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Experimental study on basalt textile reinforced concrete under uniaxial tensile loading

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HIGHLIGHTS

- The tensile behavior of TRC is related to the number of textile layers.
- First-crack stress increases with increasing prestress levels.
- Ultimate tensile strength is slightly influenced by prestress levels.
- Maintaining the prestress within an appropriate level is important.
- The tensile behavior of TRC with appropriate prestress level increases with increasing addition of short steel fibers.

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ABSTRACT

This study focuses on 24 experimental cases to investigate the influences of textile layers, prestress levels and short steel fibers on the tensile behavior of basalt textile reinforced concrete (TRC). The tensile behavior of basalt TRC is considerably influenced by the number of textile layers. The TRC specimens with one or two textile layers demonstrate no reinforcement efficiency, whereas those arranged with three to five textile layers exhibit pronounced strain-hardening behavior and consequently, prominent enhancement of tensile behavior and optimized cracking patterns. For the prestressed TRC specimens, evident increases in first-crack stress are observed with increasing prestress levels, whereas only a slight influence on ultimate tensile strength can be achieved. Moreover, maintaining the value of the prestress within an appropriate level is an important issue for TRC. Furthermore, the TRC specimens with an appropriate prestress level exhibit increasingly favorable tensile response with the rising volume fraction of short steel fibers.

1. Introduction

Textile reinforced concrete (TRC) is a relatively new class of cementitious material that integrates textile with high tensile strength and ductility into a brittle matrix. Compared with traditional building materials, TRC exhibits several advantages, including high corrosion resistance, large ultimate strain, lightweight and enhanced strength. Given its excellent mechanical properties, TRC can be highly appropriate to many applications, both for building new structures and for strengthening and repairing old structure elements [1–3].

At present, TRC is generally reinforced with carbon, alkali-resistant (AR) glass, polyethylene (PE) or aramid textile [4–7]. This study attempts to use basalt textile, which is a low-cost and environmentally friendly material, as reinforcement for TRC specimens. Recent research has included basalt textile as a reinforcing material for fiber-reinforced plastic (FRP) composites [8]. However, the related experimental investigations on this textile used in TRC just started recently [9]. Sim et al. [10] investigated the applicability of basalt fiber as a strengthening material for structural concrete members through various experimental works on mechanical properties and thermal stability. The results of their experiments indicated that, among various FRP strengthening systems, basalt fiber strengthening would be a good alternative when moderate structural strength and high resistance to fire were required for building structures. Lopresto et al. [11] determined that basalt fiber could replace glass fiber as reinforcing material in several applications where glass composites were already applied.

Rambo et al. [12] studied the mechanical properties of basalt TRC composites subjected to tensile loading and found that the behavior of TRC was strongly affected by the reinforcement ratio. The TRC specimens produced with three to five textile layers demonstrated effective cracking control and pronounced enhancement of tensile

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strength and ductility. Larrinaga et al. [9] used basalt textile with one to four layers to function as TRC reinforcement. The number and width of cracks, as well as the distance between them, were reportedly reduced as the number of reinforcement layers increased. Furthermore, a reduction of approximately 10% on TRC stiffness was observed during the post-cracking stage compared with the elastic modulus of textile reinforcement.

A relatively large deformation is produced at the maximum load-bearing capacity of TRC under tensile loading given the tolerance of this material to multiple cracking. Such large deformation prior to material failure is undesirable with regard to structural safety. For the service state, where only a small deformation is acceptable, the design load-bearing capacity of TRC must be lower than its ultimate tensile strength [13]. In recent years, researchers have already tried some methods to improve the anti-cracking capacity of TRC, including exerting prestress on textile and adding short fibers to the matrix. Reinhardt et al. [14] investigated the influence of prestress on the bearing capacity of TRC plates using four-point bending tests. They demonstrated that the prestressed AR-glass TRC plate exhibited higher tensile strength, as well as reduced crack number and deformation, compared with the unprestressed TRC plate. Prestressing made a more notable effect on impregnated carbon TRC plate. An increase in cracking strength, tensile strength, and bond performance between textile and concrete was observed. However, strain capacity and crack width decreased. Meyer and Vilkner [15,16] explored the possibilities of prestressing thin sheet glass concrete products with aramid fabrics subjected to three-point bending tests. They found that the application of prestress delayed the formation of flexural cracks and the stiffness of cracked sections increased with increasing prestress. At the same time, the ductility showed inverse proportion to prestress level. Barhum and Mechtcherine [13,17] demonstrated the evident positive influence of short glass and carbon fibers on the mechanical performance of a TRC plate under tensile loading. Cracking stress increased two to three times because of the addition of 1.0% by volume short fibers. With regard to the ultimate tensile strength and strain capacity of the TRC plate, the addition of short fibers failed to provide any improvement. Moreover, the surface of the specimen presented a higher number of cracks and finer cracks when short fibers were added to the TRC. Flavio et al. [18] found that adding short glass fibers could improve the cracking strength and ultimate tensile strength of a TRC specimen that was subjected to quasi-static and impact loading. Lima et al. [19] studied sisal fiber-cement composites reinforced with 4% and 6% of short fibers, and found that the reinforcement provided by short sisal fibers for recycled cement matrices guaranteed a composite with multiple cracking and an increase of strength after the first crack.

Based on the previous research findings, this work tries to use basalt textile to reinforce fine-grained concrete matrix. Different prestress forces were applied on the basalt textile to improve the anti-cracking performance of TRC. Simultaneously, different volume contents of short steel fibers were added to the TRC matrix to achieve increased load-bearing capacity and optimized cracking patterns. This study aims to assess the influences of textile layers, prestress levels, and volume fractions of short steel fibers on the tensile behavior of basalt TRC subjected to uniaxial tensile loading. Particular attention is directed to the course of the stress–strain relationship and cracking mechanisms.

2. Materials

2.1. Fine-grained concrete matrix

The concrete used was a fine-grained material to satisfy the specific properties of textile reinforcement. Load was applied on the textile prior to casting the matrix; hence, silica fume was added to the matrix to obtain high early strength, and thus, reduce prestress force loss resulting from the relaxation of prestressed textile. The matrix should be self-compacting and sufficiently flowable given the small mesh size of the textile and the small distance between textile layers. Table 1 summarizes the matrix composition.

2.2. Basalt textile and short steel fibers

As shown in Fig. 1(a), a particular type of biaxial textile made of basalt fiber bundles and coated with styrene-acrylic latex (with a mesh size of 5 mm × 5 mm) was used as the composite internal reinforcement in this experiment. In addition, the warp bundles were arranged along the loading direction to function as load-bearing fibers. A considerable gap existed between the tensile strength and Young's modulus values of a single fiber or filament and those of the textile [9]. Therefore, the mechanical characteristics of the basalt textile were determined by conducting tensile tests on a 40 mm (width) × 100 mm (length) basalt textile strip (the same one used in the TRC) that consisted of eight warp basalt bundles. The specific material parameters are presented in Table 2.

Copper-plated short steel fibers (Fig. 1(b)) with an average diameter of 0.22 mm and a length of 4–6 mm were applied as additional reinforcement. The fibers had a density of 7.8 g/cm^3 and a tensile strength of 2800 MPa.

3. Preparation of specimens and the test method

3.1. Preparation of specimens

The TRC specimen label used in this study is defined as the following manner. TP represents the prestress level applied on textile, L represents the number of textile layers, and S represents the volume fraction of short steel fibers. For example, the label TP17.4L4S1.6 represents a TRC specimen with a prestress level of 17.4%, four layers textile and 1.6% by volume short steel fibers.

The TRC samples with one to five textile layers functioning as the reinforcing material and the samples without textile layers had the same thickness of 12 mm. The single internal textile layer was placed at the middle plane of the TRC plate. For the TRC plates reinforced with two textile layers, the thicknesses of matrix layers on the top, bottom and in-between different textile layers are all 4 mm. For the plates reinforced with three, four and five textile layers, the thicknesses of matrix layers on the top and bottom are both 3 mm. The thicknesses of matrix layers in-between different textile layers are 3 mm for three-layer plates, 2 mm for four-layer plates and 1.5 mm for five-layer plates. The cross-section of TRC plate with four layers of textile in the mold is taken as an example in Fig. 2(a). A number of steel strips were used in-between different textile layers to control the thickness of each matrix layer. In addition, steel strips were also used to divide the

Table 1
Matrix composition.

Composition	kg/m^3
Cement P.O 42.5	645
Fly ash	274.4
Silica fume (dry)	58.8
Sand 0–0.6 mm	408
Sand 0.6–1.2 mm	817
Superplasticizer[a]	4
Water	392
Defoaming agent	2.4

[a] Solid:Water = 40:60.