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Efficacy of internal curing combined with expansive agent in mitigating shrinkage deformation of concrete under variable temperature condition

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HIGHLIGHTS

- Internal curing (IC) combined with expansive agent (EA) was used to mitigate early-age cracking in sidewall concrete.
- IC shows a higher efficacy during temperature drop stage than EA and can provide continuous expansion at the later stage compared with Ref.
- The combined use of SLWA and EA exhibits high efficacy in mitigating shrinkage deformation and can limit the reduction of mechanical properties caused by a single EA.

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ABSTRACT

The benefits of internal curing (IC) have been confirmed by extensive laboratory studies under constant room temperature. In practical engineering, sidewall concrete undergoes a variable temperature evolution, which involves significant physical, chemical, and thermal changes during the hydration process at the early age and a high cracking risk at the temperature drop stage. Expansive agent (EA) has always been used to mitigate early-age cracking, but it has limited efficacy in the temperature drop stage and low mechanical properties. This study examines the efficacy of IC through pre-soaked lightweight aggregate (SLWA) and the combined use of SLWA and EA in mitigating shrinkage deformation under constant and variable temperature conditions. Results indicate that SLWA shows a higher efficacy than EA in mitigating shrinkage deformation during the temperature drop stage and can provide continuous expansion at the later stage. The combined use of SLWA and EA exhibits high efficacy in mitigating shrinkage deformation under constant and variable temperature conditions and can limit the reduction of mechanical properties caused by a single EA.

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1. Introduction

Concrete undergoes significant physical, chemical, and thermal changes during the hydration process at the early age [1–3], and this multi-field phenomenon definitely causes deformation and induces stress inside the concrete with restraint that lead to cracking when the stress exceeds the tensile strength of concrete [4,5]. The early-age cracking phenomenon becomes prominent with the increase in the fineness and early hydration rate of cement particles. The phenomenon often occurs prior to the application of external loads on the sidewall of urban rail transit engineering and other underground space engineering. The appearance of cracks compromises the durability of the concrete structure in terms of service life, and the repair of the cracks entails significant additional cost [6,7], as shown in Fig. 1. Therefore, adequate precautions are necessary to minimize the risk of early-age cracking in modern concrete.

Early-age volume deformation and cracking are attributed to two typical reasons [1], namely, (1) moisture deformation, including autogenous shrinkage due to water consumption during hydration and drying shrinkage due to the release of water from the concrete surface, and (2) thermal deformation, including thermal expansion and shrinkage due to hydration heat and the heat exchange between environment and concrete. Thermal cracks become serious with the early removal of formwork and the sudden decrease in environment temperature. Hence, effective methods to mitigate early-age cracking include preventing the internal and surface moisture losses of concretes and compensating for shrinkage during the temperature drop stage. Researchers have suggested several approaches to mitigate shrinkage cracking, such

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Fig. 1. Cracks on the sidewall and their repair in building engineering (a: urban rail transit engineering, Shengzhen City; b: water works, Yancheng City; c: grouting repair on urban rail transit sidewall, Changzhou City).

as the use of expansive agent (EA) to provide early-age expansion to counteract drying shrinkage [8–10] and the addition of pre-soaked lightweight aggregate (SLWA)[11–15]and superabsorbent polymer(SAP)[16–18] to provide internal curing (IC) water to reduce the effects of self-desiccation. Wyrzykowski and Lura [19,20] demonstrated that the effect of IC on self-desiccation is beneficial to reducing not only the autogenous shrinkage but also the thermal expansion of the material because the coefficient of the thermal expansion of concrete depends on the internal relative humidity and decreases with self-desiccation. Thus, IC can be used to decrease the coefficient of thermal expansion at the early ages and the risk of thermal cracking.

The use of SLWA and EA has shown benefits in laboratory testing at constant temperature [8–10,21–23]. However, whether the laboratory results accurately represent the behavior of field concrete is unclear because field concrete undergoes variable temperature conditions after being cast, such as sidewall concrete (the thickness is 0.70 m and the sensor was installed in the middle of the sidewall.), as shown in Fig. 2. Although the use of EA, such as CaO-based EA, can produce a certain volume expansion at the early-age, the expansion is limited during the temperature drop stage, and the addition of EA may reduce the concrete strength. Consequently, the field concrete still possesses a high cracking risk during the temperature drop stage. Several researchers [24–26] suggested that adding SAP into expansive concrete can increase the cracking resistance of concrete, but a reduction of strength was always observed. Chen et al. [27] investigated the effects of EA and shale pottery on shrinkage reduction of lower w/c mortar,

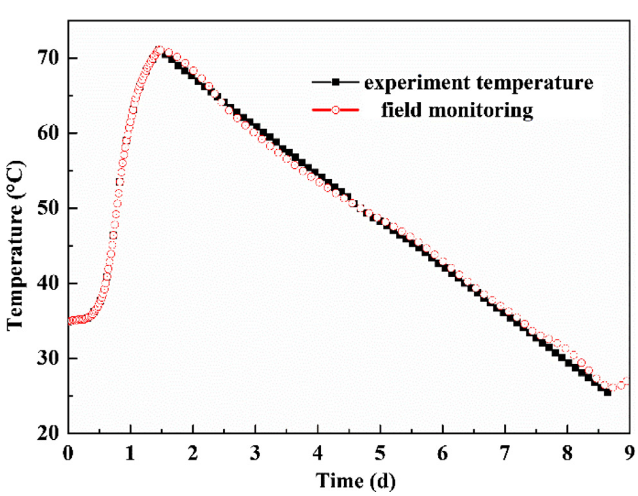

Fig. 2. Temperature evolution.

their results showed that the adverse effects on strength can be decreased by reducing the amount of shale pottery, and suggested that the combination of EA and internal curing of shale pottery would be a potential way to reduce the shrinkage of cement-based materials with a lower water-cement ratio. In a recent study [28], IC by fine LWA was used to overcome the disadvantages of heat-cured concrete, such as increasing strength and penetration resistance, but the shrinkage deformation was not discussed. In fact, few reports on the evaluation of IC using SLWA or IC combined with EA under variable temperature conditions exist. So, the efficacy of SLWA combined with EA in mitigating the shrinkage deformation of sidewall concrete under variable temperature conditions has attracted the attention of researchers.

In this study, the early-age deformation of sidewall concrete was evaluated under standard and variable temperature environments. The mix proportion and raw materials were consistent with those of the building urban railway station, and the variable temperature process was obtained from field monitoring. Mechanical properties, including compressive strength, splitting tensile strength, and elastic modulus, were also studied.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC) with a Blaine fineness of 364 m^2/kg and fly ash (FA) with a Blaine fineness of 282 m^2/kg were used in the study. The use of FA as a cement replacement in concrete reduces the rise in temperature. Thus, concrete containing FA has been widely used in fields or applications where thermal cracking due to the heat of hydration should be avoided, such as in dam construction and large foundations, including sidewalls [29–31]. Considering that FA contributes insignificantly to the compressive strength at early ages and the strength requirement of engineering, we replaced 32.4% (by mass) of the OPC in the sidewall concrete with FA to decrease the early-age autogenous shrinkage and temperature rise, as shown in Table 1. Blast furnace slag (BFS), either as a cement constituent or as a mineral admixture, has been widely applied in marine concrete because of its low permeability and refined pores. However, the use of BFS causes high autogenous shrinkage and increases the cracking risk in concrete structures. High autogenous shrinkage is ascribed to two phenomena [32–36]. One, chemical shrinkage of concrete containing BFS is greater than that of the concrete with pure Portland cement or FA. Second, the use of BFS leads to a fine cement paste pore structure, which contributes to low relative humidity and thus increases the degree of self-desiccation within the cement paste. So, BFS was not used in the project to further decrease the cracking risk in sidewall concrete. Natural river sand (S) with a fineness modulus of 2.72 and an apparent specific gravity of 2.60 and limestone (G) with a size distribution that ranges from 5 mm to 20 mm were used as the fine and coarse aggregates, respectively. Two expanded shale lightweight fine aggregates (LWAs) with a fineness modulus of 3.3 and apparent specific gravity values of 1.15 (marked A) and 1.42 (marked B) were used as IC agents. The LWAs had a 24-h water absorption of 22.7% and 11.9% according the paper towel method for A and B, respectively [37]. A commercial CaO-based EA, which was also adopted in the building station, was used in this study. A polycarboxylate-based superplasticizer was used at a rate by mass of 0.85% of cementitious materials in all mixtures.

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