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Flexural behavior of basalt textile-reinforced concrete

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HIGHLIGHTS

- Flexural strength of BTRC is related to the number of textile layers.
- First-crack flexural stress increases with increasing prestress levels.
- Chopped steel fibers increases the crack number of BTRC.
- Effect of steel fibers on flexural strength is more obvious with higher prestress.
- Calculated and experimental results of flexural strength agree well.

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ABSTRACT

Textile-reinforced concrete (TRC) as a novel high performance composite material can be used as not only strengthening material but component bearing load alone. This paper aims to investigate the influences of the number of textile layers, prestress levels of textile, and volume contents of chopped steel fibers on the flexural behavior of basalt textile-reinforced concrete (BTRC) plate through four-point bending tests on 24 experimental cases. Flexural strength and toughness were observed to improve with the increase of the number of textile layers. Prestress on the textiles contributed to improving the first-crack flexural stress and pre-cracking flexural stiffness of the BTRC, but the flexural strength and toughness were found to decrease with the increase of the prestress level. The addition of chopped steel fibers in the matrix was revealed to positively affect the first-crack flexural stress, flexural strength, and post-cracking flexural stiffness and toughness. Moreover, the crack pattern, which features a high crack number and reduced crack spacing, was achieved with the increase of the number of textile layers and the volume content of chopped steel fibers. However, the crack number reduced and the average crack spacing increased with the increasing prestress level of the textiles. The prestress and chopped steel fibers significantly improved the flexural behaviors of BTRC, which contributes to the application of BTRC flexural components. The paper presents the formulas for calculating the flexural strength of non-prestressed BTRC without chopped steel fibers, and the calculation formulas can be used to guide the design of such BTRC flexural components.

1. Introduction

Textile-reinforced concrete (TRC), as a new composite material that consists of high performance fine-grained concrete and textiles made of various type of fibers, exhibits the advantages of excellent load bearing capacity, durability, and corrosion resistance [1–3]. The concrete cover of TRC is thin due to the excellent corrosion resistance of textiles [4–6]. The textile reinforcement is placed in the direction of the tension, thereby leading to the increase in the utilization factor of the fibers [7]. Therefore, TRC tends to be lightweight and potential in complex geometrical shapes and configurations, thin-walled structures and prefabricated sandwich panels [8–14]. Consequently, it is necessary to adequately explore the mechanical properties, especially the flexural behavior of TRC.

Currently, the flexural behaviors of TRC have been experimentally investigated by some researchers. Hegger et al. [11] studied the flexural behavior of TRC reinforced with textiles made of carbon and alkali-resistant (AR) glass fibers using four-point bending

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tests, and obtained the influence of reinforcement ratio on the ultimate stress, crack spacing, and elongation in the tension zone of TRC. Zhu et al. [15] explored the flexural behavior of AR glass TRC using three-point bending tests. The results of their experiments revealed that the absorbed energy of TRC increased with increasing the number of textile layers. Reinhardt et al. [16] investigated the influences of the textile type, whether the textile is impregnated or not and the prestress on the flexural behaviour of TRC using the four-point bending tests. The prestress on the AR glass textile improved the ultimate load and reduced the ultimate deflection of the specimens. Prestress on the carbon textile reduced the ultimate load and increased the ultimate deflection of the specimens, and the crack width at failure cannot meet the requirement for normal serviceability. However, prestress on the impregnated carbon textile increased the first-crack and ultimate loads of the specimens but reduced the ultimate deflection and crack width. Hence, the impregnated carbon textile was the most suitable for the prestressed TRC according to the results. Meyer and Vilkner [17,18] conducted three-point bending tests on the aramid TRC and found that the post-cracking flexural stiffness gradually increased with the increase of prestress level but the ductility decreased. Additionally, prestress on the textiles delayed the generation of cracks. Silva et al. [19] studied the cementitious composites reinforced with unidirectional continuous sisal fibers using three-point bending tests and highlighted that the specimens exhibited the properties of strain-hardening and multi-cracking. However, the generation of cracks resulted in the decrease in flexural stiffness of TRC. Tsesarsky et al. [20] conducted three-point bending tests on the TRC reinforced with three types of textiles, and determined that the polyethylene (PE) TRC exhibited low strength but high ductility, and the AR glass TRC showed intermediate strength and brittle behavior, and moreover, the carbon TRC had high flexural strength and ductility. Pakravan et al. [21] carried out three-point bending tests on carbon TRC with polyvinyl alcohol (PVA) fibers, and found that the specimens with PVA fibers demonstrated the property of strain-softening. In addition, the bridging effect of PVA fibers constrained the propagation of cracks, resulting in the increase in the ultimate load bearing capacity, crack number, and energy absorption capability of TRC.

However, experimental investigation into the flexural behavior of BTRC has been scarce in the literature to date. Basalt fiber is a typical silicate fiber with natural compatibility with concrete, and has high temperature resistance and alkali resistance. So together with its low cost, basalt fiber has high potential for the TRC [22,23]. Larrinaga et al. [22] examined the tensile properties of the cementitious composites reinforced with one to four layers of basalt textile, and found that crack number increased but crack spacing and width decreased with the increase of the number of textile layers. Du et al. [24] studied the influence of the number of textile layers and prestress levels on the tensile properties of basalt TRC. Their results indicated that the number of textile layers was an important factor that influenced the tensile properties of basalt TRC. Besides, controlling the level of prestress at a reasonable range was necessary to show the advantages of prestress on TRC. Rambo et al. [25] investigated the basalt TRC, which was subjected to uniaxial tensile loading at room temperature, and found that the tensile properties of TRC were considerably influenced by the reinforcement ratio. The TRC exhibited improvements on the crack pattern, load bearing capacity, and ductility when the number of basalt textile layers increased from three to five.

This present paper aims to investigate the influence of the number of textile layers, prestress levels, and volume contents of chopped steel fibers on the flexural behavior of BTRC. The four-point bending tests were employed. Based on the tests, the flexural stress–deflection relationship, cracking mechanisms and failure modes of each experimental case are presented and analyzed.

2. Experimental study

2.1. Basalt textile and chopped steel fibers

Basalt appears to be a material which could offer interesting opportunities in the future to satisfy the increasing demand of the construction industry [26,27]. The basalt textile applied as an internal reinforcement in this study consists of rovings woven in the two principal directions, which geometry is illustrated in Fig. 1(a). Basalt textiles are covered by a styrene-acrylic latex coat. In addition, the warp basalt fiber bundles were arranged along the loading direction to function as loading bearing fibers. According to previous studies, there is a considerable gap between the tensile strength and Young's modulus values of a single fiber or filament and those of the textile [28]. Therefore, the mechanical characteristics of the basalt textile were determined by tensile test on textile strips with size of 100 mm (length) $\times$ 40 mm (width) that consisted of eight warp fiber bundles, as illustrated in Fig. 1(c). The tensile tests were conducted on MTS C43.304 with a loading rate of 0.5 mm/min. It is worth noting that both ends of the basalt textile strips were enhanced by corrugated aluminum according to Chinese Standard GB/T 3362-2005 (Test method for tensile properties of carbon fiber multifilament). The results obtained in the textile strip characterization are summarized in Table 1. Additionally, the cross-sectional area of a single fiber bundle is 0.1956 mm^2, which was the ratio of tex (the linear density of this material) to its bulk density [29].

Chopped steel fibers (Fig. 1(b)) are known for their superior mechanical properties, such as high tensile strength and high Young's modulus. The addition of chopped steel fibers into the concrete matrix can improve the tensile properties of the concrete matrix and interfacial bond performance between textiles and matrix. Therefore, the chopped steel fibers coated with copper were applied as additional reinforcement in this study, and the mechanical and geometrical parameters of the chopped steel fibers are listed in Table 2.

2.2. Fine-grained concrete matrix

Fine-grained concrete was used as the matrix to satisfy the requirement of high workability and self-compacting property. The maximum grain size of the aggregate was 1.2 mm to ensure that the matrix easily flows through the grids of the textiles, and guarantee the density of the matrix in the specimens, thereby the quality of the specimens. Because the textile was prestressed

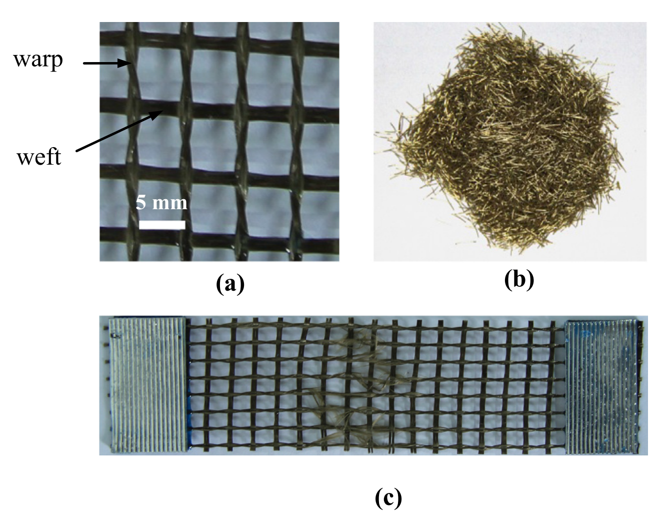

Fig. 1. (a) Basalt textile, (b) chopped steel fibers, and (c) basalt textile strip.