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Influences of geometric patterns of 3D spacer fabric on tensile behavior of concrete canvas

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HIGHLIGHTS

- A promising concrete reinforcement material was introduced for new concrete applications.
- Influences of geometric patterns of 3D spacer fabric on the tensile behavior of concrete canvas were investigated.
- Concrete canvas reinforced by 3D spacer fabric with one solid outer textile substrate exhibited improved tensile behaviors.
- 3D spacer fabric reinforcement was a better option than spacer yarns alone.

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ABSTRACT

In this study, influences of geometric patterns of 3D spacer fabric on the tensile behavior of concrete canvas (CC) were investigated. Five 3D spacer fabrics with different geometric patterns were investigated. Tensile stress–strain curves and crack propagating patterns of CCs were obtained in warp and weft directions through experiments. Experimental results revealed that the CC samples reinforced by the 3D spacer fabrics with one solid outer textile substrate exhibited improved tensile behaviors in terms of tensile strength, reinforcing efficiency factor and crack pattern. Moreover, for CCs, 3D spacer fabric reinforcement was a better option than spacer yarns alone.

1. Introduction

As a new composite material, textile reinforced concrete (TRC) has various outstanding properties such as larger load-bearing capacity, excellent ductility, thinner thickness, light-weight of components, resistance to corrosion and no magnetic disturbances [1–5]. Textile used as reinforcement can significantly improve tensile strength of concrete. However, the tensile strength, ductility and cracking pattern of TRC depends not only on its components, but also the bonding between reinforcement and the matrix which is influenced by the geometries of textile including weft yarns spacing [5], stitches size [6,7], and bundle size of yarns [6,8].

The 3D spacer fabric is a more attractive product when it is used for concrete applications [9,10]. As a special textile, 3D spacer fabric presents various advantages and shows a superior behavior as it could reinforce the cementitious composites in three directions and provide defined positioning of the two outer substrates [10]. 3D spacer fabric has been successfully applied in civil engineering [11,12] such as sandwich panels, façade elements and claddings etc. The superiority of applying 3D spacer fabric in concrete is the possibility to produce concrete elements with desired cross-section and reinforcing yarns along the thickness of the elements. Because of good stability of 3D spacer fabric, it also allows the design of extremely-thin-structural concrete elements with outstanding mechanical performance [13–15].

Among various engineering applications of 3D spacer fabric reinforced cementitious composites, concrete canvas (CC, the concept was first proposed by Brewin and Crawford in 2005) is one of the most promising products [16]. For conventional 3D spacer fabric reinforced cementitious composites, one needs to mix water with dry powder firstly, then cast the fresh mixture into the mold with 3D spacer fabric, and demold till it is harden. However, CC has different preparation process. In initial stage, CC is a flexible 3D spacer fabric impregnated with cement powder. Like soft cloth, CC can closely cover the surface of arbitrary structure or element

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before using. Then, one just needs to spray or add water to the top surface of CC. After CC hardens, a thin, durable water-proof and fire-proof composite layer forms. Its shape is completely the same as the outer profile of the structure or element where CC is covered. Therefore, CC can be quickly, efficiently and widely used in civil engineering such as a cover of prefabricated shelter, a trackway for vehicles, pedestrians or protection layer for pipe and lining.

In order to apply CC in practice, its mechanical properties should be investigated thoroughly. As a load-bearing element, the geometric patterns of 3D spacer fabric would undoubtedly affect the mechanical properties of CC. However, to the authors' knowledge, the influences of geometric patterns of 3D spacer fabric on the tensile behavior of CC have barely investigated in the literatures.

Therefore, in this study, we studied the influences of geometric patterns of 3D spacer fabric on tensile behavior of CC. Five PET-based 3D spacer fabrics with different geometric patterns were investigated. Tests have been done to obtain warp and weft tensile stress–strain curves and the crack propagating patterns of CCs.

2. Experimental program

2.1. 3D spacer fabrics

A typical 3D spacer fabric and the inside components are presented in Fig. 1. The warp yarns are inserted into the stitches and assembled together with the weft yarns, by this way a grid net can be produced and the meshes in the net can be knitted in various shapes. In addition, two different kinds of spacer yarns can be inserted into the structure. One of them, spacer yarn I, is vertical to the outer textile substrates, the other one, spacer yarn II, is inclined to the outer textile substrates. The warp direction is along machine direction while the weft direction is along the orthogonal direction of warp direction [11].

In this study, five 3D spacer fabrics with different geometric patterns of outer textile substrates and different amounts of spacer yarns were investigated to study the tensile behavior of CCs. As described in Table 1, T20 is a 3D spacer fabric with 20 mm thickness whose two outer textile substrates are identical mesh fabric. It has both spacer yarns I and II, and the pore shape of both substrates is regular triangle. The warp/weft yarn and spacer yarn are made by 342 dtex PET multifilament and 379 dtex PET monofilament, respectively. The other four are 3D spacer fabrics with 15 mm thickness (denoted as N15) in which only one of their outer textile substrates is mesh fabric and the other is solid fabric. The architecture of solid fabric of N15 is tricot, where the architecture of solid fabric of N15-IV is much looser than that of the others. Only spacer yarn II is inserted into their structure. The pore shape of mesh fabric is regular rhombus for N15-I and N15-II, and regular square for N15-III and N15-IV. The warp/weft yarn of solid fabric and mesh fabric are made by 396 dtex and 339 dtex PET multifilament, respectively. The spacer yarn is made by 495 dtex PET monofilament. In addition, all warp/weft yarns of mesh fabrics of 3D spacer fabrics are in twisted form. The other structural parameters of the fabrics are given in Table 2.

2.2. Specimens preparation and curing

Raw materials for the matrix used in this study were anhydrite and calcium sulphoaluminate cement (CSA). Their compositions are given in Table 3. The CSA cement used contains 65.5% ye'elimite and its Blaine specific surface is 442 m^2/kg. The anhydrite has a Blaine specific surface of 387 m^2/kg. Their particle size distributions determined by laser diffraction (Microtrac S3500) are given in Fig. 2. Optimized mix proportion of matrix is shown in Table 4, in which anhydrite is 20% of CSA by weight and water/binder ratio was fixed at 0.45. The selected water/binder ratio was calculated based on the mass of sample before and after spraying in preliminary exploration work, where water-spray stopped immediately if the water just penetrates through the bottom layer of 3D spacer fabric.

The preparation procedure was conducted at temperature of 25 °C and relative humidity of 75%. Firstly, CSA and anhydrite were poured into a Thunderbird ARM-02 mixer and stirred for 10 min at 94 r/min. Then, the powder mixture was gradually placed and vibrated into the mold with 3D spacer fabric of 400 mm × 100 mm × 20 mm (i.e. T20 type fabric) or 400 mm × 100 mm × 15 mm (i.e. N15 type fabrics) until the 3D spacer fabric was fully impregnated with powder. In the same way, the unreinforced control samples with the sizes of 400 mm × 100 mm × 20 mm were also prepared. To assess the bonding strength between yarns and the matrix, a type of dog-bone mold with dimensions of 235 mm × 25 mm × 25 mm was adopted (as shown in Fig. 3). A slot with 2 mm width was located in the middle of mold. A PVC slice with a single yarn passing through the center is insert into the slot. The embedded lengths of the single yarn on both sides of slice are 15 mm and 80 mm, respectively. Finally, tap water with temperature of 24.3 °C was sprayed into the mold until the water/cement ratio reached 0.45. Specimens were demolded after final setting, and moved into the standard curing room ($T = 20 \pm 2$ °C and $RH \geqslant 95\%$). To check whether water penetrates through this whole thickness of the sample, we cut along the cross section of the sample after hardened, and the result is given in Fig. 4. It can be seen from Fig. 4 that the density of the paste in bottom layer is similar to the top layer. Therefore, it demonstrates that the current water-spaying method may guarantee water penetrate through the whole thickness of sample. To obtain the suitable curing age for tensile test, the time-dependent compressive strength of cubic CSA-based CC sample with dimensions of 15 mm × 15 mm × 15 mm was preliminarily investigated and the result is given in Fig. 5. It revealed that 10-day compressive strength of the sample almost reaches the maximum mechanical strengths value. In addition, the mechanical characteristics of commercial CC made by Concrete Canvas Ltd was evaluated after 10-day curing. For the sake of comparison, the tensile behavior of CCs would be conducted after 10 days curing. According to the difference in the type of 3D spacer fabrics as shown in Table 1, the CC samples were labeled as T20-CC, N15-I-CC, N15-II-CC, N15-III-CC and N15-IV-CC, respectively.

2.3. Test methods

2.3.1. Tensile tests of yarns and 3D spacer fabrics

The tensile tests of yarns were conducted on XL-2 yarn tensile tester with 30 N capacity. The stroke-control rate was set at 50 mm/min and the initial distance between the two clamps was set at 250 mm. Each group has 10 samples. The tensile tests of 3D spacer fabrics were conducted on CMT4104 tensile machine with 10 kN capacity. The stroke-control rate was set at 10 mm/min. The sizes of specimens are 350 mm × 70 mm × 20 mm for T20 and 350 mm × 70 mm × 15 mm for N15. The tensile tests of 3D spacer fabrics were separately conducted in warp and weft directions considering the anisotropy. Each group has three samples. Before tests, all specimens were cured under temperature of 20 ± 2 °C and relative humidity of 65.0 ± 4.0% for 12 h. Tensile stress–strain curves were obtained for all yarns and 3D spacer fabrics, but only the average values and standard deviation were reported in this study.

2.3.2. Yarns pull-out tests

The bonding strength between yarns and the matrix were tested by using a CMT4103 electromechanical universal tensile machine with 1 kN load cell. The stroke-control rate was set at 0.5 mm/min. Five parallel samples of each group were tested and the average values and standard deviation were presented. Almost all yarns were pull out from the side with shorter embedded length of yarn. The curves of pull-out load P per unit remaining embedded length versus slip displacement Δs were obtained. The remaining embedded length is the difference between the initial embedded length L and the slip displacement Δs. Considering the very short region of embedded yarns that adhesive bonding strength exerts on, it is assumed that the yarns are held in matrix only by frictional bonding with no adhesive bonding.

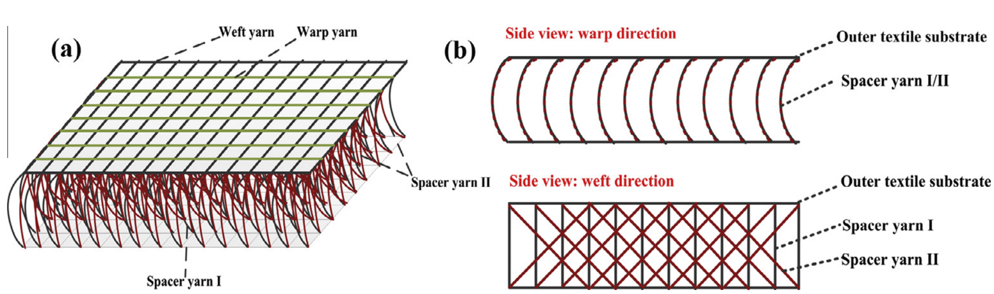

Fig. 1. A typical 3D spacer fabric: (a) global view and (b) side view.