to cement content in low microsilica mixes, but not in high microsilica content mixes. They also observed that although the diffusion coefficient, D_c, is affected by microsilica content, however such effect is less significant when w/c ratio of the mixes is kept constant. Haque and Al-Khaiat [13] studied the durability of lightweight concrete in hot marine exposure conditions and the behavior of concrete in a chloride–sulfate rich environment. They concluded that water penetrability and the extent of carbonation of sand light weight concretes have been found to be more sensitive to the extent of initial curing than their compressive strength. Al-Khaiat and Fattuhi [14] studied carbonation of concrete exposed to hot and arid climate similar to that of UAE. Their results showed that the most significant factors influencing concrete carbonation were: the use of surface coating; water/cement ratio; water-curing period; and the season when the concrete was initially cast and exposed. They also concluded that a decrease in the water/cement ratio and an increase in the water-curing period resulted in a decrease in concrete carbonation. Early attempts to study durability of concrete in the Arabian Gulf were carried out by Anderson and Sweeney [15], Al-tayyib et al. [16], Al-rabiah et al. [17] and Sabouni [18], among others. They investigated the relationships between chloride penetration and cement type, concrete age, exposure condition, temperature, aggregate type, among other parameters.

It is evident that research on concrete durability has attracted the attention of many researchers worldwide, including those in the Arabian Gulf region. In the UAE, the use of concrete has been increased without enough research on the effect of chloride exposure; a major long term challenge in this region. The authors believe that this study is vital for this region when using local materials in the harsh environment of UAE on which the construction industry is developing at an unprecedented rate. This research is a first step in an ambitious program to predict the service life of buildings in UAE, a desired attribute required equally by the construction industry and the clients.

Accordingly, the objectives of this paper are to study the properties of two types of commonly used local aggregate in UAE and examine their effects on the initial surface absorption and chloride diffusion for normal and high performance concrete by using GGBS.

2. Materials, concrete mix design and specimens

2.1. Raw materials

2.1.1. Binder

For high performance concrete, Portland cement and GGBS were used. The GBBS was kept as 40% of the total binder. For normal concrete (NC), only Portland cement was used as binder.

2.1.2. Aggregate

Two commonly used local coarse and fine aggregates from different sources were employed. Since a highly absorptive aggregate could lead to a low durability concrete, specific gravity and water absorption tests were conducted on the aggregates. Several standard aggregate tests were conducted on the aggregates [19] from the two sources and the results of these tests are shown in Table 1. Fine and coarse aggregates used for high performance concrete did meet the requirement of ASTM C33 Specification for Concrete Aggregates [20] as a minimum requirement.

2.1.3. Superplasticizer

Superplasticizer was used in all mixes. The superplasticizer was based on modified polycarboxylic ether.

2.2. Concrete mix design

2.2.1. Mix procedure

The two local aggregates (type AA and type AD) were examined to produce a trial mix, employing batching, mixing, testing fresh concrete, casting cubes, curing for the required age, and finally testing for hardened concrete properties and durability criteria. The mix design proce-