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Tensile behavior of basalt textile grid reinforced Engineering Cementitious Composite

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ABSTRACT

To overcome the shortness of organic bonding in fiber-reinforced polymer (FRP) retrofitting, textile-reinforced mortar (TRM) has been studied as an alternative composite for retrofitting structural concrete. However, the brittleness of mortar brings the conflict between the efficient using of FRP and durability performance of TRM. To solve this problem, Engineering Cementitious Composite (ECC) can potentially be used to replace mortar in TRM, due to its "ductile" property. The new textile-reinforced composite is named as TR-ECC. In this paper, the tensile failure mechanism and mechanical properties of TR-ECC composite, which was composed of basalt textile grids and one kind of ECC, Ultra High Ductility Cementitious Composite (UHDCC) as the matrix, was investigated. The uniaxial tensile tests on 24 TR-ECC specimens (eight groups) were carried out. The variables include thickness of UHDCC per layer, textile grid geometry configuration and volumetric ratio of textile grids. The influence of variables on the failure pattern, initial elastic and hardening modulus, crack tensile stress, ultimate tensile strain and stress of TR-ECC were analyzed. Finally, the stress-strain behavior and strength of TR-ECC were compared with that of traditional TRM. The test and comparison results show that ECC can largely improve the textile reinforcement effect than the mortar and well control the cracking width.

1. Introduction

The organic resins (e.g. epoxy) are commonly used as the binder for fiber-reinforced polymer (FRP) strengthening, while, the drawbacks are gradually recognized by the researchers, including deteriorated bond performance after fire or UV radiation exposure, inability of application on wet surface or under low temperature, etc. [1]. To overcome these problems, textile-reinforced cementitious products were developed in the early 1980s, but it drew research interest in material products, strengthening and new construction in 21st century among the research community [2]. Textile-reinforced mortar (TRM) is one of the major products with inorganic binders, which composed of FRP textile with open-mesh and cementitious mortar. Unlike the textile itself, the uniaxial tensile behavior of TRM shows a non-linear stress-strain relationship which can be divided into three stages (Fig. 1) [3]. It develops from linear elasticity to multiple cracking with minor increase of load, and then has linear hardening with cracks opening until the failure of textile. The peak strength of TRM is only contributed by the FRP textile. TRM shows good resistance at high temperature, compatible to concrete substrate surface and gains more attention in retrofitting of existing concrete structures [4–7]. Application of TRM for retrofitting of reinforced concrete (RC) members includes the following cases: flexural strengthening of RC beams [1,4], shear retrofitting of RC beams [6,8], and confinement for columns [7,9] joints [10,11] and RC or masonry walls [12,13]. It is also applied in the construction of shell structures [14–16], as an alternative composite for steel mesh reinforced concrete.

The matrix of TRM, mortar, is the brittle material. The multi-cracking stage is very short. In this stage, the crack width can remain fine, but it generally lasts until reaching the tensile strain of approximately 0.5%. It is far below the rupture strain of textile which is usually 1%–3% [17]. After multi-cracking stage, the crack width will increase until the textile reaching its rupture strain and hence, the larger the rupture strain of textile is, the larger the crack width is. The test results in Ref. [18] showed that the crack widths after the second stage ranged from 0.3 mm to 0.5 mm for polyparaphenylene benzobisoxazole (PBO)-grid-TRM and carbon-grid-TRM, even larger (from 0.6 mm to 0.9 mm) for glass-grid-TRM. According to ACI 224 [19], the crack width limitation for RC structures under service loads ranges from 0.1- 0.4 mm for different environmental conditions. In other words, the stress level of TRM corresponding to the crack width limitation is rather smaller than the ultimate strength. The high strength property of textile grids

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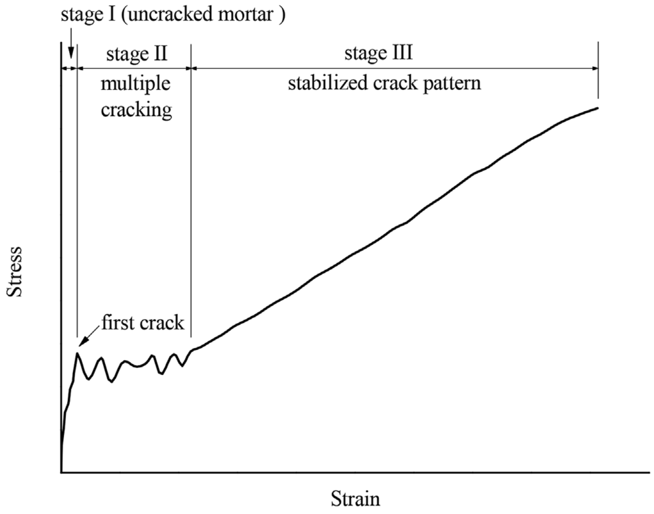

Fig. 1. Typical axial tensile stress-strain curve of TRM [3].

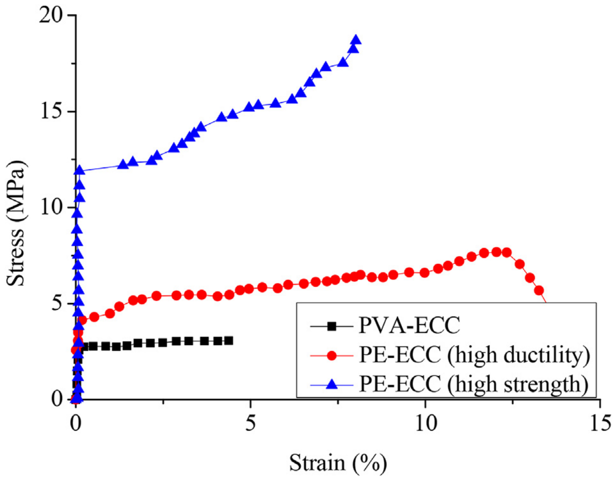

Fig. 2. Tensile behavior of different ECCs [36].

cannot be fully utilized. This phenomenon is more obvious for RC members in marine environment, whose crack width limitation is stricter.

In order to overcome the shortness of mortar and enhance the tensile performance of TRM, the mortar mixture with short fibers was investigated and demonstrated improvement of pre-crack and multiple cracking performance of TRM, while the strength was still determined by the reinforcement, and the failure pattern was still brittle [20–22]. With the development of Engineering Cementitious Composites (ECCs), brittle cementitious materials were designed to behave in a "ductile" way. ECC can achieve tensile extension capacity as high as 3% with short fibers' volume fraction no more than 2%, and exhibit excellent ductility and micro-cracking of self-controlled widths with average crack width less than 0.1 mm [23–28]. This level of crack width is right below the crack-width limitation of RC structures under service loads [19]. If ECC replaces the mortar as the matrix, it may have potential to overcome the conflict between the efficient utilization of FRP and durability performance of TRM. The new composite is named as TR-ECC, and was firstly mentioned by Dai et al. [29], followed by Zheng and Wang [30]and Zheng et al. [31]. Dai et al. [29] has demonstrated the advantages of micro-cracking and full utilization of FRP textile through flexural strengthening for RC beam. However, the tensile performance of TR-ECC has not been thoroughly studied. References [30] and [32] are the only published works in the open literature. Orosz et al. [32] were the pioneering researchers investigating the potential of TR-ECC in tensile and concluded that TR-ECC could have a more significant and consistent tension-stiffening than TRM. Zheng and Wang [30] studied the tensile behavior with the variation of grid thickness. From their study, it was shown that the uniaxial tensile behavior of TR-ECC was characterized by the bilinear stress-strain curve, which would be enhanced by the grids' thickness increase. Another prominent feature they found was the multiple cracking occurrence until the fracture strain of TR-ECC. Thus, TR-ECC, as a new kind of TRM, can serve as a potential solution to benefit the FRP retrofitted RC building structures from fire resistance as the intact RC structures or protect the concrete substrate and existing steel reinforcement in the corrosive environment. However, the current researches still have gap to guide the design of TR-ECC in the specifications. The work in this paper aims to fill the gap, and focuses on three factors' effect on the failure mechanism and tensile properties of TR-ECC under direct tensile. Three factors are the matrix thickness, textile grid geometry and volumetric ratio of textile grids.

Table 1
Properties of basalt textile grid.

Spec. type	Center-to-center distance of wrap yarns (mm)	Center-to-center distance of weft yarns (mm)	Cross section area of one yarn (mm^2)	Out-of-plane stiffness
A	5 ± 1	5 ± 1	0.369	Very soft
B	10 ± 1	10 ± 1	0.324	Very soft
C	25 ± 1	25 ± 1	3.082	Medium soft

2. Material property of two components

In the research of Orosz et al. [32] and Zheng and Wang [30], polyvinyl alcohol (PVA) fiber-based ECC (PVA-ECC) was used and the fracture strains were found to be smaller than 2%. The strain level of PVA-ECCs still cannot catch the rupture strain of majority of FRP materials, especially some FRP composites (e.g. polyethylene terephthalate

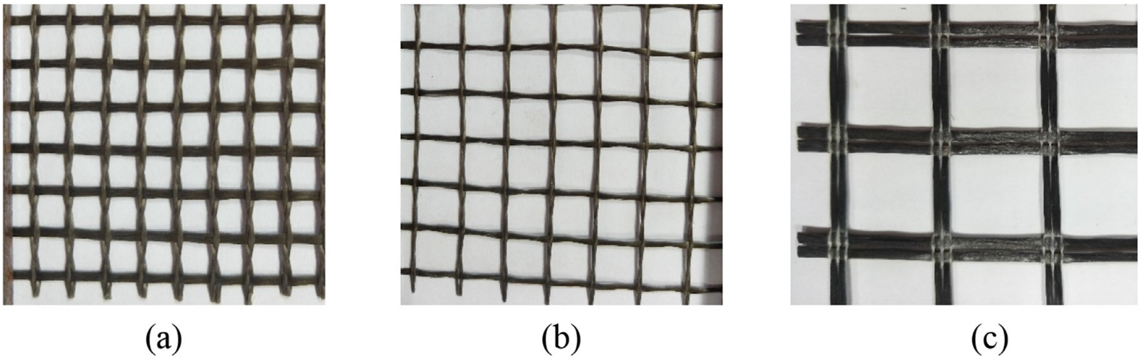
(a) (b) (c)

Fig. 3. Basalt textile (a) type A; (b) type B and (c) type C.