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Early-age tensile creep and cracking potential of concrete internally cured with pre-wetted lightweight aggregate

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HIGHLIGHTS

- The autogenous shrinkage of concrete reduces for internal curing.
- The early-age basic tensile creep of concrete reduces for internal curing.
- The early-age cracking potential of concrete reduces for internal curing.

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ABSTRACT

High-performance concrete (HPC) is widely used in practice due to its potential long-term benefits, such as high strength and low permeability. However, high self-desiccation and high temperature rise occur due to the low water-to-cement (w/c) ratio of HPC, both of which would increase the cracking potential of concrete at early age. Although the creep and cracking potential of early-age HPC have been investigated, studies on the tensile creep and cracking potential of internally cured concrete with pre-wetted lightweight aggregates (LWAs) at early age under adiabatic condition at various w/c ratios remain lacking. In present study, the tensile creep and cracking potential of concrete at early age were experimentally investigated under adiabatic condition using the temperature stress test machine. Test results and corresponding analysis showed that: (1) a model for predicting the compressive strength of concrete was presented in consideration of the influence of pre-wetted LWAs; (2) the adding of pre-wetted LWAs reduced the autogenous shrinkage of concrete with different basic w/c ratios; (3) the basic tensile creep/shrinkage and absolute value of basic tensile creep of internally cured concrete were lower than that of normal concrete when the basic w/c ratios were the same; (4) the basic tensile creep/shrinkage and absolute value of specific basic tensile creep of normal and internally cured concrete at the age of cracking both increased with the decrease of basic w/c ratio; (5) the cracking potential of normal and internally cured concrete both increased with the decrease of basic w/c ratio and the adding of pre-wetted LWAs reduced the cracking potential.

1. Introduction

Concrete has undergone significant changes for the past decades, water-to-cement (w/c) ratio is reduced in practice in order to obtain high-performance concrete (HPC) [1–4]. Low permeability, high modulus, and high strength are achieved due to the low w/c ratio of HPC [5], however, along with the low w/c ratio, some drawbacks such as high temperature rise and high self-desiccation in the concrete [6,7] also occur, both of which can increase the potential for cracking of concrete at early age and then decrease the service life of concrete structures [8,9]. Autogenous shrinkage, which is a consequence of self-desiccation of concrete, is a significant issue at early age that leads to excessive distortions and even cracking if restrained internally by aggregates skeleton and externally by the hyperstaticity of the structure [10]. Concrete with low w/c ratio does not have insufficient water to hydrate the cement [11]. Internal curing (IC) method is used to reduce the early-age cracking potential of concrete. Usually, pre-wetted lightweight aggregates (LWAs) are added to the concrete to play the role of

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water reservoir. The pre-wetted fine LWAs is also utilized to prevent autogenous shrinkage cracking [12]. Therefore, assessing the early-age cracking potential of internally cured concrete with pre-wetted LWAs is necessary.

High thermal stresses occur in mass concrete and cracking will be a main concern. It is difficult to quantify the stress development and evaluate the cracking potential of concrete structures [13]. Most experiments about the influence of pre-wetted LWAs on the cracking potential are conducted by ring or doubly restrained plate [14,15], and the temperature profiles are mostly constant temperature [14–16]. However, the restraint degree cannot be kept constant in ring test and the restrained stress cannot be obtained by doubly restrained plate [14]. Therefore, a uniaxial restrained device called temperature stress test machine (TSTM) is modified in [17] to determine temperature change, stress development, deformation, and creep of concrete at early age at uniaxial constant restraint degree. Result in [7] shows that adiabatic temperature rise profile is more close to the interior temperature of mass concrete. The early-age cracking potential of concrete could be evaluated using TSTM under adiabatic condition. Although studies on the influence of the amounts of pre-wetted LWAs and different curing temperatures on the cracking potential of concrete using TSTM have been conducted [18,19], the studies on the influence of w/c ratio on the early-age internally cured concrete with pre-wetted LWAs using TSTM remain lacking. Therefore, the influence of w/c ratio on the early-age cracking potential of internally cured concrete with pre-wetted LWAs under adiabatic condition and at uniaxial constant restraint degree needs to be studied.

Early-age tensile creep has a significant impact on the shrinkage and stress development. Although most experiments about the creep of concrete are conducted at mature age, the studies about the early-age creep of internally cured concrete remain lacking [20]. Early-age creep of concrete under tensile condition is different from that under compressive condition [21]. However, the early-age tensile creep is hard to measure due to the constantly changing physical and chemical properties [13]. The tensile creep can be obtained by free and restrained shrinkage test simultaneously using TSTM [17]. The creep of concrete with pre-wetted LWAs at early age has not been systematically investigated, especially for tensile creep [22]. Results on the influence of pre-wetted LWAs on the creep at early age are inconsistent. Result in [12] shows that the creep increases with the increase of the amounts of pre-wetted LWAs. However, result in [22] shows that the specific creep of concrete decreases due to the adding of pre-wetted LWAs. Results on the influence of w/c ratio on the tensile creep of concrete at early age are also inconsistent. Results in [23] show that the specific tensile creep of concrete with Cement Type I at early age decreases with the decrease of w/c ratio, while results in [24] show that the specific tensile creep of normal concrete and concrete with steel fiber at early age increases with the decrease of w/c ratio. Therefore, investigations on the influence of w/c ratio and pre-wetted LWAs on the tensile creep of concrete at early age remain lacking. Thus, studying the influence of w/c ratio and pre-wetted LWAs on the tensile creep of concrete under adiabatic condition and at uniaxial constant restraint degree using TSTM at early age is necessary.

Although the early-age cracking potential of concrete with different w/c ratios or pre-wetted LWAs has been studied [14,25], temperature, restrained stress, autogenous shrinkage, and tensile creep are not considered simultaneously under adiabatic condition. Thus, the influence of w/c ratio and pre-wetted LWAs on strength, restrained stress, autogenous shrinkage, tensile creep, and cracking potential under adiabatic condition and at uniaxial constant restraint degree should be further investigated using TSTM for better understanding the cracking potential of early-age concrete.

2. Experimental program

2.1. Mixture proportions and materials

Six concrete mixture designs were evaluated in present study. Each mixture was identified by a label X-Y. The first part of the specimen name X referred to type of concrete (i.e., NC = normal weight concrete; IC = internal curing concrete), Y indicated the basic w/c ratio of concrete (i.e., 33 = 0.33 (basic w/c ratio); 40 = 0.40 (basic w/c ratio); 50 = 0.50 (basic w/c ratio)). Mixtures NC-33, NC-40, and NC-50 were the reference concrete without IC and the basic w/c ratio was 0.33, 0.40, and 0.50, respectively. Mixtures IC-33, IC-40, and IC-50 were the internally cured concrete with pre-wetted LWAs and the basic w/c ratio was 0.33, 0.40, and 0.50, respectively. The LWAs had a 24 h absorption value of 12% by mass of the dry material. The water absorbed by LWAs is defined as entrained water, as reported in [26]. The entrained water was 16.1, 16.6, and 16.8 kg/m^3 for mixtures IC-33, IC-40, and IC-50, respectively, as shown in Table 1. Therefore, the entrained w/c ratio was 0.031, 0.037, and 0.042 for mixtures IC-33, IC-40, and IC-50, respectively. The total w/c ratio is defined as the sum of basic w/c ratio and entrained w/c ratio [26]. Therefore, the total w/c ratio w_t/c was 0.361, 0.437, and 0.542 for mixtures IC-33, IC-40, and IC-50, respectively. Mixture designs are shown in Table 1. The normal weight coarse aggregates were replaced by pre-wetted LWAs of the same diameter by volume in present study, and the replacement ratios were all about 30% of the total volume of coarse aggregates for the internally cured concrete. The cement contents were not kept constant in concrete mixtures in present study, which was similar to the mixtures reported in [27–29].

Ordinary Portland Cement (Cement II 52.5R) was employed in accordance with China National Standard GB 175-2009. The chemical compositions of the cement are shown in Table 2. The Blaine fineness of the cement was 375 m^2/kg and the loss on ignition was 3.11%. The fineness modulus of river sand used in present study was 2.05 and the maximum size was 1.8 mm. The coarse aggregates used in present study were crushed limestone and the maximum size was 26 mm. The LWAs used in mixtures IC-33, IC-40, and IC-50 were manufactured rotary kiln expanded clay. The LWAs had a dry-bulk density of 1050 kg/m^3. The image and the sieving curve of the LWAs are shown in Fig. 1. A liquid polycarboxylate-based superplasticizer was added to mixtures NC-33, NC-40, IC-33, and IC-40. Tap water was used as mixture water. The concrete was mixed for about 2 min.

2.2. Test details

A TSTM system developed in [17] is modified for testing shrinkage of sealed specimens under free and restrained conditions. Three temperature history profiles could be achieved by the modified TSTM system, such as constant temperature, simulated actual temperature of concrete in reality, and adiabatic temperature rise. TSTM system used in present study has been used in different experiments, such as in [18,19]. There were two molds in one TSTM system called free and restrained specimens for calculating the creep and elastic deformation. In order to obtain the temperature history, the temperature sensors were anchored in concrete. Adiabatic condition is realized by circulating a specific liquid, of which the temperature is controlled to be the same as the specimen, along the sides of molds [18,19,30]. The adiabatic temperature rise of concrete is related to the following parameters [31]: the proportion and chemical composition of the cement (of blended cement); the fineness and particle size distribution of the cement; the w/c ratio; the initial reaction temperature; the