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Effect of shrinkage-reducing admixture and expansive agent on mechanical properties and drying shrinkage of Engineered Cementitious Composite (ECC)

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HIGHLIGHTS

- The expansive agent can improve the 28 days compressive strength of ECC, which is the opposite with the shrinkage-reducing agent.
- The shrinkage-reducing agent can obviously reduce the tensile strength of ECC.
- The shrinkage strain instead increases when the PVA fiber content is greater than 1%.
- Fly ash, expansive agent and shrinkage-reducing agent reduce the shrinkage strain.
- The increase of PVA fiber content can greatly improve the crack resistance.

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ABSTRACT

In order to reduce the drying shrinkage strain of traditional ECC and diminish the shrinkage differences between concrete and PVA (PolyVinyl Alcohol) fiber, this paper designs eighteen groups mix proportions based on Taguchi Methods. The influences of water-binder ratio, sand-binder ratio, fly ash content, expansive agent content, shrinkage-reducing agent content and PVA fiber volume content on the compressive strength, tensile properties and drying shrinkage are researched. In addition, the effect of PVA fiber on the crack resistance is investigated. The results indicate that the shrinkage strain of ECC increases with the raising of water-binder ratio, and decreases with the increasing of sand-binder ratio, fly ash content, expansive agent, and shrinkage-reducing agent; The anti-cracking performance is significantly improved along the fiber volume content changes, but it has little effect on ECC shrinkage strain. The compressive and tensile strength of ECC will greatly reduce with the increasing of shrinkage-reducing agent, rather, the compressive strength of ECC will enhance with the increase of expansive agent; But the expansive agent will lower the tensile strength and ultimate tensile strain. In the scope of this research, the water-binder ratio, sand-binder ratio, and fly ash content is about 0.25–0.33, 0.33–0.45, and 65% respectively. The research generated a set of reliable and valuable test data for the researchers and practical structural engineers in the field of ECC drying shrinkage.

1. Introduction

Compared with common cement-based materials, ECC (Engineered Cementitious Composite) has higher impact strength and toughness. Its ultimate tensile strain is as high as 2%-8% which is 300 times than the ordinary concrete [1,2]. The ultimate tensile strain of ordinary SFRC (Steel Fiber-reinforced Concrete) is generally less than 1%, although the descending section of decline is relatively slow. SFRC still shows single crack damage due to strain softening property. However, the tensile stress of ECC does not decrease obviously after initial cracking, it first changes little with the increase of strain and then the stress-strain curves show a stable rising trend. In addition, the ECC behaves strain hardening properties with multiple cracks whose crack width are less than 0.1 mm [3–5].

Due to its large elastic modulus and high tensile strength, steel fiber can improve the initial cracking strength and impact resistance, so SFRC meets the ever-increasing demand of ECC

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performance within practical engineering applications. But the SFRC density is about 3 times more than ordinary concrete, and its incorporation will increase the weight of concrete since the steel fiber diameter is relatively large, so the use of its dosage is subject to certain restrictions [6–8]. Although its performance is better, the Polyethylene (PE) fiber does not have the promotion value on the actual project because the price is much higher than PVA. PVA fiber is widely researched and popularized because of its excellent performance and reasonable price.

Although it has the good performance compared to ordinary cement-based materials, but ECC still has some shortcomings: due to the higher cement-based materials content, ECC produces larger drying shrinkage strain; although adding fiber can reduce the shrinkage [9–12], ECC on 28 days shrinkage strain value is still up to 1200 με–1800 με; the same age ordinary concrete and steel fiber concrete shrinkage value is only 400 με–800 με [13]. Furthermore, as the repairing material or the connecting material, ECC inevitably causes the restraining shrinkage on the existing concrete or newly poured concrete when it works together with them. That results in shrinkage cracks in the ECC and penetrating cracks through the interface, and the workability of ECC and the interoperability between ECC and concrete are reduced [14]. Therefore, it shall research how to reduce the ECC shrinkage and decrease the shrinkage difference with existing or newly poured concrete; the success of the research is conducive to that ECC will be more widely popularized and applied.

A large number of researches on ECC have demonstrated that the mechanical properties of ECC are closely related to the water-binder ratio, the sand-binder ratio, the fly ash content and the fiber volume content [15–20]. The use of low shrinkage cementitious material in the matrix [13,28] greatly reduces the ECC shrinkage, while the factors such as the expansive agent, the shrinkage-reducing agent and others have a great influence on the shrinkage performance of the mortar, the concrete, the fiber reinforced concrete and the other cement-based materials [21–27]. Nonetheless, it is still rare to research the effect of the expansive agent and the shrinkage-reducing agent on the ECC shrinkage performance.

Based on the traditional compounding ratio, the ECC shrinkage deformation is very large. In order to research how to reduce the ECC shrinkage deformation, this project had designed eighteen groups of single-factor test ratio by changing the water-binder ratio, the sand-binder ratio, the fly ash content, the fiber volume content, and adding the expansive agent and shrinkage-reducing agent, to research the mechanical properties and shrinkage properties of ECC. Meanwhile, the effect of the fiber volume content on the shrinkage and anti-cracking properties of ECC, the slab test under the restrained condition and the ECC drying shrinkage mechanism were respectively investigated.

2. ECC mix design

The materials used in the production of the ECC mixture consists of the following: P.O 42.5 ordinary Portland cement, 80–100 mesh quartz sand, Class I fly ash, SBTJM_III (C) low-alkali concrete expansive agent, SBT®-SRA (I) shrinkage-reducing agent (No water reducing effect), polycarboxylate-type superplasticizer, and Japan KURALON K-II PVA fiber whose specific parameters are shown in Table 1.

In order to research the effects of cement matrix components, the expansive agent, the shrinkage-reducing agent and the fiber volume content on ECC drying shrinkage, the researchers adjusted the general ECC mix ratio and prepared the following Table 2: A group of ECC single factor mix ratio of different cement-based materials, the expansive agent content, the shrinkage-reducing agent content and the fiber volume content, all based on the Taguchi Methods. When the expansive agent is added in the ECC, ECC is constrained during expansive process which will generate the compressive prestress of 0.2 MPa–0.7 MPa to counteract the tensile stresses in concrete caused by shrinkage and compensate for

Table 1
PVA fiber parameters.

Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Limited elongation (%)	Length (μm)	Diameter (μm)
1.3	1620	42.8	7.8	12	26

Table 2
ECC single factor mix ratio D-1–D-18 (weight ratios).

Test number	Water	Cement	Fly ash	Silica sand	Super plasticizer (%C)	Fiber volume ratio (%)	Shrinkage-reducing admixture (%C)	Expansive agent (%C)	*W/C*	*S/C*	*FA/C*
D-1	1	1.06	1.97	1.36	0.077	2	0	0	0.33	0.45	0.65
D-2	1	1.4	2.6	1.8	0.4	2	0	0	0.25	0.45	0.65
D-3	1	0.85	1.59	1.1	0	2	0	0	0.41	0.45	0.65
D-4	1	1.06	1.97	2	0.077	2	0	0	0.33	0.66	0.65
D-5	1	1.06	1.97	1	0.077	2	0	0	0.33	0.33	0.65
D-6	1	0.61	2.42	1.36	0.077	2	0	0	0.33	0.45	0.80
D-7	1	1.52	1.52	1.36	0.077	2	0	0	0.33	0.45	0.50
D-8	1	1.06	1.97	1.36	0.077	2	0	0.091	0.33	0.45	0.65
D-9	1	1.06	1.97	1.36	0.077	2	0	0.182	0.33	0.45	0.65
D-10	1	1.06	1.97	1.36	0.077	2	0	0.273	0.33	0.45	0.65
D-11	1	1.06	1.97	1.36	0.077	2	0.030	0	0.33	0.45	0.65
D-12	1	1.06	1.97	1.36	0.077	2	0.061	0	0.33	0.45	0.65
D-13	1	1.06	1.97	1.36	0.077	2	0.091	0	0.33	0.45	0.65
D-14	1	1.06	1.97	1.36	0.077	2	0.121	0	0.33	0.45	0.65
D-15	1	1.06	1.97	1.36	0.031	0.5	0	0	0.33	0.45	0.65
D-16	1	1.06	1.97	1.36	0.039	1	0	0	0.33	0.45	0.65
D-17	1	1.06	1.97	1.36	0.058	1.5	0	0	0.33	0.45	0.65
D-18	1	1.06	1.97	1.36	0	0	0	0	0.33	0.45	0.65

Note: W/C is water-binder ratio, S/C is sand-binder ratio, FA/C represents the ratio of fly ash to total amount of cementitious material (cement and fly ash), %C means the ratio of admixture to total amount of cementitious material (cement and fly ash), D represents single factor.