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Workability, strength and shrinkage of fiber reinforced expansive self-consolidating concrete

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HIGHLIGHTS

- Effects of fibers on properties of expansive self-consolidating concrete (ESCC) were studied.
- Workability of fresh concrete decreases with increased volume fraction of fibers.
- Steel fiber improves the linear load-deflection relationship of ESCC beams.
- Free expansive rate of ESCC reduces with the increase of steel fibers content.

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ABSTRACT

A testing program was undertaken to evaluate the effects of fibers on properties of expansive self-consolidating concrete (ESCC). Hooked end steel fibers and monofilament polypropylene fibers were used in the tests with three selected volume fractions (0.25%, 0.50% and 0.75% of the total volume of concrete) for steel fibers and one volume fraction (0.10%) for polypropylene fibers. Workability of fresh concrete, mechanical properties and shrinkage of hardened concrete were investigated. Slump flow, J-ring and V funnel tests were carried out to evaluate the filling ability, passing ability, and viscosity of the fresh concrete. Mechanical properties including compressive strength, splitting tensile strength and flexural strength of hardened concrete were studied. Test results indicate that workability of fresh concrete decreases with increased volume fraction of fibers. The compressive strength of ESCC is improved at 7 days with added expansive admixture. Combined addition of expansive admixture and fibers reduces the concrete strength at 7 days, while it does not influence the 28 days strength noticeably. For flexural performance, steel fiber improves the linear load-deflection relationship of ESCC beams. Steel fiber reinforced beam specimens with fiber content higher than 0.50% show deflection-hardening behavior. It is also found that free expansive rate of ESCC reduces with the increase of steel fibers content. Overall, fiber reinforced ESCC both at 0.25% and 0.50% volume content satisfy the target performance criteria.

1. Introduction

Self-consolidating concrete (SCC) is a highly flowable, non segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation [1]. It has excellent properties and has been widely used in engineering fields. Since high content cementitious materials are used in the design, self-consolidating concrete is prone to shrinkage cracks, seriously affecting the service life of SCC-made buildings and bridges. One way to decrease shrinkage of SCC is adding expansive agent[2,3]. It compensates shrinkage of self-consolidating concrete and improves the cracking resistance of SCC. It was reported that sulphoaluminate has a micro-expansion effect and it is the main component of expansive agent studied by researchers [3–4]. The benefit of using this type of expansive agent is that it can provide increased workability for SCC other than shrinkage-compensation. Meng et al. [3] reported that the shrinkage of SCC decreases with the increase of expansive agent dosage as well as increasing concrete age within a certain range. Ettringite is produced mainly at the beginning 1–7 days. It also shows that curing time plays a significant role on the shrinkage of SCC with expansive agent indicating that the shrinkage is smaller when curing time is longer. It is worthwhile to mention

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Table 1
Properties of SCC with 8% and 10% expansive admixture.

Expansive admixture	Compressive strength (MPa)		Splitting tensile strength (MPa)	Free expansive rate at 28 days (um/m)
	7 days	28 days		
0%	38.5	52.0	3.64	−148
8%	42.3	52.1	3.54	1208
10%	31.3	42.1	2.36	5103

Note: 1 mm = 0.0394 in, 1 MPa = 145.14 psi.

that overdosage use of expansive agent could result in reduction of mechanical properties of concrete. Thus, incorporation of expansive agent mainly increases cracking resistance of SCC.

Fiber reinforced self-consolidating concrete (FRSCC) has gained a lot of attention and extensive research has been conducted. The fibers that are used in SCC include steel fiber, polypropylene (PP) fiber, aramid fiber and basalt fiber, etc. Steel fiber has been widely employed because of its high modulus of elasticity and tensile strength. PP has low density, good adhesive properties with SCC, and it does not segregate with concrete under its own weight. Therefore, PP can be used to restrict the micro-cracks when uniformly distributed in SCC. Aslani and Nejadi [4] studied workability and deformation of four different mixtures with one SCC and three fiber reinforced SCC. Test results indicated that, in general, addition of fibers decrease workability as well as shrinkage of SCC. It also demonstrated that fibers slightly reduce the creep of SCC. Similarly, it was reported [5] that steel fibers are effective in restricting the drying shrinkage of cementitious materials. As well known, incorporation of fibers in SCC decreases workability of the fresh SCC and the reduction becomes larger as fiber content increases [6–11]. Fiber could increase early strength of concrete especially for steel fibers [12]. Fibers have lower effect on modulus of elasticity of concrete in compression [12], but it can enhance the modulus of elasticity in tension [13]. There is no doubt that steel fibers can improve the tensile strength of SCC, however it was reported that propylene fiber decreases the tensile strength of SCC [12–13]. Flexural performance of beam specimens was improved by steel fibers and hybrid fibers when the steel fiber volume content exceeds 0.50%, and the post-peak load capacity was increased [13–14].

Although the effect of expansive agent [2–3] and fibers [4–14] on properties of SCC has been studied respectively, the combined effect of fiber and expansive agent has rarely been investigated. In this paper, an experimental program is performed to evaluate the effects of fibers on properties of expansive self-consolidating concrete (ESCC). The calcium oxide-sulphoaluminate type expansive agent was used to produce expansive concrete with targeted expansion rate. Then fibers (single steel fibers, hybrid steel and PP fibers) were adopted to optimize ESCC and the effect of fibers on workability, mechanical properties and shrinkage was studied.

2. Research significance

Fibers are usually added into concrete to improve tensile strength, impact resistance and toughness of concrete. Research [24] has indicated that, compared with single fiber, hybrid fibers present a higher crack resistance and shrinkage reduction as well as strengthening due to various scales of reinforcement in cementitious matrix. It is necessary to investigate how the workability and mechanical properties of SCC are affected by the incorporation of hybrid fibers and expansive admixture. Research findings will assist engineers to design and implement fiber reinforced expansive SCC in engineering fields.

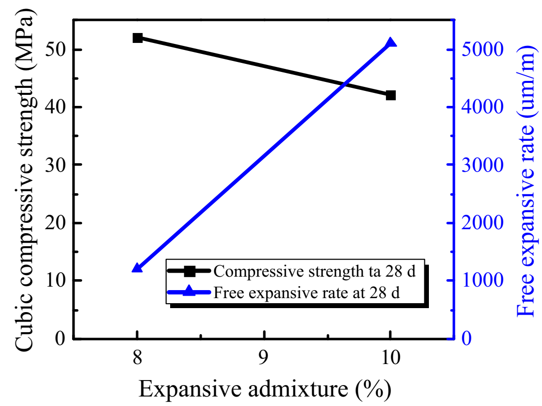

Fig. 1. Properties of SCC with 8% and 10% expansive admixture (Note: 1 MPa = 145.14 psi).

Table 2
Properties of "P.O 42.5R" cement.

Component		Test value
80um screen (%)		0.9
Specific surface (m^2/kg)		–
Setting time	Initial time	2–30
(h-min)	Final time	3–35
Stability		Qualified
Undissolved substance		–
SO_3 (%)		2.52
Lost on ignition (%)		3.52
Alkali ($Na_2 + 0.658K_2O$) (%)		0.7

3. Experimental procedure

3.1. Materials

The materials used in the self-consolidating concrete composition included Type "P.O 42.5R" ordinary Portland cement which meets the Chinese standard GB175-2007 [15] with a density of 3.1 g/cm^3 (193.53 lb/ft^3), Type I fly ash with density of 2.3 g/cm^3 (143.59 lb/ft^3), calcium oxide-sulphoaluminate expansive admixture with expansion rate of (15–18) $\times$ 10^{-4}. The dosages of expansive admixture are 8% and 10% of cementitious materials in mass which are shown in Table 1. Fig. 1 presents the property results for screening test. Properties of Cement and fly ash are shown in Tables 2 and 3. River sand with fineness modulus of 2.72 and density of 2.65 g/ cm^3 (165.44 lb/ft^3), coarse aggregate with 5–16 mm (0.20–0.63 in) gravel full grade with density of 2.7 g/cm^3 (168.56 lb/ft^3), and glycolic acid-based white powder superplasticizer (HRWRA) were used. Sieve results of aggregates are shown in Table 4. The content of active HRWRA is maleic anhydride: acrylic acid polyethylene glycol ester: sodium acrylic acid by ratio of 1:3:2.4. HRWRA is added at 0.3% of cementitious materials which is the recommended dosage from supplier. The properties of steel fiber (SF) and polypropylene (PP) fibers are shown in Table 5, the shape and dimension are shown in Fig. 2. Table 1