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Tensile creep and cracking potential of high performance concrete internally cured with super absorbent polymers at early age

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HIGHLIGHTS

- The tensile creep and cracking potential considering SAPs were studied by TSTM.
- The temperature rise of concrete increased with the increase of SAPs amounts.
- The specific basic tensile creep decreased with the increase of SAPs amounts.
- A model for tensile creep compliance function considering SAPs was proposed.
- The cracking potential at early age decreased with the increase of SAPs amounts.

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ABSTRACT

High performance concrete (HPC) has been extensively applied in practice. However, the water-to-cement (w/c) ratio of this concrete is low, high temperature rise and high self-desiccation will occur, and both of which can increase the cracking potential of HPC at early age and then decrease the service life of concrete structures. Therefore, super absorbent polymers (SAPs) are applied in HPC as an internal curing (IC) agent. Although the autogenous shrinkage, relative humidity, and stress relaxation of concrete internally cured with SAPs have been studied, investigations on the influence of SAPs on the tensile creep and cracking potential of HPC are still lacking. In present study, the influence of SAPs as an IC agent on the temperature, autogenous shrinkage, restrained stress, basic tensile creep, and cracking potential of HPC were simultaneously studied by Temperature Stress Test Machine. Test results and corresponding analysis showed that: (1) the adiabatic temperature rise of HPC was 27.6, 29.3, 31.0, and 34.9 °C and increased with the increase of amount of SAPs; (2) the rate of restrained tensile stress of HPC was 1.7, 1.5, 1.4, and 1.2 MPa/day and decreased with the increase of amount of SAPs; (3) the specific basic tensile creep of HPC at the age when the restrained specimen of mixture SAP-0 cracked was 45, 23, 13, and 7 με/MPa and decreased with the increase of amount of SAPs; (4) a model for predicting the basic tensile creep compliance function of HPC considering the influence of amount of SAPs was proposed; (5) the cracking potential of HPC which was based on the integrated criterion decreased with the increase of amount of SAPs.

1. Introduction

High performance concrete (HPC) has been extensively applied in many key constructions such as high-rise buildings which need long durability [1,2]. With the application of lower and lower water-to-cement (w/c) ratio (w/c ratio < 0.40), higher strength, higher modulus, and lower permeability are achieved. However, along with this low w/c ratio, some drawbacks such as high temperature rise and high self-desiccation in the concrete [3,4] also occur, both of which can increase the cracking potential of concrete at early age and then decrease the service life of concrete structures [5,6]. Traditional external curing through water ponding may not be effective in large concrete elements due to the low permeability of HPC, which prohibits water from permeating through the concrete [7]. Internal curing (IC) has developed as a new

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method that holds promise for producing concrete with reduced early-age cracking potential and enhanced durability [8]. It has been proved to be a very promising way to reduce self-desiccation and induced autogenous shrinkage [4,9]. Several materials are applied in HPC as IC agents, such as lightweight aggregates, wood fibers, and super absorbent polymers (SAPs) [10,11]. SAPs are cross-linked polyelectrolytes which start to swell upon contact with water resulting in the formation of a hydrogel [12]. SAPs are developed in the late 1980 s and are applied in diapers firstly [12]. Then it is applied in HPC because it can absorb amount of water many times of its own weight, retain it, and release it when the internal or external environments change [13]. SAPs can provide internal water equally throughout the cross section and increase the degree of reaction of the cement and other supplemental cementitious materials [14]. The self-desiccation of HPC at early age will be reduced by the addition of SAPs. Therefore, investigations on the cracking potential of HPC internally cured with SAPs at early age are necessary.

The cracking potential of HPC at early age is influenced by many factors, such as autogenous shrinkage, restrained stress, and tensile creep. Autogenous shrinkage is one of the main causes of cracking in concrete at early age especially for HPC [15]. Autogenous shrinkage is caused by self-desiccation which occurs when the w/c ratio of concrete is low. If the concrete structures are restrained, restrained tensile stress will occur due to the shrinkage of concrete, and cracking will be observed when the restrained tensile stress is beyond the tensile strength of concrete at early age [16]. Attacking species will migrate into the concrete and reduce the durability of structure through the cracks [17]. Therefore, it is important to reduce the cracking potential of HPC at early age in order to ensure the durability of structures. Studies on the drying shrinkage [18], tensile relaxation [19], restrained stress [19], autogenous shrinkage [20], and internal relative humidity [21] of concrete and mortar internally cured with SAPs have been conducted. However, investigations on the cracking potential of HPC internally cured with SAPs at early age are still lacking. Therefore, investigations on the restrained stress and autogenous shrinkage are necessary for better understanding the cracking potential of HPC internally cured with SAPs at early age.

Tensile creep is important for evaluating the cracking potential of HPC correctly and is relevant for durability of concrete in case of restrained shrinkage at early age. The effect of tensile creep is found to be relatively large and significant in development of self-induced stress [24]. Tensile creep can reduce detrimental stress when the early-age concrete is particularly weak. Compressive creep of early-age concrete and mature concrete has been evaluated [25,26], however, limit literatures about tensile creep of HPC at early age are available due to the difficulties of measuring tensile creep accurately (the constantly changing physical and chemical properties) [27]. Investigations on the influence of IC on the tensile creep of HPC at early age are lacking and there is no consistency about the influence of IC on the tensile creep of HPC. The tensile creep of HPC internally cured with pre-wetted lightweight aggregates with the same total w/c ratio is evaluated in [28], and results in [28] show that the tensile creep coefficient increases for the HPC internally cured with pre-wetted lightweight aggregates. Results in [29] show that the compressive creep of concrete internally cured with SAPs is higher than that of normal concrete without SAPs. Results in [30] show that the tensile creep of concrete internally cured with SAPs is lower than that of normal concrete without SAPs with the same total w/c ratio and comparable to that of normal concrete without SAPs with the same basic w/c ratio. Therefore, the influences of IC on the creep behavior are inconsistent. Early-age creep of concrete under tensile condition is different from that under compressive condition [31]. The tensile creep has been evaluated using ring test [21–23], however, the restraint degree cannot be kept constant in ring test. The tensile creep varies at constant and changeable restraint degree [27]. Uniaxial constant restraint degree can be achieved and the tensile creep can be obtained by free and restrained shrinkage test simultaneously using the Temperature Stress Test Machine (TSTM) [32,33]. TSTM is modified in [32] to determine temperature change, stress development, deformation, and creep of concrete at early age at uniaxial constant restraint degree. The adiabatic temperature rise profile can be realized by TSTM. Results in [4] show that adiabatic temperature rise profile is more close to the interior temperature of mass concrete. Therefore, the early-age cracking potential of internally cured HPC could be evaluated using TSTM under adiabatic condition. However, investigations on the cracking potential of early-age HPC internally cured with SAPs using TSTM under adiabatic condition at uniaxial constant restraint degree remain lacking. Therefore, the influence of SAPs on early-age tensile creep and cracking potential of internally cured HPC under adiabatic condition at uniaxial constant restraint degree needs to be further investigated using TSTM.

The majorities of available studies concerning the early-age cracking potential of concrete at early age internally cured with SAPs do not simultaneously consider temperature history, autogenous shrinkage, restrained stress development, and tensile creep under adiabatic condition [19–21]. The influence of all relevant parameters must be studied and quantified to investigate the early-age cracking potential of concrete internally cured with SAPs more accurately. However, relevant studies are still lacking. Therefore, whether and how SAPs influence the tensile creep and cracking potential of HPC at early age need to be further studied. In present study, the influence of SAPs as an IC agent on the temperature, autogenous shrinkage, restrained stress, tensile creep, and cracking potential of internally cured HPC at early age were simultaneously studied using TSTM. Furthermore, a model for the tensile creep compliance function of internally cured HPC was proposed based on the test results in consideration of the amount of SAPs.

2. Experimental program

2.1. Mixture proportions and materials

Four HPC mix 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., SAP = concrete internally cured with SAPs), Y indicated the percentages of amount of SAPs to amount of cement (i.e., 17, 35, and 49 represented that the amount of SAPs was about equal to 0.17%, 0.35%, and 0.49% by mass of cement). Four mix designs were named as SAP-0, SAP-17, SAP-35, and SAP-49. Mixture SAP-0 was the reference concrete without SAPs and the basic w/c ratio was 0.33. Mixtures SAP-17, SAP-35, and SAP-49 were the HPC internally cured with SAPs. The SAPs used in present study is shown in Fig. 1.

The water absorbed by dry SAPs is defined as IC water in [1]. Therefore, the IC w/c ratio is defined as the IC w/c ratio. The quantity of IC water needed to ensure adequate water for the maximum degree of hydration and the amount of SAPs needed to hold the IC water can be calculated with the following equation [34].

$$V_{wat} = C_f \times CS \times \alpha_{\max} \quad (1)$$

where V_{wat} is the volume of water per unit volume of concrete needed to fill the empty capillary pores in the paste resulting from chemical shrinkage in kg/m^3; C_f is the cement content of the mixture in kg/m^3; CS is the chemical shrinkage of the cement at complete (100%) hydration (kg of water/kg of cement) with a typical conservation value of 0.07 kg of water/kg of cement for Portland cement [34]; $\alpha_{\max}$ is the maximum expected degree of hydration