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Distributed models of self-stress value in textile-reinforced self-stressing concrete

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HIGHLIGHTS

- Adapts textile reinforced self-stressing concrete (TRSSC) composite materials.
- TRSSC sheets and beams gain better crack resistance than TRC.
- The distributed models of self-stress value in TRSSC are suggested and verified.

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ABSTRACT

Self-stressing concrete and textile are combined to form a new composite material, namely, textile-reinforced self-stressing concrete (TRSSC), which can improve the crack resistance of concrete structures under service loading. First, the basic mechanical properties of self-stressing concrete and fiber bundles are characterized. Second, all load-deformation curves influenced by the type of matrix and Tex of bundles are obtained through uniaxial tension test of the composite sheets. Results indicate that the cracking load and self-stress of TRSSC increase with the expansion of the matrix and Tex of fiber bundles. However, this phenomenon is not observed in normal concrete. Furthermore, the distributed model of self-stress in the matrix is deduced as a quadratic function. Specific analytical functions are assessed through compound material mechanics theory. Finally, beams with TRSSC are subjected to bending test. The cracking loads of the beam are consistent with the theoretical analytic solutions.

1. Introduction

Concrete, is a widely used building material in civil and hydraulic engineering because of its irreplaceable role in important structures, particularly hydraulic ones. However, concrete easily cracks in serviceable state. Cracks on the concrete surface lead to concrete carbonization and steel bar corrosion, which severely impair the durability of the structure [1]; this phenomenon results in huge economic loss and severe security risk.

Mechanical pre-stressing and reinforcement of concrete with fiber are two methods used to improve the crack resistance ability of structural components, reduce the width of cracks, and enhance the durability of structures, two measures are conducted generally, namely, mechanical pre-stressing and reinforcement of concrete with fiber. Mechanical pre-stressing is increasingly used in civil and bridge engineering [2,3] but is difficult to apply in dams, harbor structures, and mass concrete engineering [4,5]; moreover, steel bar corrosion under harsh environmental conditions can be inhibited using a thick protective coating, which increases the self-weight and decreases the structural efficiency of the structure [6].

Ideally, steel bar corrosion can be inhibited using fiber-reinforced concrete without a protective coating to address pre-stressing [7]. Consequently, early-stage shrinkage and long-term cracks of the matrix can be reduced; the elastic modulus of the composite can also be improved compared with that in common concrete because of the bridging effect of randomly distributed fibers [8–10]. Moreover, fiber-reinforced concrete exhibits crack resistance, improved toughness, and corrosion resistance [11–13]. This material is applied in highway construction [14], reinforced simply supported bridge [15], and seismic-strengthened mass-gravity dam [16]. Currently, sophisticated construction technologies are required to ensure excellent working performance of fiber-reinforced concretes, which contain high amounts of fiber; furthermore, the strengthening effect is disoriented, and quantitative and directional reinforcing results cannot be obtained. The use of textile-reinforced concrete (TRC) does not simplify the difficulty of

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concrete construction but exerts enhanced effect on a specified direction. The mechanical and material properties of TRC have been extensively investigated locally and globally [17–22] for practical applications [23–26]. A maturing brand of TRC has been released in Germany; the commercialization and industrialization of this technology is ongoing [27]. TRC does not inhibit cracks quantitatively and directionally but also improves the crack resistance by the bridging effect.

A new concrete material has been developed to suppress crack resistance ability, both quantitatively and directionally. In this study, sulfo-aluminate-based self-stressing cement with expansion ability was used as cementing material. This matrix could generate a compressive self-stress of 1–3 MPa; and becomes more compact with improved anti-penetration and crack resistance properties when expansion is limited during curing and hardening. This matrix material is extensively applied in tubular products to sustain high tension [28]. This cement can be combined with steel fiber to generate a new efficient material for bridge engineering [29–30].

In this study, self-stressing concrete (SSC) matrix was combined with textile to form a new composite material, namely, textile-reinforced self-stressing concrete (TRSSC). In this material, textile functions as expansion confinements to SSC to attain self-stress. The value and direction of self-stress can be quantitatively controlled by changing the grid dimension and textile trend. Self-stress is distributed along the fiber bundle in the textile and exhibits similar effect to that of mechanical pre-stress. Crack resistance is improved compared with that of TRC, and the construction process becomes less difficult. The expansive ability and mechanical properties of sheets have been evaluated by scholars in China [31–33]. Self-stress is further reduced to form fiber bundles as a result of the fading effect of expansion confinements. Thus far, the self-stress distribution model of TRSSC has not been reported in China and worldwide.

The mechanical properties of the SSC matrix and fibers were first investigated in this study. The tensile test of TRSSC sheets and the bending test of TRSSC beams were then conducted. Based on the tensile test of the TRSSC sheets, the self-stress value distribution was assumed as a quadratic function along the cross section. A specific mathematical model was determined according to composite material mechanics theory and then verified by bending test. The experimental results mainly corresponded with the theoretical solutions, thereby confirming the validity of the proposed model. The crack resistance of hydro-structures or key position in the structures can be controlled quantitatively, directionally and flexibly by changing the depth of the embedded textile in self-stressing concrete.

2. Test profile

2.1. Mechanical properties of textile

The textile was woven in 40 mm × 40 mm orthogonal grids by using roving, non-twisting fibers with high zirconium content and alkali-proof property. Epoxy resin was brushed thinly on the surface of the bundles to strengthen the synergy forced ability of fiber silk [34]. The textile is shown in Fig. 1.

The mechanical properties of fiber bundles are listed in Table 1. Three types of fiber bundles, namely, *a* (18.4 k), *b* (27.6 k), and *c* (36.8 k) were distinguished based on Tex content.

2.2. Mechanical properties of concrete matrix

The experiment used sulfo-aluminate cement (P.O. 32.5 Portland cement, with level 4 stress), limestone rubbles (nominal size of 5–16 mm), high-quality river sand, and third-generation polycarboxylate superplasticizer SikaIII to prepare concrete. The matrices of normal concrete (NC) and self-stressing concrete (SSC1and SSC2) were casted according to the mixing proportion shown in Table 2.

Cubic test specimens (size of 100 mm × 100 mm × 100 mm) and prism specimens (size of 150 mm × 150 mm × 300 mm) were prepared. Cubic compressive strength f_{cu} and axial compressive strength f_c were obtained based on the reference [35]. The results are listed in Table 3, and the analysis is detailed in Section 3.2.1.

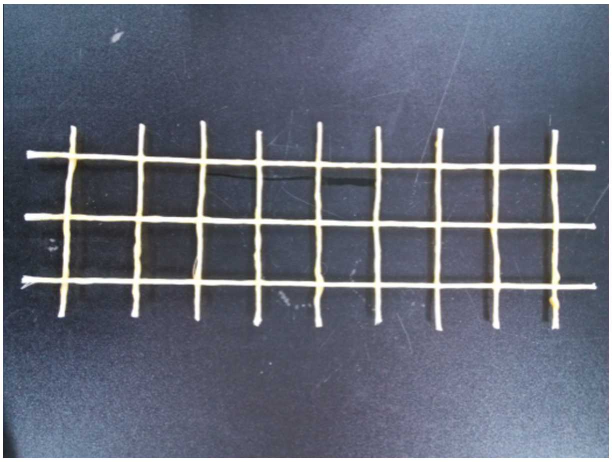

Fig. 1. Textile physical image.

Table 1
Mechanical properties of alkali-proof glass fiber bundles.

Fiber type	Bundle Tex k	Tensile strength MPa	Elastic modulus GPa	Linear mass g/Tex	Theoretic area mm^2
ARC13-2700H	9.2	1600	72	2700	0.975

Table 2
Concrete mix ratio.

Matrix	Cement/ kg m^{-3}	Water/ kg m^{-3}	Fine aggregate/ kg m^{-3}	Coarse aggregate/ kg m^{-3}	Super plasticizer/ kg m^{-3}
NC	663	239	796	530	1.19
SSC1	663	239	796	530	1.19
SSC2	625	281	500	750	0.93

Table 3
Compressive strength of matrix (MPa).

Compressive strength	SSC1	SSC2	NC
f_{cu}	42.4	46.4	50.7
f_c	40.3	43.7	45.4

2.3. Specimen preparation and testing procedure

TRSSC sheets were combined with self-stressing concrete and textile. The three fiber bundles were stretched in an electronic universal testing machine (DNS300) with displacement controlled at 0.20 mm/min. The length of each fiber bundle was 300 mm, and the load and stretching deformation were determined using sensors installed in the machine. The test picture is shown in Fig. 2.