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ScienceDirect

Building and Environment 42 (2007) 1770–1776

BUILDING AND ENVIRONMENT

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Effects of cement type, water/cement ratio and cement content on sea water resistance of concrete

Hüseyin Yiğiter*, Halit Yazıcı, Serdar Aydın

Engineering Faculty, Department of Civil Engineering, Dokuz Eylül University, 35160 Buca, Izmir, Turkey

Received 20 September 2005; received in revised form 24 November 2005; accepted 19 January 2006

Abstract

In this study, effects of cement type, cement content and water/cement (W/C) ratio level on the sea water resistance of concrete were investigated. Test samples were exposed to sea water by wetting–drying manner. Residual splitting tensile and compressive strength, and chloride penetration depths of specimens after exposure were determined. Besides, energy dispersive spectrometer (EDS) analyses were performed on scanning electron microscope (SEM) images of selected mixtures. Test results indicate that blast furnace slag cement (SC) mixtures have considerably greater resistance to sea water than portland cement (PC) mixtures both from the point of mechanical properties and chloride penetration.

Keywords: Sea water; Chloride; Granulated blast-furnace slag; Mechanical properties

1. Introduction

A large number of the concrete/reinforced concrete structures are in contact with marine environment either directly or indirectly and exposed to both physical and chemical detrimental effects during their service life. Erosion, wetting–drying and freezing–thawing can be considered as physical effects while sulfate, chloride, magnesium and carbonic acid attacks are chemical effects. These effects are more pronounced when they realized in repeated cycles. The rate at which the hardened cement paste is deteriorated due to the exposure to harmful chemicals depends mainly on the concentration of the chemicals, the duration of exposure, and the chemical resistance of concrete [1,2]. Some of the most important phenomena governing the movement of pollutants in concrete are diffusion of substances in the pore water, adsorption (and desorption) of pollutants onto the pore walls, and hydrodynamic dispersion and convection of substances due to flow of the pore water [3].

Considerable developments in concrete technology have been taken place in last quarter of the century. Compared to the past, to achieve sufficiently high strength levels at early ages, Blaine fineness and tricalcium silicate ($3CaO \cdot SiO_2$) contents of cements were increased. Thus, same strength levels obtained with less cement or with higher water/cement (W/C) ratio results in an increase in the permeability of concrete. So, nowadays, many concrete structures built after 1970s, have been suffering because of durability problems [1,4]. In Turkey, after the Kocaeli earthquake, it has been better realized that reinforcement corrosion had been initiated in many structures and this is one of the important factors that causes damage. Also, many coastal structures have durability problems within the short time of about 5–10 years, due to only strength-based concrete mix design approach.

In the aggressive exposures, the concrete quality should be specified in terms of durability, in addition to workability and strength [5]. Prediction of service life and durability can only be made by characterization of both the material properties and the environment. Pollutants may be contributed by either the mix constituents or they may penetrate the hardened concrete from external environment. The concomitant presence of sulfate and chloride

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*Corresponding author. Tel.: +90 232 412 70 44; fax: +90 232 412 72 53.
E-mail address: huseyin.yigiter@deu.edu.tr (H. Yiğiter).

0360-1323/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2006.01.008

ions is also known to aggravate the corrosive attack on concrete and reinforcing steel bars.

In fact, one of the main causes of the deterioration in reinforced concrete structures is the chloride-induced corrosion of embedded steel reinforcement. Although after the application of the electrochemical chloride extraction (ECE) method, both corrosion potentials and corrosion rate values show a reduction in the steel degradation process. Fajardo et al. concluded that it is not possible to affirm that the steel is repassivated. ECE applied to structures having strong chloride contents and high corrosion rates is not sufficient to guarantee a prolongation of the service life of the structures [6].

Barberon et al. have presented the results of a multinuclear magnetic resonance study on the fixation of chloride in the hydration products and the characterization of new phases potentially appearing due to chloride ingress [7]. They concluded that, while sodium does not seem to be affected by the hydration process, chloride disappears very fast due to chemical reactions with components of cement. ^{27}Al and ^{29}Si spectroscopy proved that only aluminum interacts with chloride and that the exposure of concrete to a NaCl solution leads mainly to a rehydration of residual cement without affecting the structure of calcium silicate hydrate product.

It is well known that pozzolanic materials improve the sulfate and sea water resistance of concrete [1,2,4,8,9]. Dongxue et al. found that the strength of pure portland cement (PC) decreased to various extents in sea water, while the strength of steel slag cement (SC) maintained or even increased to different extents; especially the flexural strength increased considerably [8].

Luo et al. investigated ordinary PC and ground granulated blast furnace slag (GGBS) blended cement with respect to their pore structure, chloride diffusion coefficients, internal and external chloride binding capabilities by the expression method and leaching method and the microstructure analysis on Fridel's salt such as differential thermal analysis (DTA), X-ray diffraction (XRD) and scanning electron microscope (SEM). They have concluded that GGBS can improve the pore structure of concrete, decrease the chloride diffusion coefficient and increase the chloride binding capability greatly [10].

Yeau and Kim carried out rapid chloride permeability tests on GGBS concrete specimens [11]. Based on test results they have concluded that, chloride-ion permeability of GGBS concrete specimen is reduced as period of curing or amount of GGBS by binder weight was increased. Accelerated chloride-ion diffusion test results have indicate that much longer transition periods and much lower chloride-ion concentration can be achieved if higher volumes of GGBS are added. Result of half-cell potential tests showed a tendency to decrease corrosion potential readings according to the increase of thickness of concrete cover and GGBS content. GGBS of 40% or more by binder weight can increase the corrosion resistance of a steel bar more than two times, compared to GGBS-free cement concrete.

Limited numbers of experimental study realized effects of cement type, W/C ratio and cement dosage on sea water resistance of concrete with slag. The present study investigates all these factors with mechanical strength tests (compressive and splitting tensile), chloride penetration depth measurements, and SEM–EDS analysis.

2. Experimental

An ordinary PC—CEM I 42.5 N and blast furnace SC—CEM III/A 42.5 N which contains 54% steel slag, procured from Cimentas and Oysa cement plants in Turkey, respectively were used in this study. The chemical composition and some physical and mechanical properties of cements are given in Table 1.

Concrete mixtures were prepared with two different cements (PC, SC), three different W/C ratios by weight (0.43, 053, 0.63) and three different cement contents (250, 350, 450 kg/m^3). Natural river sand and crushed limestone were used as fine and coarse aggregates. The properties of aggregates are in conformity with the Turkish Standard for concrete aggregates—TS 706 EN 12620 [12]. A superplasticizer (SP) of sulfonated naphthalene formaldehyde type was used meeting standard specifications in ASTM C 494 [13] and TS EN 934-2 [14]. Mixture proportions are shown in Table 2. Although the dosage of the SP was varied, constant slump values can not be obtained particularly at 250 kg/m^3 cement content. Due to overdosage usage of SP in some mixtures caused stability problems such as bleeding. However, slump values of other mixtures were close to each other at constant cement

Table 1
Physical, chemical and mechanical properties of cements

	PC	SC
Chemical composition (%)		
SiO_2	19.3	28.9
Al_2O_3	5.6	9.2
Fe_2O_3	3.5	2.2
CaO	63.6	47.4
MgO	0.9	5.1
Na_2O	0.1	
K_2O	0.8	
SO_3	2.9	1.7
Cl^-	0.013	0.012
Loss on ignition	2.8	0.4
Insoluble residue	0.4	
Free CaO (%)	1.2	
Physical properties		
Specific gravity	3.15	2.96
Initial setting time (min)	119	170
Final setting time (min)	210	230
Volume expansion (mm)	1.00	
Specific surface (m^2/kg)	352	496
Compressive strength (MPa)		
2 days	27.2	18.0
7 days	42.4	27.0
28 days	52.7	48.0