Cement and Concrete Research 41 (2011) 854–864

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: http://ees.elsevier.com/CEMCON/default.asp

Capillary porosity depercolation in cement-based materials: Measurement techniques and factors which influence their interpretation

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ARTICLE INFO

Article history:
Received 16 December 2010
Accepted 12 April 2011

Keywords:
Capillary porosity
Chemical shrinkage
Conductivity
Depercolation
Shrinkage reducing admixture (SRA)

ABSTRACT

The connectivity of the capillary porosity in cement-based materials impacts fluid-and-ion transport and thus material durability, the interpretation of experimental measurements such as chemical shrinkage, and the timing and duration of curing operations. While several methods have been used to assess the connectivity of the capillary pores, the interpretation of some experimental procedures can be complicated by the addition of certain chemical admixtures. This paper assesses capillary porosity depercolation in cement pastes using measurements of chemical shrinkage, low temperature calorimetry (LTC), and electrical impedance spectroscopy. The experimental results are analyzed to identify the time of capillary porosity depercolation. In addition, the factors that influence the interpretation of each technique are discussed. Experimental evidence suggests that capillary porosity depercolation, as defined by Powers, occurs after hydration has reduced the capillary porosity to around 20% in cement paste systems. The influence of capillary porosity depercolation on the transport properties is demonstrated in terms of a reduction in the electrical conductivity of the cementitious material. Special attention is paid to understand and interpret the influence of shrinkage-reducing admixtures (SRAs) on the freezing behavior of cementitious systems, particularly in regard to the inapplicability of using LTC to detect porosity depercolation in cement pastes containing such organic admixtures.

1. Introduction and background

The desire to increase the service-life of civil engineering infrastructure has led in many cases to the increased use of low *w/c* (water-to-cement ratio) concretes in construction. However, low *w/c* concretes are not without problems, as the refined pore size distribution of these materials amplifies autogenous shrinkage, magnifying the risk of cracking at early-ages [1,2]. To minimize the risk of early-age cracking several approaches have been developed including: (1) internal curing using water reservoirs such as pre-wetted lightweight aggregates or superabsorbent polymers [3–5], (2) the extension of recommended wet curing durations during construction [6,7], (3) the use of shrinkage-reducing admixtures (SRAs) to reduce capillary stress development [8–10] and (4) the utilization of expansive cements or additives that can generate an expansion to mitigate tensile stress development at early ages [11,12].

Curing is carried out to provide sufficient water for binder hydration and limit the impact of self-desiccation in cementitious materials. However, this assumes that water is able to freely migrate through the concrete to locations where it may be needed to promote hydration and maintain saturation [13,14]. While this assumption may be reasonable for concretes with a higher *w/c* (e.g., 0.45 and greater), it may not be the case for low *w/c* mixtures, when the capillary pore-structure may become discontinuous [15–17]. For example: in the case of internal curing, if moisture is released from curing reservoirs after the capillary pore-structure has disconnected, the distance that water can travel may be considerably limited [13,14]. For external curing, if the capillary porosity disconnects prior to or during curing, moisture would be unable to penetrate the full depth of the concrete, limiting curing effectiveness to the topmost portions of the covercrete.

These concerns demonstrate the need for a more complete understanding of capillary porosity depercolation/disconnection in cement-based materials. Since it is recognized that the porosity within cement-based materials always remains percolated when the gel pores are considered, here, consistent with the original work of Powers *et al.* [15,18], it is depercolation or discontinuity of the

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0008-8846/$ – see front matter
doi:10.1016/j.cemconres.2011.04.006