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Case Study

Case study of the gradient features of in situ concrete

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ABSTRACT

The recognition of gradient features of the properties of in situ concrete is important for the interpretation/prediction of service life. In this work, the gradient features: water absorption, porosity, mineralogy, morphology and micromechanical properties were studied on two in situ road concretes (15 and 5 years old, respectively) by weighing, MIP, XRD, IR, SEM/EDS and micro-indentation techniques. Results showed that a coarsening trend of the pores of the concrete leads to a gradual increase of liquid transport property from inside to outside. Although the carbonation of the exposed surface results in a compact microstructure of the paste, its combined action with calcium-leaching leads to a comparable porosity of different concrete layers. Moreover, the combining factors result in three morphological features, i.e. a porous and granular exposed-layer, a fibrous and porous subexposed-layer and a compact inner-layer. Micro-indentation test results showed that a hard layer that moves inward with aging exists due to the alterations of the mineralogy, the pore and the gel structure.

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1. Introduction

During the service life of concrete structures, deterioration induced by environmental impacts, such as the ingress of CO_2 into concrete and the neutralization process of calcium-bearing constituents followed by chloride and moisture transportation through pores to the reinforcing steel bars, would lead to alteration of the properties of the binder, reduction of the load-bearing capacity and volume stability, and consequently a shortened service life of the structure. From the safety and economy standpoint, it is desirable to know the deterioration process of the concrete structure and the residual life expectancy, both of which have been in the research scope over the last decades.

Compared with its long service life, the maturing process of cement-based material is quite short and it is believed that over 70% of this process finishes at 28 days after casting (Taylor, 1997). For the cover concrete, normally determined as those within 4–5 cm from the exposed surface (Patel et al., 1985), although the hardening process continues after the initial curing, it was believed to be slowed down or terminated due to the decrease of the moisture content as a result of self-desiccation accompanying hydration and moisture diffusion to the dry environment (Jiang et al., 2007) to a level of about 80%RH (Patel et al., 1985; Flatt et al., 2011). On the other hand, the environment-exerted impacts on the properties of the cover concrete gradually take place, which, under most circumstances, do harm to the material. To elucidate the

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influences of environment on the properties of hardened concrete, great efforts have been made to reveal the property evolution of concrete structures under environmental conditions. By monitoring the properties of cement-based materials under various conditions, especially the volume stability (Ishida and Iqbal, 2009; Zeng et al., 2012), the distribution and the tortuosity of the pore structure (Ishida and Iqbal, 2009; Song and Kwon, 2007; Haga et al., 2005; Ustabas, 2012), the gel property (Black et al., 2007), characteristics and mechanisms of the physical/chemical/physiochemical deteriorations on concrete have been intensively investigated. Based on these findings, models, aimed at predicting the service life of concrete structures have been proposed and verified through lab experiments or field studies by using Darcy's or Fick's law. However, these predictions are far from satisfactory.

When predicting the service life of a concrete structure, transport parameters such as permeability and diffusivity are the key inputs. Moreover, studies on the coupling effect of ion/gas penetration, freezing–thawing, loading, etc. on the properties of concrete have been on thriving (Chung et al., 2010; Li et al., 2011). When evaluating these basic transport parameters, concrete sections having consistent properties were assumed, which, however, always under or overestimate the real values. For example, constants representing the transport properties of cement-based materials of permeability, diffusivity (Mangat and Limbachiya, 1999; Zhang and Gjørv, 1996; Chatterji, 1995) may vary according to the variations of physical (Djerbi et al., 2008), chemical (Schwotzer et al., 2010) and electrochemical features (Yu and Page, 1991; Ngala et al., 1995; Roy et al., 2000) of the gel, and these are the core features of the real transport process (Schwotzer et al., 2010). Although equations were proposed for obtaining these time and location dependent parameters (Mangat and Molloy, 1994), their relationships with the alteration of the gel properties has been rarely reported.

It is easy to understand that the nearer the inside concrete to the exposed surface, the greater the possibility of the occurrence of deterioration, leading to a gradient alteration of the properties (Song and Kwon, 2007; Ryu et al., 2011; Patel et al., 1985). Recognizing that different transport properties of cement-based materials can result due to the differences in physicochemical properties, it would be of great importance to know the gradient alteration features of the in situ concrete, which has been rarely and specifically studied (Song and Kwon, 2007).

In this work, detailed studies of the gradient features of two road concrete samples of 15 and 5 years old, including mineralogical, morphological, compositional, structural and micromechanical gradients have been investigated, and it is hoped that a glimpse for further investigations of the durability-prediction of concrete structure on site can be obtained.

2. Materials and test methods

2.1. Materials

Two concretes (Fig. 1), one about 15 years old (sample A) sampled from a declining road and the other about 5 years old (sample B) sampled from level ground, were analyzed in this work. Ordinary Portland cement was used in both concretes that were cast in situ and mixed at a water-to-cement ratio of about 0.6. For the location of these two concretes, the lowest temperature is about −8 °C with a winter duration of 4 months per year. It can be seen in Fig. 1 that the carbonation depth of samples A and B was about 2.5 cm and 2.0 cm, respectively. Concrete layers parallel to the surface were sectioned at different thicknesses using water-cooled saws. Generally, a 5 mm-thick saw was used to prepare samples (about 7 mm thick and 50 cm^2 in size) for macro-property measurement, and a 1 mm-thick saw was used for preparing samples (about 7 mm thick and 4 cm^2 in size) for micro-property testing.

2.2. Test methods

2.2.1. Water absorption ratio and the initial water absorption coefficient (IWAC)

Water absorption characteristics of the newly cut concrete layers, i.e., layers parallel to the concrete surface, were measured by following processes described in a separate paper (Hou et al., 2014). The initial water absorption coefficient (IWAC), i.e., the slope of the water absorption ratio vs. square root of time (in seconds) at the beginning of water absorption as described in Pihlajavaara and Pihlman (1974) was used to evaluate the water transport properties. Before water absorption measurements, the concrete sections were oven-dried at 105 °C for 24 hours. When calculating the water absorption ratio per square centimeter, the area of coarse aggregate was excluded by using image analysis techniques. Three samples were tested and averaged to be taken as the representative value.

2.2.2. Mercury intrusion porosimetry

Mercury intrusion porosimetry (MIP, Quantachrome, PM60GT-18, USA) was used to quantitatively evaluate the pore tructure of different concrete layers. When preparing samples for MIP test, aggregates were avoided from sampling and about 0.4–0.6 g sample was used for each measurement. A pressure of more than 400 MPa can be achieved by the machine and this pressure allows the mercury to penetrate pores as fine as 0.003 μm diameter, (minimum diameter – allowing for the "ink bottle" effect).

2.2.3. SEM-EDS

A Quanta FEG-250 equipped with energy dispersive spectroscopy (EDS) was used to analyze the morphology and elemental compositions of the cross section of the concrete layers parallel to the concrete surface at different depths.

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