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Study on the mechanical property of textile reinforced self-stressing concrete sheets

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HIGHLIGHTS

- Adopts textile reinforced self-stressing concrete (TRSSC) composite materials.
- Pull-out and bending tests of TRSSC sheets to gain better stress distribution of the bond behavior and bending property.
- The calculation formula of the bond strength is established based on Tepfers' partly cracked thick-walled cylinder model.
- Derivation of calculation models for TRSSC sheets elimination pressure moment.

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ABSTRACT

This study tests the mechanical property of textile reinforced self-stressing concrete (TRSSC) sheets, particularly the bond behavior between fiber bundles and self-stressing concrete sheets and the bending property of a TRSSC one-way sheet under four-point loading to understand the enhancement mechanism associated with TRSSC. Bond test results show that the ultimate pull-out force increases with an increase in the initial bond length. The bond behavior between textiles and self-stressing concrete is superior to that between textiles and common concrete. The calculation formula of bond strength is established, and the bending test results show that the cracking load of the TRSSC sheets is greater than that of textile reinforced concrete (TRC) sheets. The cracking capacity and ultimate bearing capacity of TRSSC is analyzed, and the calculation results are congruent with the experimental results.

1. Introduction

Textile reinforced concrete (TRC) is characteristically corrosion resistant, anti-magnetic, and lightweight, and it can be used for certain special structures [1,2]. However, its load capacity significantly decreases at the concrete cracking point, and the debonding phenomenon occurs in the textile and matrix interface because of stress concentration. The crack behavior of TRC specimens depends on the bond behavior between the fiber bundles and the concrete. This study adopts a self-stressing concrete with a self-expansion behavior to improve the bond behavior in TRC. The self-expansion behavior is restrained by textiles in the hardening process and produces self-pressure, which can significantly improve the cracking load. The restrained matrix exerts a strong gripping, which significantly improves the bonding property. The enhancement mechanism of textile reinforced self-stressing concrete (TRSSC) is quite different from that of TRC because of the self-expansion behavior. Using the pull-out and four-point bending tests on the TRSSC sheets and the TRC specimens for comparison, this study discusses bond behavior and bending property. The micro-morphology of the bond interface between the textile and self-stressing concrete is observed through a scanning electron microscopy (SEM) test. The calculation formula of the bond strength is established based on Tepfers' partly cracked thick-walled cylinder model, and the bending mechanical behavior of TRSSC one-way sheets is calculated and analyzed.

2. Materials and experimental procedures

2.1. Materials

2.1.1. Textile

The textiles used in this experiment consisted of both the warp and weft made from alkali-resistant glass fibers using plain weaving methods. Given that epoxy resin greatly improves the synergistic ability of textiles [3,4], the surface of the fiber

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Table 1
Property of alkali-resistant glass fiber.

Fiber type	Number of fibers	Tensile strength/MPa	Elastic modulus/GPa	Linear density/Tex	Theoretical area/mm^2
ARC13-2700H	9.2	1600	72	2700	0.975

Note: ARC13-2700H stands for alkali resistant continuous roving with fibrils diameter of 13 μm and linear density of 2700. *H* means that the content of ZrO_2 is more than 16%.

Table 2
Concrete mixture proportions.

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

Note: Self-stressing cement units were more than 550 kg m^{-3} because the SSC mix is designed to withstand a large self-stress value. This comprehensive consideration is based on the expansion property and mixture performance.

Table 3
Mechanical property of the matrix.

Matrix type	Compressive strength of 28d/MPa	Flexural strength of 28d/MPa	Free expansion rate/10^{-6}		
			7d	21d	28d
SSC1	33	8.46	11,435	13,856	14,201
SSC2	35	7.83	6198	7620	7733
C	47	5.28	1125	250	−875

Note: The curing conditions for three types of mixes is 20 ± 2 °C, and the humidity is over 95%. The free expansion rate of 28 d is negative because of the common concrete contraction process after the expansion in the process of hydration.

bundle was impregnated with epoxy resin to ensure that the fibers have strong synergistic force. Each textile grid had a space of 20 mm or 40 mm; the specific material parameters are shown in Table 1.

2.1.2. Self-stressing concrete

The traditional mix ratio of self-stressing concrete must be optimized to improve the bonding behavior of textiles and self-stressing concrete. Given the small mesh size of the textile, the maximum grain size of coarse aggregates cannot be larger than 16 mm. The flow ability of the matrix must be improved to ensure that the concrete fully warps the textiles. Self-stressing cement uses level-4 safety self-stressing cement [5]; Common cement uses P.O.42.5 cement. Three kinds of concrete mixes are shown in Table 2 [6]. The common concrete mix was used for the comparison test. The mix of SSC1 and C was used for the bond test, and that of SSC1, SSC2, and C was used for the four-point bending test. The physical and mechanical property of the three kinds of matrices is shown in Table 3.

2.2. Experimental procedures

2.2.1. Bond test

The ability of textiles and self-stressing concrete to coordinate with each other is dependent on the bond behavior. Pull-out tests can realistically reflect the stress distribution of the bond surface when a structure bears loads [7]. Pull-out tests examine the influence of the initial bond length of a textile and the matrix on bond behavior, thereby allowing the comparison of the common concrete matrix specimens. The size of clamping fixture was designed with 50 mm to eliminate the influence of the clamp part of the bond test. First, the wooden molds of 800 mm × 400 mm × 20 mm and 800 mm × 400 mm × 15 mm are made. The mold with the cover thickness is first made, and the textile is fixed on it, and the remaining part of the mold is installed. The concrete is poured into the molds with the slight vibration. The test sheets were sawn from 200 mm × 80 mm × 20 mm and 200 mm × 80 mm × 15 mm plate after the standard curing condition for 28 days.

The bond test was conducted on eight groups, each of which contained five specimens (Table 4). The pull-out specimen for each cutting seam was reserved as the fiber bundle. The electronic universal testing machine was used for loading at a rate of 1.0 min/mm [8]. The load–displacement curve was obtained through the Germany IMC dynamic testing system (Fig. 1).

2.2.2. Four-point bending test

The test sheet was sawn from a 400 mm × 120 mm × 20 mm metal plate. The textile was laid at cover thickness distance from the bottom surface. The bending test specimens were tested in nine groups, and each group consisted of four specimens (Table 5). The electronic universal testing machine was used to apply the load; the four-point bending test device is shown in Fig. 2. Load and displacement sensors determine the load and span deflections. The load–displacement curve is collected by the Germany IMC dynamic testing system. The loading method is displacement control, and the loading rate is 0.3 mm/min [9]. Test is stopped when the curve peak decreases significantly, or the first fiber bundle fractures (Fig. 3).

Table 4
Groups of specimens.

Matrix type	Thickness/mm	Bond length/mm	Cover thickness/mm
SSC1(C)	15	20	7
		30	7
		40	7
		50	7
	20	20	10
		30	10
		40	10
		50	10

3. Results and discussions

3.1. Bond behavior

3.1.1. Effect of fiber bond length on bond behavior

The ultimate pull-out force increases when the initial bond length is enhanced (Fig. 4). The friction resistance between the fiber bundle and the self-stressing concrete is more serious because of the longer bond length and larger contact area with the matrix than those of between the fiber bundle and the common concrete. When the embedded fiber bundle length is less than 30 mm, the fiber bundle can be slowly pulled out from the specimen (Fig. 5a). The surface of the fiber bundle displays wear condition. When the embedded fiber bundle length is more than 40 mm, the curve appears to drop steeply (Fig. 5b). This finding indicates that the fiber bundle cannot bear the load when the internal parts of the fibers reach the ultimate load. During this process, a very clear fracture sound occurs during the pull out.