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Simulation of moisture field of concrete with pre-soaked lightweight aggregate addition

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HIGHLIGHTS

- Internal relative humidity of concrete internal curing with pre-soaked lightweight aggregate.
- Water movement model of concrete internal curing with pre-soaked lightweight aggregate.
- Moisture diffusivity of concrete internal curing with pre-soaked lightweight aggregate.

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ABSTRACT

Use of pre-soaked lightweight aggregate (PSLWA) as an internal reservoir to provide water as the concrete dries is an effective method to reduce shrinkage of concrete. In this paper, a moisture distribution model of concrete internal cured with PSLWA is developed based on the experimental measurement on internal relative humidity of concrete with and without internal curing under sealing status. The function of internal curing with PSLWA is considered in the model through a parameter called critically released water, W_c, that was experimentally determined from experiments. Meanwhile, self-desiccation and moisture capacity are taken into account in development of the diffusion equation. To verify the model, a series tests to measure the internal relative humidity of three kinds of internal cured concrete under drying and sealing conditions were conducted. Through comparing the model and test results of humidity profiles, the moisture dependent diffusivity of the three internal cured concretes is obtained. The developed moisture movement model and finite differential method can well predict the moisture distribution as well as its variations with time of concrete internal cured with PSLWA.

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1. Introduction

Concrete shrinks as moisture is lost to the environment or by self-desiccation. As concrete shrinks, tensile stress will be developed in the structure due to restraints from adjunct materials or connected members. The stress may exceed the tensile strength and cause concrete to crack. Therefore, shrinkage of concrete may be one of the major sources of the formation of cracks in concrete structures. The magnitude of the shrinkage strain is normally proportional to the amount of moisture loss [1–4]. In general, environmental drying and cement hydration are the two main processes causing moisture loss inside the concrete. As environmental humidity is lower than the humidity inside of concrete, the water in concrete evaporates and shrinkage of the concrete arises. This kind of shrinkage is called drying shrinkage. Another process causing moisture loss is through cement hydration, which is called self-desiccation and the corresponding shrinkage of concrete is called autogenous shrinkage. In order to avoid the shrinkage induced cracking in concrete, it is necessary to compensate the moisture loss from both cement hydration and environmental drying. Use of pre-soaked lightweight aggregate (PSLWA) as an internal reservoir to provide water as the concrete suffers drying is an effective method to reduce shrinkage of concrete [5,6].

Meanwhile, shrinkage strain develops near the drying surface much faster than that in the center of a concrete element [7]. This suggests that the moisture content inside of concrete differs from surface to center and moisture gradient exists before the hygrometric equilibrium with the surroundings is reached. Local shrinkage is directly related to the pore humidity. Thus, a gradient of shrinkage strain should exist throughout the moisture losing process. The evaluation of the shrinkage induced stress distribution on the structure requires the knowledge of the distribution

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of shrinkage deformation, which, in turn needs the information of moisture distribution first [1]. Therefore, the moisture content and its distribution inside of concrete, especially in early ages, are critically needed to calculate the shrinkage induced stresses, creep, deflection in concrete structure and further to predict the formation of cracks, durability and the service-life of the structures.

A number of references are noted in literatures regarding the moisture content and its variations with time of concrete without internal curing. Andrade et al. measured internal relative humidity and temperature behavior of matured concrete cylinders exposed to the outdoor climate [8–10] conducted experimental studies on the internal relative humidity of matured concrete specimens exposed to natural weathering or in contact with seawater. Recent years, Huang et al. [11] experimentally investigated the development of humidity inside of concrete at early-age by measuring the interior humidity of concrete immediately after specimen casting until 28 days. Based on the experimental findings, a mathematical modeling on moisture distribution and its variation with time was carried by Zhang et al. [12]. In this simulation, constant moisture capacity (slope of moisture content and relative humidity curve) of concrete was assumed and this assumption may induce some error on relatively low strength concrete and/or high water to cement ratio concrete. Obvious nonlinear performance on sorption isotherm in the high humidity zone was displayed on these concrete [10,13]. Recently, an improved model for moisture distribution of concrete is developed, in which self-desiccation due to cement hydration and non-linear moisture capacity of cementitious materials are considered [14]. For concrete with PSLWA internal curing, even quite number of references can be found regarding the effectiveness of this method on shrinkage reduction [5,6,15]. However, the studies of moisture distribution in the internal cured concrete are still lacking, which makes the evaluation of shrinkage induced cracking of such concrete under environmental drying becomes difficult.

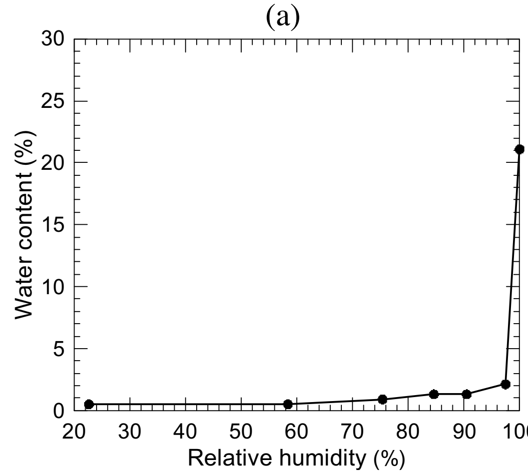
The aim of this article is to simulate the moisture distribution of concrete with PSLWA internal curing. First, the moisture movement in three internal cured concretes with water to binder ratio of 0.62, 0.43 and 0.30, representing low, middle and high strength concrete in practice respectively, is experimentally investigated by measuring the internal relative humidity at some selected locations in the concrete samples. Two parallel concrete specimens under fully plastic film sealing and drying conditions respectively were employed in tests. The mechanism of internal relative humidity development in concrete since casting was analyzed. Second, based on the experimental findings, mathematical modeling on moisture distribution of internal cured concrete, in terms of internal relative humidity distribution and its variation with time, was conducted and discussed in details. Finally, the effect of environmental humidity and internal curing degree, which are both principal parameters for concrete curing in practice, on progress of internal humidity in the three concretes is analyzed using the developed model.

2. Experimental program

2.1. Details of materials and specimens

Three basic concrete mixtures with water to binder ratio of 0.62, 0.43 and 0.30, representing low, middle and high strength concrete in practice respectively, were used in the experiments. Based on the above basic mixtures, three corresponding internal cured mixtures were designed with a certain amount of normal aggregates replaced by PSLWA according to the same volume replacement. The mixtures of concrete containing lightweight aggregate are designed according to the amount of internal curing water required based on the above basic mixture proportion. Fly ash based lightweight aggregate with particle size of 2–5 mm, porosity of 0.27, water absorption of 21% after 7 days of soaking, dry density of 1375 kg/m^3 was used as carrier of internal curing water. Fig. 1(a) is the photograph of the lightweight aggregate used in experiments. Fig. 1(b) presents the dewater characteristic

(a)



(b)

Fig. 1. Photograph of the lightweight aggregate (a) and the dewater characteristic of the pre-soaked lightweight aggregate (b).

of the PSLWA in terms of water content in percentage of dry lightweight aggregate and environmental relative humidity under 23 °C. All mixtures were made with the same Portland cement. Natural sand and crushed limestone with a maximum particle size of 5 mm and 20 mm, respectively, were used as normal fine and coarse aggregates. Concrete mixture proportions and compressive strength at 28 days are listed in Table 1. A superplasticizing admixture was used in the mixtures to ensure that the three concretes have a comparable slump in 80–100 mm. According to the compressive strength, we denote the three concretes as C30, C50 and C80 respectively. A mold with the inner dimension of 100 × 100 × 400 mm was used to cast the specimen. To create the space for drying, one removable plastic filler with a dimension of 100 × 100 × 50 mm was used at one-end of the mold. Thus, the actual dimension of the specimen was 100 × 100 × 350 mm, as showed in Fig. 2. For each concrete, two parallel specimens were cast at the same time. One used for drying test and the other used as a reference specimen under continuous plastic film sealing.

2.2. Devices for measuring the internal relative humidity and temperature

In the present study, resistance based digital sensor was used for relative humidity and temperature measurements. The accuracy of the relative humidity and temperature measurements is 1.5–2% and 0.5 °C respectively. A total of five sensors were used for each concrete. Three were used in the drying specimen and two were used in the sealing specimen. The location of the sensor in drying and sealing specimens is shown in Fig. 2a and b respectively. In order to maintain the sensor at the desired location in the concrete, a PVC tube with an inner diameter of 15 mm was used to hold the sensor. One end of the PVC tube was covered with a plastic sheet glued to the end. To maintain the moisture exchange with the surrounding concrete, three rectangular holes were made at the surface of the PVC tube (see Fig. 2c). In order to prevent fresh cement paste from flowing into the tube through the oblong holes, an aluminum bar with a little smaller diameter than that of the PVC tube was put into the tube first during concrete casting. A few minutes after casting, the steel bar was removed from the tube and the sensor was inserted. To ensure that the measured humidity and temperature are the actual values inside

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