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Review

An overview on the effect of internal curing on shrinkage of high performance cement-based materials

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HIGHLIGHTS

- Internal curing (IC) material is divided into two categories based on the water absorbing mechanism.
- The effect of (IC) on autogenous shrinkage is explained by internal RH and the saturation degree of critical capillary pores.
- Drying shrinkage under (IC) is related to the surface porosity of cement-based materials.

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ABSTRACT

High performance cement-based materials, such as high or ultra-high performance concrete (HPC or UHPC) have been widely used and still faces the risk of cracking caused by shrinkages, especially autogenous shrinkage. Internal curing is an effective method to reduce or even eliminate autogenous shrinkage and has effects on chemical shrinkage, dry shrinkage, etc. The commonly used internal curing materials include super-absorbent polymer (SAP) and porous materials. Porous materials refer to lightweight aggregate (LWA) and porous superfine powders. In this paper, the internal curing materials has been divided into two categories based on water absorbing mechanism. The effects of these two categories of internal curing materials on shrinkage of high performance cement-based materials are reviewed. The addition of internal curing materials releases internal curing water, postpones the drop of internal RH, and reduces autogenous shrinkage, but increase chemical shrinkage. The addition of internal curing materials with extra water increases drying shrinkage. The mechanisms of shrinkage on internal curing are also summarized and discussed. However, those mechanisms only focus on certain type of shrinkage. To reduce the risk of cracking more effectively, the relationship of different type of shrinkages should be established.

Contents

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1. Introduction

Cracking, a common phenomenon for cement-based materials, has severe effects on durability of concrete structure. It is usually thought to be related to shrinkage. The common types of shrinkage includes chemical shrinkage, autogenous shrinkage, drying shrinkage, carbonation shrinkage, and thermal shrinkage etc. High performance concrete (HPC), reactive powder concretes (RPC) and ultra-high performance concrete (UHPC) demonstrate excellent mechanical properties [1–3] and durability [4], which is nearly impermeable to carbon dioxide, chlorine ion and sulphates. The low water-to-binder ratio (W/B) and use of high content of fine supplementary cementitious materials (SCMs), such as silica fume, can lead to great autogenous shrinkage and even cracking of HPC or UHPC in some cases [5]. The cracking of high performance cement-based materials is closed related to chemical shrinkage and autogenous shrinkage [6,7] and the capillary porosity left by the chemical shrinkage is the prerequisite for autogenous shrinkage [8]. In addition, the drying shrinkage of high performance cement-based materials have also been paid attention to and the cracking caused by the drying shrinkage was also found [9].

Conventional external curing methods, such as watering and covering with wet burlap, are difficult to have obvious effects due to a relatively low surface porosity of high performance cement-based materials. Internal curing is thought to be a very effective way to retain the internal relative humidity (RH) of concrete by releasing water of internal curing materials [10]. Lightweight aggregate (LWA) proposed by Philleo [11] and super-absorbent polymer (SAP) proposed by Jensen [12] are two frequently-used internal materials. Rice husk ash (RHA) has been used as an internal curing material for UHPC in recently years [13]. In addition, people have also found several other internal curing materials, such as bottom ash [14] and cenospheres [15]. Internal curing was firstly defined in ACI 308-2001 [16]. RILEM TC 225 was set up in 2007 to promote research and application of SAP. Many studies have been carried out in the recent years about the effects of SAP or LWA on the shrinkage of concrete [17,18]. However, most researches are only limited to certain type(s) of shrinkage, but several types of shrinkage often occur at the same time.

To make better use of internal curing materials in high performance cement-based materials, the categories of internal curing materials, the effects of internal curing materials on shrinkage and relevant mechanisms are reviewed in this paper.

2. Internal curing materials

General requirements for internal curing materials of cement-based materials include: 1) thermodynamic availability requires the water to have an activity close to one, in other words an equilibrium RH close to 100%; and 2) kinetic availability refers to the transport of water from the reservoir to all parts of the self-desiccating cementitious material [19]. Several materials can be used for internal curing of cement-based materials, including LECA (lightweight expanded clay) [11,20–23], Pumice [24,25], expanded shale [7], zeolite [21], perlite [26], cenospheres [15], SAP [27], recycled aggregate [28], wood-derived powders and fibers [29], rice husk ash (RHA) [30], coal bottom ash [31], bio-LWA [32], and bentonite clay [33]. Among these materials, SAP and LWA are the most commonly used because they are inexpensive due to abundant supplies, and other materials, such as RHA, coal bottom ash and bentonite clay, were found with the function of internal curing recently. SAP presents superior desorption capacity than other candidate materials. Compared with LWA, SAP has also some peculiarities since it can be used as a dry concrete admixture and take up water during the mixing process [19]. The use of SAP permits free design of the shape and size of the formed inclusions [19]. However, when SAP releases water, it leaves voids in the dense cement matrix, which can reduce mechanical properties and structural loading capacity to the concrete [34]. This shortcoming, on the other hand, is not found when using LWA [35,36]. Ground rice risk ash (RHA) and coal bottom ash has porous structure with nm-size pores [37]. In addition, it can absorb some of the mixing water during mixing and acts as internal curing materials. According to water-absorbing mechanism, internal curing materials can be classified into two categories: substances containing physically adsorbed water and porous materials, and porous materials can divide into LWA (including fine lightweight aggregate (fine LWA)) and porous superfine powders, as summarized in Table 1. The following sections described the characteristics of these two categories of internal curing materials.

2.1. Substances containing physically adsorbed water

Substances containing physically adsorbed water include SAPs and bentonite clay, and SAP has been widely used. Chemically speaking, SAPs are cross-linked polyelectrolytes which start to swell upon contact with water or aqueous solutions and result in the formation of hydrogel [18]. They include acrylamide/acrylic acid copolymer and polyacrylic acid [18,40]. The main driving force for the swelling of SAPs is the osmotic pressure that is proportional to the concentration of ions in the aqueous solution. That is, the absorption of SAPs is strictly dependent on the concentration of ions in the swelling medium [18]. SAPs have water absorption of up to 5000 times of their own mass, but only 50 g/g in salt solution [12]. Because of the fast absorption rate of SAP [12,41] and avoidance of 'gel blocking' [18], (Gel blocking is a special property of very fine SAPs having a particles size of less than 100 μm. If the SAP is brought into contact water in pure form, little absorption takes place at the surface and the slightly swollen particles stick together), it is necessary to blend SAP with cement and SCMs before adding water. The dosage of SAP in concrete is calculated according to the need of internal curing water. From the powers model [42], Jensen et al. [12] proposed the following values for internal curing water to cement ratio $(w/c)_e$ that are necessary to secure complete hydration of the cement:

1) $w/c \leq 0.36$, $(w/c)_e = 0.18(w/c)$;
2) $0.36 \leq w/c \leq 0.42$; $(w/c)_e = 0.42 - (w/c)$.

When taking the internal curing water to binder ratio $(w/c)_e$ into consideration, it is also necessary to consider the composition, dosage [27,43–45], type [40], particle size [27,43,44], as well as the water-saturated state of the SAP (effective water to cement ratio of concrete) [46,47] since they have essential influence on internal curing effects.