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Expansion behavior of self-stressing concrete confined by glass–fiber composite meshes

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HIGHLIGHTS

- Proposed that glass fiber composite meshes can be used as a reinforcement for SSC.
- Established the method for expansion strain calculation of CM-SSC.
- Analyzed the expansion behavior of SSC under restriction of composite meshes.
- Investigated the influence of mesh yarn and layer on expansion property of CM-SSC.

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ABSTRACT

Confined self-stressing concrete (SSC) efficiently improves the crack resistance of concrete materials. Considering the drawbacks of steel bar- or fiber-reinforced SSC, we propose glass–fiber composite mesh-reinforced SSC. Some mechanical properties of mesh-reinforced SSC have been investigated, but their expansion properties remain unclear. In this research, expansion experiments were conducted to understand the expansion behavior of this new combination. The development of expansion deformation was obtained and generalized using exponential and cotangential models. Theoretical analyses of the expansion behavior were deduced from the experimental results. The analyses showed that the expansion strain increases with the increment of width confinement and decreases with the increment of longitudinal confinement. Glass–fiber composite mesh-reinforced SSC has the potential to improve the crack resistance of concrete materials.

1. Introduction

Concrete, widely used as a structural material, can be applied to building engineering, transportation engineering, offshore platforms, and other engineering practices. However, concrete is brittle and has a small tensile strength. In addition, cement hydration is usually accompanied by volume shrinkage, which might lead to concrete cracks. Freeze–thaw effect, chloride or sulfur erosion, or other types of corrosions could dramatically decrease the strength and other properties of cracked concrete and harm the security of the entire structure [1,2]. Nowadays, concrete durability is important to the design of concrete structures.

Many types of special concrete, such as high-performance concrete, self-compact concrete, fiber-reinforced concrete, pre-stressed concrete, and carbon nanotube concrete, have been applied to engineering practices to enhance the durability of concrete materials [3,4]. However, such special types of concrete are usually expensive.

Self-stressing concrete (SSC) is a suitable crack-resistant material that can be easily applied in engineering practices [5]. The matrix in SSC can undergo large expansion deformation because of the chemical reaction inside the material [6]. Confinement of SSC by steel bars, steel fibers or textiles can introduce self-stresses that improve the crack resistance of the concrete matrix and the tensile strength of reinforced SSC members. In some cases, self-stress can even increase the compressive strength of the material to 8 MPa [7].

In the last 50 years, several studies have focused on self-stressing cement and expansion concrete in several countries. In particular, some studies have explored the expansion mechanism [8,9], pore property [10], and interfacial transition zone [11] of SSC. Other research has investigated the hydration process of

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expansion and self-stressing cement to identify the expansion components of expansive cement [12]. Experiments have also been conducted to understand the workability [13], mechanical properties, and durability of different types of self-stressing cement and concrete [14–16]. During hydration, AFt (abbreviation for "alumina, ferric oxide, tri-sulfate") can be produced from expansion components of self-stressing cement, which causes expansion deformation [17,18]. Volume expansion may dramatically decrease the strength of the interfacial transition zone and thus weaken the structure of SSC under unconfined conditions. By contrast, the microstructure of SSC can be greatly enhanced under confined conditions [19]. In most cases, SSC can be confined by steel bars, steel tubes, or short-cut fibers. Several studies have concentrated on steel bar-reinforced SSC, steel fiber-reinforced SSC, and steel tube filled with SSC. Calculation theories of self-stress of reinforced SSC were obtained. In general, the mechanical properties and durability of SSC specimens are better than those of normal concrete ones [20]. Among these studies, Jian-Guo Dai [14] presented a back-calculation method for predicting the deformation of self-stressing concrete based on BP-KX creep model, and proposed the calculation method for calculating the self-stresses of steel bar reinforced self-stressing concrete. Huanan He [21] and Boxin Wang [22] investigated the long-term expansive deformation of steel fiber reinforced self-stressing concrete and found out that the loss of self-stress is slight.

However, steel bar-reinforced SSC and other types of reinforced SSC also have inherent shortcomings. The steel bar used to reinforce SSC cannot influence the entire concrete cross-section uniformly. Placing the concrete near the steel bar could produce confinement, whereas placing the concrete far from the steel bar may cause deformation without confinement. Also, when the free expansion strain of the SSC matrix is too high, concrete located distant from the steel bar could incur cracks because of overexpansion. Meanwhile, the confinement efficiency in short-cut fiber-reinforced SSC is low because short-cut fibers are in 3D random distribution. The value and direction of self-stress in fiber-reinforced SSC are difficult to control [23].

SSC and glass–fiber composite mesh can be combined to realize a 2D confinement in SSC and thus allow the easy control of the value and direction of self-stress. A previous study [20] investigated the mechanical and bond properties of composite mesh-reinforced SSC (CM-SSC), but the expansion behavior of SSC under the confinement of composite meshes remains unclear. In this study, expansion experiments of both free SSC specimens and CM-SSC specimens were conducted. The general expansion scheme of both SSC and CM-SSC was obtained, and the influences of composite meshes on the expansion behavior of SSC were quantitatively investigated. Here we only investigate the specimens whose length is more than three times longer than its width. For specimens like this, the expansion in width direction can be neglected compare to the longitudinal expansion [6].

2. Materials and experiments

2.1. Experimental materials

Composite mesh-reinforced SSC consisting of self-stressing cement, coarse aggregates, fine aggregates, high-performance super-plasticizer, and glass–fiber composite meshes was used as the experimental object. Details about each material are enumerated below.

2.1.1. Cement

Sulfur-type self-stressing cement (Chinese building industry standard JC715-1996) was used to obtain a large and stable expansion. The compressive strength of self-stressing cement is 43.8 MPa. The initial setting time is 70 min, and the ultimate setting time is approximately 99 min. Table 1 shows the detailed physical and chemical properties of this type of cement.

2.1.2. Aggregates

River sand with a fineness modulus of 2.509 was used as fine aggregate, and limestone with a nominal diameter of 5–10 mm was used as coarse aggregate.

2.1.3. Super-plasticizer

Concrete workability can be obtained by using the super-plasticizer. A high-performance poly-carboxylate super-plasticizer that meets the Chinese national standard GB 8076-2008 was applied. This high-performance super-plasticizer can be used in ready-mixed concrete, self-compact concrete, and high-performance concrete. No chloride ion and other erosion matters of concrete are included in this material.

2.1.4. Mixture proportion of concrete

Concrete mixture should be designed specifically to obtain a suitable expansion capacity. The water/cement ratio was set to 0.36, whereas the cement/aggregate ratio was set to 0.50. The sand ratio was set to 45% on the basis of previous research [13,20]. Detailed mixture proportion is shown in Table 2. The amount of super-plasticizer added depended on concrete workability; thus, concrete slump tests were conducted. The slump value was approximately 53 mm when the contentment of super-plasticizer was 1.23 kg/m^3.

2.1.5. Glass–fiber composite meshes

Alkali-resistant glass fiber roving that meets the Chinese building industry standard JC/T572-2002 was used in the glass–fiber composite mesh. The diameter of each filament is 13 μm, a single yarn consists of 9200 filaments, the linear density (the mass of textile per unit of length) of a single yarn is 2758 tex (tex means g/km), and the standard density (the mass of textile per unit of volume) of a single yarn is 2.77 g/cm^3. Thus, the whole cross-section area of a single yarn can be calculated as

$$A_y = \frac{m_y}{D_y}, \quad (1)$$

where A_y is the cross-section area of a single yarn, m_y is the linear density of a single yarn, and D_y is the standard density of a single yarn. The cross-section area of a single yarn in this research was calculated to be approximately 0.996 mm. Glass–fiber composite meshes were fabricated by placing resin-penetrated yarns orthogonally. The mesh size was 40 mm × 40 mm. Concrete cannot penetrate into the yarn; thus, only outer filaments can develop a robust bond with the concrete matrix, which may considerably decrease the tensile capacity of the entire mesh cross-section. Hence, the fiber rovings were covered, penetrated, and fixed with epoxy resin to avoid tensile weakening and shear lag effect, as well as to bond two-way yarns. Figs. 1 and 2 show both unpenetrated and penetrated meshes, and Fig. 3 shows the microstructure of a penetrated yarn after fracture, in which we can see that the epoxy resin can penetrate the spaces between filaments.

2.2. Experimental works

Each specimen was 100 mm × 100 mm × 400 mm in size. Glass–fiber composite meshes were placed inside the concrete matrix symmetrically. The specimen was manufactured by placing a $H/(N+1)$-thick layer of SSC in the mold and positioning the mesh layer on top of this mold. H is the height of the specimen, and N is the total number of layers of glass–fiber meshes. Another $H/(N$