



Shrinkage of internal cured high strength engineered cementitious composite with pre-wetted sand-like zeolite



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HIGHLIGHTS

- New internal curing agent for cementitious materials.
- Shrinkage control of high strength engineered cementitious composites.
- Shrinkage performance of high strength engineered cementitious composites with pre-wetted sand-like zeolite particles.

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ABSTRACT

In this paper, shrinkage and internal relative humidity of internal cured with calcinated zeolite particles of high strength engineered cementitious composite (HSECC) are experimentally investigated, in which the natural sand-like zeolite particles with average particle size of 0.18 mm were used as internal curing agent. Impacting factors, such as calcination, pre-wetting process and amount of internal curing agent, on shrinkage of HSECC were considered in the test program; meanwhile their effects on compressive strength of the composites were included as well. The test results show: 1) Two-stage progressing mode of shrinkage and internal relative humidity of HSECC are observed; 2) Applying the pre-wetted calcinated zeolite particles in HSECC, more than 60% of autogenous and/or drying shrinkage at 28 days is reduced while the strength of the composite remains as higher as the reference; 3) Calcination on zeolite particles is necessary for internal curing of high strength cementitious composites.

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1. Introduction

To overcome the brittle nature of concrete, a class of high performance fiber reinforced cementitious composite, called engineered cementitious composites (ECC), has been developed in recent two decades [1]. This material has a unique property that after first cracking, tensile load-carrying capacity continues to grow, resulting in strain-hardening accompanied by multiple cracking. For each individual crack, the crack width first increases steadily up a certain level and then stabilizes at a constant value. Further increase in strain capacity is resulted from the formation of additional cracks until the cracking reaches a saturated state with crack spacing limited by the stress transfer capability of the fibers. After that, a single crack localizes and the load slowly drops with increased deformation. Typically, strain localization occurs at a tensile strain of 3–5%, with crack spacing of 3–6 mm and crack width around 60 μm [1]. However, in order to obtain this strain-

hardening and multiple cracking performance, only a small amount of fine sand is allowed to be applied in order to control the fracture toughness of matrix [2–5]. Therefore, the shrinkage, including autogenous and drying shrinkages, must be higher than normal concrete due to its high cementitious materials content.

In addition, even the ability of crack width controlling of ECC is strong, a number of applications, such as permanent formwork for concrete structures, steel-concrete composite bridge decks and joint-less concrete pavements, still wish the material has a relatively higher strength, meanwhile remaining adequate ductility as long as satisfying the deformation requirements resulting from temperature change, shrinkage and mechanical loading [6,7]. In these applications, cementitious composites with properties of low moisture transport coefficient, high freezing resistance and low permeability are generally required apart from ductility. Strength is the governing parameter that controls the penetration of water and chemical agents during service of the structures at the stage without cracking. Strain capacity and formation of fine cracks are the critical points which control the long term durability of the structures at the stage that cracks may occur. Compressive

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strength of traditional ECCs is normally lower than 50 MPa, which apparently may not fully satisfy the requirements of above applications. High strength engineered cementitious composite (HSECC) is therefore needed to be developed. ECC with compressive strength around 80–100 MPa under normal curing condition had been developed recently [8]. However, the shrinkage of HSECC may be greater than normal strength ECC due to its very low water to binder ratio. The high shrinkage strain may result in cracking at an early age in structures that should shorten the service period without cracking. In addition, the large difference on shrinkage strain between ECC and normal concrete may lead to quick delamination of ECC-concrete composite structures.

Shrinkage of cementitious materials, including concrete, is one of the major sources of the formation of cracks in the structures. The magnitude of the shrinkage strain of cementitious materials is normally proportional to the amount of moisture loss [9–12]. In general, environmental drying and cement hydration are the two major processes leading moisture loss inside the material. As environmental humidity is lower than the humidity inside of the material, the water inside of material evaporates and shrinkage arises, which is called drying shrinkage. Another process causing moisture loss is through cement hydration, which is called self-desiccation and the corresponding shrinkage of the material is called autogenous shrinkage. Generally, the autogenous shrinkage of cementitious materials is a function of water to cement ratio of the material. The higher the water to cement ratio, the lower the autogenous shrinkage. Strength of cementitious material is inversely proportional to water to cement ratio. Therefore, high strength cementitious material normally has higher autogenous shrinkage comparing with that of normal strength one.

To reduce the shrinkage of cementitious materials, it is necessary to complement or slow down the moisture loss. Use of pre-wetted lightweight aggregate as an internal reservoir to provide water as the concrete dries is an effective method to decrease autogenous shrinkage of high strength concrete [13–15]. However, the particle size of lightweight aggregate is generally larger than 4 mm, which is too large to be used in ECC as the larger particle will weaken the fiber bridging stress that controls strain hardening and multiple cracking performance of the material. Another method to reduce shrinkage of concrete is to use super absorbent polymer, but the addition of super absorbent polymer in concrete will decrease concrete strength due to the introduction of additional pores in cement matrix [16,17]. Therefore, it is necessary to seek materials that may be used for internal curing of HSECC, meanwhile satisfying the requirements on fiber bridging of ECC materials. In this paper, zeolite particles with size of 0.18 mm were used as internal curing agent of HSECC. Shrinkage and internal relative humidity of HSECC with pre-wetted sand-like zeolite addition are measured. The test results show that by applying calcined zeolite particles in HSECC, internal relative humidity can significantly be increased under both sealing and drying condition. Meanwhile, autogenous and drying shrinkage of the composite are greatly reduced. Efficiency on shrinkage reduction of HSECC may achieve 60% while strength remains as higher as the reference.

2. Experimental program

2.1. Details of materials and specimens

The purpose of this test program goes to regulate shrinkage of HSECC. An optimized cementitious binder composition of 70% cement, 10% silica fume, 10% grounded granulated blast furnace slag, 10% fly ash in weight, which achieving the highest compressive and bending strength of matrix under given water to binder ratio and normal curing condition [18], was used in the present

experiments. Calcium sulfoaluminate cement (SAC), that possesses extra high early-age strength [19], was used as cementing material. The chemical compositions of SAC and silica fume, grounded granulated blast furnace slag and fly ash, used in the tests are showed in Table 1. Silica sand with particle size of 0.075 to 0.150 mm was used to form the mortar matrix. Constant water to binding material ratio (w/b) of 0.2 and constant sand to binder ratio of 0.833 were used in the matrix mixture proportion. Polyvinyl alcohol fiber (PVA) supplied by Kuraray Company in Japan was employed as reinforcement and the fiber properties are given in Table 2. Constant fiber content of 2% in volume fraction is utilized in the composites.

Based on the above reference mixture or called ordinary curing mixture (OC), six internal cured mixtures (IC) were designed using sand-like zeolite particles as internal water reservoir, which replaces silica sand in the proportions. The average particle size of the zeolite is 0.18 mm that was produced in China. Zeolite is aluminosilicate mineral containing relatively large amount of micropores and physically bonded water in it. To investigate the effect of calcination on the efficiency of the shrinkage reduction of the composites, two kinds of zeolite particles were prepared. One was the particles undergo 500 °C calcination in a muffle furnace for 30 min, called Zeolite-500. Another was the natural particles without calcining, called Zeolite-N. Therefore, we designed two internal cured mixtures, IC-1Y and IC-2Y using Zeolite-N and Zeolite-500 respectively as internal curing agent. Label Y means the zeolite particles were pre-wetted in water for 3 days before mixing with other components. To study the effect of pre-wetting of the zeolite particles on shrinkage of the composite, two internal cured mixtures were designed, IC-2Y and IC-2N, where N indicates the zeolite particles without pre-wetting were utilized. To investigate the effect of the amount of internal agent on shrinkage of the composite, two zeolite particle additions of 15% and 20% of the silica sand in weight were used respectively in the tests, forming internal cured mixtures of IC-2Y and IC-3Y. It should be noted that the total water content, including water absorbed by zeolite, was keeping constant in above internal cured mixtures. Therefore constant water to binder ratio of 0.20 in above mixtures was presented. However, it is understandable that the internal curing water should stay in the pores of the internal curing agent. Therefore, the above water should not influence the formation of capillary pores of the cement matrix theoretically, which may be reflected through strength tests. To investigate the effect of the pre-absorbed water on shrinkage and strength properties of the composite, two additional internal cured mixtures, named as IC-4Y and IC-5Y were designed, which assuming about 0.26 g of water per gram of zeolite that was determined from nitrogen adsorption test, was pre-absorbed before mixing with cement and other components, and therefore this absorbed water was not included in the mixing water. Thus, a little higher water to binder ratio in IC-4Y and IC-5Y is displayed compared with other mixtures. A polycarboxylate superplasticizer with 30% solid content was used to guarantee all the fresh mixtures have a similar flow-ability. All the mix proportions used in the present study are listed in Table 3. Fig. 1 shows the particle distribution of the Zeolite-N and Zeolite-500. For comparison, the size distribution of the quartz sand used in the present study is displayed also. Clearly, calcination has a little effect on particle size of the zeolite (particles between 1 and 20 μm increase a little and particles between 200 and 1000 μm decrease a little) and a similar most probable particle size of 0.15–0.2 mm among the three particles is observed. The specific surface area of Zeolite-500, Zeolite-N and quartz sand is 49 m^2/g , 41 m^2/g and 1.2 m^2/g respectively. The pore size distribution of the Zeolite-500 and Zeolite-N and quartz sand is displayed in Fig. 2 based on nitrogen adsorption test. As expected, high pore volume is obtained in Zeolite-500 than that of Zeolite-N. Heating the zeolite particles will

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