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Influence of prewetted lightweight aggregates on the behavior and cracking potential of internally cured concrete at an early age

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HIGHLIGHTS

- TSTM is employed to investigate the cracking potential of internally cured concrete.
- The cracking stress of concrete decreased with an increase in the amount of LWAs.
- The compressive creep of concrete increased with an increase in the amount of LWAs.
- The ratio of cracking stress to tensile strength increased with an increase in LWAs.
- The cracking potential of internally cured concrete with prewetted LWAs was reduced.

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ABSTRACT

High-performance concrete (HPC) is widely used in practice. The water-to-cement ratio of HPC is low, and self-desiccation and high temperature rise occur. Internal curing (IC) with prewetted lightweight aggregates (LWAs) is applied to enhance the early-age behavior of concrete structures in terms of temperature, shrinkage, creep deformation, and stress, thus resulting in low cracking potential. Although tests on the effect of prewetted LWAs on the cracking potential of concrete under semi-adiabatic or isothermal conditions have been conducted, studies on the influence of the amount of prewetted LWAs on the cracking potential of internally cured concrete under adiabatic conditions remain lacking. In this study, the cracking potential of internally cured concrete with prewetted LWAs was experimentally investigated with a temperature stress testing machine. The effect of prewetted LWAs in reducing the cracking potential in HPC was investigated with different amounts of LWAs (0%, 10%, 30%, and 50%) in four pairs of large prismatic HPC specimens tested simultaneously under free and fully restrained shrinkage. Test results showed that (1) both temperature rise and drop of concrete occurred as prewetted LWAs increased; (2) the autogenous shrinkage and cracking stress of concrete decreased with the increase in the amount of prewetted LWAs; (3) the tensile stress rate of concrete with prewetted LWAs decreased; (4) the ratio of cracking stress to the tensile strength of concrete increased with the increase in the amount of prewetted LWAs; (5) the cracking age of concrete with the LWAs increased; (6) the specific tensile creep of concrete with prewetted LWAs decreased; and (7) the cracking potential of concrete with prewetted LWAs was reduced, as obtained from the integrated criterion. Internally cured concrete with prewetted clay LWAs is more robust for construction at early ages.

1. Introduction

With the increasing promoted use of high-performance concrete (HPC), decreasing water-to-cement (*w/c*) ratio is being applied in practice [1–3]. Although HPC can offer high strength and low permeability, this lower *w/c* ratio comes with other drawbacks, including high self-desiccation [4,5] and high temperature rise in the concrete [6]. Self-desiccation, which induces marked autogenous shrinkage, leads to higher cracking potential [7]. Given

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that less water and more cement are used in HPC to attain high strength, the available water in the hydration progress decreases, and the inner concrete environment yields a lower chemical potential of water [8]. Although external water curing is utilized in HPC, its cracking potential is increased because of the low penetration of concrete with low *w/c* ratio [9]. Therefore, internal curing (IC) technology is employed to reduce the cracking potential [10]. IC, which is defined by the American Concrete Institute as "a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water" was proposed by Robert Philleo as a means of avoiding self-desiccation using saturated lightweight fine aggregate in high-strength concrete in 1991 [11]. IC provides curing water equally throughout the cross section in the concrete structure, whereas external curing water can only penetrate several millimeters into concrete with low *w/c* ratio [9]. IC water can also increase the degree of reaction of the cement and other supplemental cementitious materials [9]. IC keeps the pores within the hydrating cement paste fluid filled and thus helps reduce or even eliminate capillary stress, thereby minimizing the likelihood of cracking [12]. An experimental study on the stress development, temperature drop necessary to crack, and cracking age of mortars containing prewetted lightweight aggregates (LWAs) with the dual ring test has shown a lower rate of stress development, higher temperature drop, and longer age to crack [9]. Internally cured concrete with a larger amount of LWAs shows a greater reduction in the rate and volume of autogenous shrinkage [2], and the use of LWAs with reduced stiffness can improve the shrinkage cracking resistance of concrete [13]. As a result, the cracking potential is reduced in internally cured concrete with prewetted LWAs.

Temperature stress testing machine (TSTM) is employed to study the early-age cracking behavior of concrete with prewetted LWAs [5,14]. This device enables measurements directly after casting. This characteristic is important because autogenous shrinkage has to be measured accurately at very early age (<24 h). The characteristics of early-age concrete, including temperature change, strain, restrained stress, and creep, can be determined in one TSTM test [15]. Therefore, studying the cracking resistance of internally cured concrete with prewetted LWAs by using TSTM is necessary to thoroughly understand the mechanism.

The cracking resistance of early-age concrete is affected by the temperature history [6]. The isothermal condition is used to study the cracking resistance of early-age concrete by single or dual ring test [10], and semi-adiabatic or isothermal conditions are adopted with TSTMs [1,5,16,17]. The performance of mortar with different amount of fly ash cured at semi-adiabatic condition was also investigated using the dual ring [6,9]. The interior concrete of mass concrete is close to adiabatic temperature rise [6,18]. The cracking resistance of early-age concrete under adiabatic conditions has been investigated with TSTM [19]. Cracking temperature drop is increased in internally cured concrete [12]. However, results on cracking resistance of internally cured concrete at early age under adiabatic conditions using TSTM remain lacking. Thus, the effect of prewetted LWAs on temperature change and the cracking resistance of concrete under adiabatic conditions should be studied.

Early-age creep is important in evaluating the cracking resistance of concrete. The restrained stress and cracking potential in early-age mortar cured at isothermal condition with different amount of prewetted LWAs or concrete are influenced by creep [10,14,20]. The early-age creep of concrete is difficult to measure because physical and chemical properties simultaneously change at early ages [21]. Creep strain of early-age concrete can be obtained by simultaneous testing on restrained and free shrinkage specimens with TSTM [15]. TSTM has been utilized to indirectly determine the tensile creep of high-strength concrete under uniaxial non-constant tensile loading at early ages [1]. A few studies have concentrated on the early-age creep of concrete mixed with prewetted LWAs, but the effect of prewetted LWAs on creep has not been systematically investigated [22]. The creep of internally cured concrete with prewetted LWAs under non-constant stress has been studied with modified TSTM [5], and the amount of total water (mix water and IC water) is kept the same [14] while the total *w/c* was normally increased by internal curing water provided by LWAs to promote hydration. An experimental study on the compressive creep of internally cured concrete under constant loading has been conducted [22]. The tensile creep of internally cured concrete under changing restraint degree has been conducted with the dual ring test [14]. The restraint degree of ring was changing constantly [10] and cannot be controlled. Test result shows that the creeps of early-age concrete under constant and varying restraint degree are different, and the development of stress and microcracking of concrete was also affected by the creep [20]. Thus, the cracking resistance of concrete is influenced by restrained degree. Investigation on the early-age tensile creep of internally cured concrete with LWAs under constant restraint degree is still lacking. Although the amount of prewetted LWAs has been shown to affect the efficiency of IC on concrete [23], the effect of the amount of prewetted LWAs on tensile creep has not been studied. Thus, the influence of the amount of prewetted LWAs on creep of internally cured concrete with different amounts of total water under constant restraint degree needs to be further investigated using TSTM.

However, the majority of available studies concerning the cracking resistance of internally cured concrete with prewetted LWAs did not simultaneously consider temperature history, autogenous shrinkage, restraint, and creep under adiabatic conditions [6,10]. Although internally cured concrete with prewetted LWAs has been adopted in several projects [24,25], such as the Indiana deck, it has not been used in mass concrete in which the temperature variation is close to adiabatic condition. Thus, whether and how prewetted LWAs influence the cracking resistance of concrete need to be investigated. The effect of prewetted LWAs on temperature history, restrained stress development, autogenous shrinkage, creep behavior, and cracking potential needs to be studied further to better understand the cracking resistance of concrete with prewetted lightweight clay aggregates.

2. Experimental program

2.1. Mixture proportions

Four concrete mixtures with low *w/c* ratio were used in this study. The mixture proportions, designated as LWA-0, LWA-10, LWA-30, and LWA-50. Mixture LWA-0 is the reference concrete with no IC, and Mixtures LWA-10, LWA-30, and LWA-50 use IC with prewetted LWA [14,26]. For the internally cured concrete in which part of the normal-weight coarse aggregate is replaced with LWAs, the replacement ratios of coarse aggregates are 10%, 30%, and 50% of the total volume of coarse aggregates for Mixtures LWA-10, LWA-30, and LWA-50, respectively. All mixtures have a *w/c* ratio of 0.33.

2.2. Materials

Ordinary Portland Cement (Cement II 52.5R) with a Blaine fineness of 375 m^2/kg was employed in accordance with China National Standard GB 175–2009. The physical and chemical compositions of the cement are provided in Table 1. The strength characteristics of the cement are shown in Table 2; the initial setting time is 168 min, the final setting time is 223 min, the compressive strength in 3 days is 36.4 MPa, and the compressive