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Influence of shrinkage-reducing agent and polypropylene fiber on shrinkage of ceramsite concrete

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HIGHLIGHTS

- Investigation on both the self-shrinkage and drying shrinkage of CC.
- Combination of PPF and SRA to reduce shrinkage.
- Determination of the optimum mix proportion based on balancing shrinkage reduction and early excessive expansion exclusion.

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ABSTRACT

This paper reports a study done on the impact of a shrinkage-reducing agent (SRA) and polypropylene fiber (PPF), individually and jointly, on ceramsite concrete (CC). The results indicate the following: (1) CC mixed with SRA alone, results in early micro-expansion increases as SRA content increases while self-shrinkage and drying shrinkage decreases. (2) CC mixed only PPF, results in early micro-expansion, self-shrinkage and drying shrinkage decreases as PPF content increases; amplitude decrease is large for early micro-expansion, but insignificant for self-shrinkage and drying-shrinkage, and shrinkage reduction is smaller compared to SRA. (3) If an SRA-PPF mix is added to CC, both contributed significantly to self-shrinkage, drying shrinkage, and reduction.

1. Introduction

Ceramsite concrete (CC) play a significant role of high-rise buildings, long-span bridges, and special projects due to its lightweight, engineered strength, high durability, thermal insulation and other properties [1]. CC is not as sound in terms of volumetric stability as ordinary concrete (OC) owing to its special attributes in aggregates. Concrete shrinkage usually results in a series of problems, including, among other things, structural leakage, reinforcing steel corrosion, and, strength reduction. It may further reduce concrete durability, cause structural damage, and increase collapse risk [2]. Shrinkage also severely affects building safety and service, and hinders CC applications in load-bearing structures [3].

Browning et al. found that a vacuum saturated lightweight aggregate can greatly reduce the early concrete shrinkage [4]. Bogas et al. reports that lightweight aggregate shrinkage is related to lightweight aggregate porosity [5]. Cusson et al. discovered that adding prewetted ceramsite reduces the first-day autogenous shrinkage [6]. Tao Ji et al. indicates that the degree of prewetting ceramsite has strong effect on early age self-shrinkage of lightweight aggregate concrete [7]. Early cement hydration delay can lead to a rough pore structure, increased drying rates, and a reduction of limiting cement slurry deformation. When a hydration reaction occurs, a small amount of compensating water stored in lightweight aggregate evaporates. The lack of early water curing and an increase in cement slurry volume could inhibit shrinkage.

A shrinkage-reducing agent (SRA), act as a chemical additive and controls concrete drying shrinkage by reducing capillary pore water surface tension. Weiss found that the impact of an SRA on cement-based material drying rates was related to environmental humidity. It was not either simple acceleration or delayed drying [8]. Collepardi, Berke and Bentz concluded that an SRA shrinkage effect directly related to surface tension reduction in the concrete pore solution [9–11]. Bentz et al. investigated early drying of concrete mixed with an SRA, and found that an SRA could effectively decrease concrete drying shrinkage. Shrinkage inhibition in cement-based materials with a lower water-cement ratio, in particular, was much better at drying shrinkage reduce [11].

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PPF has stable chemical properties and exhibits better bonding with concrete hydrates. Romualdi, Betson, and Mandel reports on the constraint effect on the form and development of fiber concrete cracking and proposed a fiber-interval theory based on linear elastic fracture mechanics. Pelisser showed that polypropylene fiber had a significant inhibition effect on plastic shrinkage cracks [12]. Filho and Sanjuan reported on experimental studies on the impact of low-elastic-modulus polypropylene fiber (PPF) on early free shrinkage and limited shrinkage in cement slurry, and found that PPF could effectively decrease free plastic shrinkage cement slurry in concrete [13].

SRA and PPF can both reduce concrete shrinkage, but each have drawbacks. Many investigators have simultaneously utilized an SRA and fiber. Passuello et al. found that an SRA greatly reduces concrete free shrinkage [14]. A application of an SRA-PPF mix was shown to have a great inhibition effect with respect to concrete cracking, and achieved a more optimal and comprehensive results. This joint application of shrinkage-reducing measures in lightweight aggregate has yet to be reported in the literature. This research is a study of the self-shrinkage and drying shrinkage performance of CC with a combined application of SRA and PPF.

2. Raw materials and mix proportions

2.1. Raw materials

This study used Po 42.5 ordinary Portland cement (Hunan, China). The chemical and physical compositions of the shale ceramsite appear in Tables 1 and 2. The SRA used was BT-5001-type polycarboxylic acid SRA (Hunan, China). Its properties are listed in Table 3. Polypropylene fiber (Hebei, China) was used. Its technique index is in Table 4. The aggregate used was natural river sand with a 2.58 fineness modulus 0–5mm continuous gradation particle size, 8% sediment content, and a 2660 kg/m^3 appearance density.

2.2. Mix proportion design

Ceramisite mix proportions of SRA, FFP, and the SRA-PPF mix appear in Table 5.

2.3. Methods

2.3.1. Self-shrinkage

A non-contact probe combined with corrugated pipe method was used [15]. Concrete volumetric deformation in a flowing state was transferred into a longitudinal deformation of corrugated pipe. The pipe inner diameter was 65 mm and its length, 340 ± 5 mm, matched the size of the steel frame. Two specimens were tested for each mix. Self-shrinkage values were obtained by taking the average value from the two specimens. The eddy current displacement sensor had a testing range of 0–4 mm, resolution of 0.5 μm, and a precision of 0.05% (Fig. 1).

2.3.2. Drying shrinkage

Three 75 mm × 75 mm × 275 mm prismatic specimens were used for each test group. A sensor head was embedded into two ends of each specimen. The concrete was cast into prismatic molds and cured for 7 days under standard curing conditions (temperature 20 ± 2 °C and relative humidity above 95%). Specimens were cured for 7 days under standard curing conditions and kept at a 20 ± 2 °C and a relative humidity of 60 ± 5% for 4 h and then demolded. Specimen lengths were measured according to the marked testing direction. Before testing, a standard rod was used to adjust the dial indicator origin of the refractometer (Fig. 2). After testing the initial lengths, mortar specimens were stored at 20 ± 2 °C and a relative humidity of 60 ± 5%. Specimen lengths were measured at 1, 3, 7, 14, 21, 28, and 56 days.

3. Results

3.1. SRA and PPF influence on self-shrinkage

3.1.1. Blending SRA

Specimens expanded rapidly beginning 10 h after formation. Most self-shrinkage occurred within 10–48 h and slowed after 48 h (Fig. 3). Self-shrinkage strain values within 72 h for the control group L-0, as well as the three groups (SRA-1, SRA-2, and SRA-3) were 202, 129, 70, and 38 F, respectively. Compared to L-0, SRA-1, SRA-2, and SRA-3 self-shrinkage, within 72 h, was reduced by 36.1%, 65.3%, and 81.2%, respectively. The SRA mix significantly reduced CC self-shrinkage, and the presence of increased SRA resulted in significant self-shrinkage inhibition. This shrinkage-reducing effect produced larger early-stage micro-expansion. Maximum micro-expansion strain values for specimens SRA-1, SRA-2, and SRA-3 were 153, 204, and 245 με, respectively. Compared to the strain value of 126 με for the control group L-0, strain values increased by 21.4%, 61.9%, and 94.4%, respectively. As the amount SRA mix increased, so too did early micro-expansion.

SRA-2 and SRA-3 exhibited better self-shrinkage effects when compared to the control group. Both exceeded 65%, SRA-3 provided the best self-shrinkage-reducing effect. SRA-3 early micro-expansion increased by 94.4% compared to the control group which was disadvantageous to volumetric stability. Ceramsite particles are a lightweight aggregate and can absorb water content during mixing. With an even distribution in concrete, ceramsite particles are an internal water reservoir, which effectively improves internal humidity filed and saturates the pores during the early hydration process. The hydration product gel is able to combine with more water molecules which tends, to a degree, to overcome the cohesion between gel materials and produce micro-expansion [16]. The effect of micro-expansion may partially offset self-shrinkage during the hydration process. A SRA mix may reduce pore solution surface tension in cement stone pores and decrease capillary channel additional pressures thus reducing pore shrinkage stress during the dehydration process. CC self-shrinkage was further reduced [17]. It was shown that early hydrated calcium hydroxide and ettringite in the concrete and cement mortar system with SRA had a higher saturation [18]. SRA may hinder, or delay, rates of cement hydration. Sulphur crystal products, such as ettringite or a single-sulphur type of calcium sulphoaluminate, formed late in cement hydration can result in expansion [19].

It was found that, when using SRA alone, early micro-expansion subsequently increased as SRA increased. The amplitude increase was great. Self-shrinkage subsequently decreased. A amplitude decrease was great. The SRA-3 group provided the best reduction effect of self-shrinkage with only SRA.

3.1.2. Blending PPF

Specimens rapidly expanded beginning after 10 h of formation. This expansion was less than that of the SRA only mix. Self-shrinkage mainly occurred within 10–48 h and slowly increased after 48 h (Fig. 4). Self-shrinkage strain values for the control group L-0 and the three groups designated PPF-1, PPF-2, and PPF-3 within 72 h were 202, 188, 178, and 169 με, respectively. Compared to L-0, PPF-1, PPF-2, and PPF-3 self-shrinkage within 72 h lessened by 6.9%, 11.9%, and 16.3%, respectively. The maximum micro-

Table 1
Shale ceramsite particle composition.

SiO_2	Al_2O_3	Fe_2O_3	MgO + CaO	K_2 O + N a_2 O	Organic	Firing vector
64.27	15.54	6.85	3.14	4.87	0.68	3.46