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Cement & Concrete Composites 27 (2005) 449–461
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

A study on reinforcement corrosion and related properties of plain and blended cement concretes under different curing conditions

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Received 28 March 2003; accepted 28 May 2004

Abstract

This paper presents the results of an experimental investigation on the steel reinforcement corrosion, electrical resistivity, and compressive strength of concretes. Concretes having two different water–cement ratios (0.65 and 0.45) and two different cement contents (300 and 400 kg/m^3) were produced by using a plain and four different blended portland cements. Concrete specimens were subjected to three different curing procedures (uncontrolled, controlled, and wet curing). The effect of using plain or blended cements on the resistance of concrete against damage caused by corrosion of the embedded reinforcement has been investigated using an accelerated impressed voltage setup. The resistivity of the cover concrete has been measured non-destructively by placing electrodes on concrete surface. The compressive strength, electrical resistivity, and corrosion resistance of the concretes were determined at different ages up to 180 days. The results of the tests indicated that the wet curing was essential to achieve higher strength and durability characteristics for both plain and especially blended cement concretes. The concretes, which received inadequate (uncontrolled) curing, exhibited poor performance in terms of strength and corrosion resistance.

Keywords: Concrete; Corrosion resistance; Curing conditions; Electrical resistance; Plain and blended cements; Strength

1. Introduction

Performance of concrete is generally judged by strength and durability properties. Probably the most important durability issue with reinforced concrete is deterioration due to reinforcement corrosion [1,2]. A detailed description of the corrosion process can be found in the study of Rosenberg et al. [3]. In the alkaline cementitious environment, a stable oxide film is formed on the steel surface which protects the interior steel from corroding. However, corrosion starts due to the carbonation of concrete leading to a reduction in the alkalinity, or the presence of chloride ions causing pitting damage of the protective film on the steel bar. The corrosion product absorbs water and increases in volume. Once the expansion becomes excessive, concrete cracking will occur. Following the approach proposed by Tuutti [4], the corrosion process can be divided into two parts: an initiation (depassivation) stage and a propagation (corrosion) stage. During the initiation stage, corrosion agents such as chloride ions and carbon dioxide penetrate into the concrete cover, but their concentration around the steel reinforcement is not high enough to cause corrosion yet. The end of the initiation stage or the beginning of the propagation stage is the moment when corrosion starts at threshold concentration of aggressive species. Within the propagation stage, steel corrosion is accompanied by the growth of radial cracks from the steel bar, which will eventually lead to spalling of the concrete cover.

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doi:10.1016/j.cemconcomp.2004.05.006

Performance measurements of reinforced concrete related to the corrosion of embedded steel may be based on the type and condition of steel bar and thickness and quality of concrete cover, properties of cement paste, mortar, and concrete, and electrochemical conditions of the reinforcement in contact with the solution, paste, mortar, or concrete. Issues relating to reinforcement type have been extensively discussed in the literature [5–7], and the use of galvanized steel, stainless steel, or coated reinforcement in preventing chloride-induced steel corrosion in concrete have been investigated [8–10]. Cracking has been noted to increase the likelihood of damage to reinforced concrete [11–13]. Cover to reinforcement is considered of prime importance by some researchers while others believe that concrete type/quality is more critical than the cover thickness [14,15]. Further information on concrete cover, its modification, cracking, and delamination can also be found in the literature [16,17].

Blended (or pozzolanic) cements are being used worldwide to produce dense and impermeable concrete. They contain a blend of portland cement clinker and a variety of natural pozzolans and/or supplementary cementing materials such as blast furnace slag, fly ash, and silica fume. The use of these materials is also environmental friendly because it helps to reduce the CO_2 emission to the atmosphere [18]. The interest in the use of such mineral additives resulted in more detailed specifications in the United States and Europe for blended cements. The range of compositions as specified by the U.S. and European standards are summarized in Table 1. The beneficial effects of incorporating these materials in concrete are widely discussed in the literature [19–23]. Use of pozzolanic materials in concrete considerably reduces its permeability and rate of diffusion of moisture and aggressive species to the steel–concrete interface. Due to the increased density of concrete, resulting from the addition of pozzolanic materials, damage due to sulfate attack, alkali-aggregate reaction, and reinforcement corrosion is greatly reduced. The addition of a wide range of blending materials of differing chemical composition also introduces significant diversity into the cementing system. The wide variation in the performance of the blending materials may be attributed to the variation in their physical, chemical, and mineralogical composition resulting from the industrial processes related to their production and the properties of the raw materials used. Furthermore, the reported longer curing period required for blended cement concretes, as opposed to plain cement concrete, is still a question often debated among concrete technologists. Since pozzolanic reaction is highly dependent on good curing practice, there is often concern as to the effect of curing on the permeability of pozzolanic cement concrete. Many investigators [24–26] believe that a curing period of about 28 to 90 days is required for pozzolanic cement concrete specimens to attain properties superior than that of plain cement concrete. This is attributed to the pozzolanic reaction of these materials, which is often quite slow [24].

This paper is part of a large research project on evaluating the various durability aspects of plain and blended cement concretes. The objective of this study is to investigate the relative performance of a range of portland and blended cement concretes exposed to high chloride concentrations. The performance evaluation has been carried out in terms of corrosion of embedded reinforcement and related properties including compressive strength and electrical resistivity under three different curing conditions. Based on the test results, the effects of the type of cement, water–cement ratio (w/c), age, and curing conditions have been discussed.

Table 1
Blended cements according to American and European specifications

Specifications	Name	Portland cement content	Blended minerals
ASTM C595	Portland blast furnace slag	30–75%	Granulated blast furnace slag
	Slag-modified portland cement	>75%	Granulated blast furnace slag
	Portland pozzolan cement	60–85%	Pozzolan
	Pozzolan modified portland cement	>85%	Pozzolan
	Slag cement	<30%	Granulated blast furnace slag
EN 197	CEM I portland cement	95–100%	Minor addition constituents
	CEM II[a] portland composite cement	65–94%	Blast furnace slag, silica fume, pozzolans (natural or calcined), fly ash, burnt shale, limestone
	CEM III[b] blast furnace cement	5–64%	Blast furnace slag
	CEM IV[c] pozzolanic cement	45–89%	Silica fume, pozzolans, fly ash
	CEM V[d] composite cement	20–64%	Blast furnace slag, pozzolans, fly ash

[a] Includes subclassification depending on type of blended mineral.

[b] Includes subclassification depending on content of slag: 36–65%, 66–80%, 81–95%.

[c] Includes subclassification depending on content of pozzolans (silica fume + pozzolans + fly ash): 11–35%, 36–55%.

[d] Includes subclassification depending on content of blending minerals (blast furnace slag + pozzolans + fly ash): 36–60%, 62–80%.