Effect of Different Matrix Compositions and Micro Steel Fibers on Tensile Behavior of Textile Reinforced Concrete

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Abstract. This paper presents results of a research on uniaxial tensile behavior of textile reinforced concrete (TRC) prepared with different matrix compositions containing different contents of micro steel fibers. TRC exhibits very favorable stress–strain behavior, high Load-carrying capacity and a certain ductility which results in a strain-hardening behavior. At this paper, different Glass-TRCs were prepared using different commonly used normal and also innovative matrix compositions containing different volume fractions of micro steel fibers. Three commonly used matrices, a polymer-based composite and also a UHPC mixture were prepared containing different percentages of micro steel fibers. The direct tensile tests were applied on all specimens to study the tensile properties (first crack stress and ultimate tensile strength) and strain-hardening behavior. Considering the stress-strain curves of all specimens, it has been found that the tensile properties and strain-hardening behavior of Glass-TRC can be considerably improved by using steel micro fibers in an appropriate matrix composition.

1. Introduction

Textile reinforced concrete (TRC) has emerged in recent years as an attractive cement composite which can provide numerous advantages for developing new type of thin sheet component for a variety of building systems [1-9]. It is a composite material consisting of fine-grain concrete and multi-axial textile reinforcement. By using corrosion-free fibers such as alkali-resistant glass (AR-glass) fiber, carbon fiber, aramid fiber, and basalt fiber, TRC possesses superior durability [1, 5-8]. Furthermore, the high strength fiber along the main stress direction of TRC makes this composite have high effectiveness in strengthening of plain concrete members [1, 5-8]. To ensure the performance, the mechanical behavior of TRC has been investigated. Besides the properties of fiber and matrix themselves, the mechanical behavior of TRC members is also significantly associated with the interface bond characteristics between fiber and matrix, which is influenced by fabric geometry, knitting type, mesh size and fiber type, textile surface treatment methods and matrix properties. Jesse et al. [1] summarized major factors which influence the load-bearing capability of TRC, including reinforcing ratio, fiber filament damage during production, fabric reinforcing direction, and interface bond characteristics between textile and matrix. Peled et al. [2, 3, 9, 10] investigated the effect of fabric geometry on the bonding performance and reinforcing effectiveness of TRC. It was discovered that the type of knitting (or weaving) had important influence on the interfacial bond strength.

To obtain a complete interfacial bond characterization between matrix and fiber, many researchers have performed a lot of experiments. Colombo et al. [11] presented experimental investigation of TRC on tensile tests, considering the influence of reinforcement ratio, fabric geometry, curing conditions, displacement rate, and specimen size. Cevallos and Olivito [12] studied the effects of the fiber type,
fabric geometry, physical and mechanical properties of fabrics and the volume fraction of fibers on the tensile stress–strain response and crack propagation of cementitious composites reinforced with natural fabrics. It was found that the fabric geometry and the volume fraction of fibers were the parameters that have the greatest effects on the tensile behavior of these composite systems. Mumenya et al. [13] conducted uniaxial tensile testing on weathered textile concrete samples to analyze the multiple cracking patterns. Peled et al. [14] used closed-loop uniaxial tensile tests to study the tensile behavior of pultruded cement composites with various fabric types. It was found that hybrid composite made of PE and AR glass sustained strains better than 100% AR glass composite, and was stronger than single PE fabric composite. Larrinaga et al. [15] investigated the experimental and numerical modeling of basalt textile reinforced mortar to deepen the knowledge of this composite material in terms of tensile behavior. Santis and Felice [16] presented an experimental study on the tensile behavior of strengthening systems comprising two different textiles and five mortar matrices.

The stress–strain behavior of TRC under tensile loading can be subdivided into three states [17], as presented schematically in Fig. 1. The first state (I) is the free-crack state. In this state, the stiffness of both matrix and fibres determines the slope of this part of the curve, where TRC shows nearly linear-elastic behavior up to the point at which the increase in stress leads to the formation of the first crack. The second state (IIa) is defined by further crack formation, leading to pronounced quasi-ductile behavior of the composite. In this state more relatively fine cracks form due to the increase in the tensile stress. The slope, the length, and the coarseness of this part depend on the quality of the bond between textile and matrix [18] as well as on the volume proportion of the fibers in the composite activated for load transfer. Indeed, they can be related to the number of cracks and crack widths. The crack-widening state (IIb) is the final state in the stress–strain relationship. In this state either no new cracks or only a few appear, but the existing cracks grow and become wider until the ultimate stress is reached. The load in this state is carried only by the multifilament-yarns of the textile reinforcement and increases until the tensile strength and the strain capacity of these yarns are reached and the TRC fails. The sequence of these states can be observed on the specimen’s surface by the naked eye during testing under tensile load.

![Figure 1. Schematic representation of a typical response of a TRC specimen subjected to uniaxial tensile loading with indication of cracking states.](image)

This research present the results of a research on uniaxial tensile behavior of textile reinforced concrete (TRC) produced with different matrix compositions. At this paper, different Glass-TRCs were prepared using different commonly used normal and also innovative matrix compositions containing different percentages of steel micro fibers. Three commonly used matrixes, a polymer-based composite and also a UHPC mixture were prepared containing different percentages of micro steel fibers. The direct tensile tests were applied on all specimens to study the tensile properties (first crack stress and ultimate tensile strength) and strain-hardening behavior.
2. Experimental program

2.1. Materials

2.1.1. Matrices

Different Glass-TRC specimens are prepared using different commonly used normal and also innovative matrix compositions containing different percentages of steel micro fibers. PZ, M3 and M7 as commonly used matrices [19] and a polymer-based composite (PC) and also a UHPC mixture as innovative matrix compositions are prepared containing different percentages of steel micro fibers [20]. Table 1 gives the compositions and compressive strength of the mentioned commonly used and also innovative matrix compositions containing different percentages of steel micro fibers. PZ, M3 and M7 different Glass-TRC specimens are prepared using different commonly used normal and also innovative matrix compositions containing different percentages of steel micro fibers. PZ, M3 and M7 as commonly used matrices [19] and a polymer-based composite (PC) and also a UHPC mixture as innovative matrix compositions are prepared containing different percentages of steel micro fibers [20]. Table 1 gives the compositions and compressive strength of the mentioned commonly used and also innovative matrices. The workability of cement-based matrices is evaluated through flow table test and is kept in the range of 180-200 mm.

| Mix No | Cement (kg/m³) | Fly ash (kg/m³) | Silica fume (kg/m³) | Pumice (kg/m³) | W/b | Water (kg/m³) | Resin-epoxy suspension (kg/m³) | Sand (kg/m³) | Hyperplasticizer (kg/m³) | Compressive strength (MPa) |
|--------|----------------|----------------|--------------------|---------------|-----|---------------|-----------------------------|-------------|--------------------------|--------------------------|
| PZ-0%  | 490            | 175            | 35                 | ---           | 0.4 | 280           | ---                         | 715         | 4                        | 63                       |
| PZ-1%  | 490            | 175            | 35                 | ---           | 0.4 | 280           | ---                         | 715         | 4                        | 70                       |
| PZ-2%  | 490            | 175            | 35                 | ---           | 0.4 | 280           | ---                         | 715         | 4                        | 73                       |
| M3-0%  | 549            | 246            | 25                 | ---           | 0.4 | 280           | ---                         | 1092        | 5.5                      | 75                       |
| M3-1%  | 549            | 246            | 25                 | ---           | 0.3 | 246           | ---                         | 1092        | 5.5                      | 80                       |
| M3-2%  | 549            | 246            | 25                 | ---           | 0.3 | 246           | ---                         | 1092        | 5.5                      | 83                       |
| M7-0%  | 839            | ---            | ---                | 0.33          | 0.33| 277           | ---                         | 1189        | 8                       | 84                       |
| M7-1%  | 839            | ---            | ---                | 0.33          | 0.33| 277           | ---                         | 1189        | 8                       | 84                       |
| M7-2%  | 839            | ---            | ---                | 0.33          | 0.33| 277           | ---                         | 1189        | 8                       | 85                       |
| UHPC-0%| 757            | 265            | 300                | 0.2           | 0.2 | 264           | ---                         | 789         | 9.5                      | 145                      |
| UHPC-1%| 757            | 265            | 300                | 0.2           | 0.2 | 264           | ---                         | 815         | 9.5                      | 160                      |
| UHPC-2%| 757            | 265            | 300                | 0.2           | 0.2 | 264           | ---                         | 815         | 9.5                      | 163                      |
| PC-0%  | 600            | ---            | ---                | ---           | 350 | 1098          | ---                         | 88          |
| PC-1%  | 600            | ---            | ---                | ---           | 350 | 1098          | ---                         | 95          |
| PC-2%  | 600            | ---            | ---                | ---           | 350 | 1098          | ---                         | 102         |

2.1.2. Glass textile reinforcement

A particular type of polymer-coated, biaxial fabric made of alkali-resistant (AR) glass was used as textile reinforcement for the TRC specimens. The spacing between yarns was 13 mm and the average tensile strength of the yarns was approximately 1200 MPa, as reported by the manufacturer.

2.1.3. Micro steel fiber

Brass-coated micro steel fibers with an average diameter of 0.2 mm and a length of 6 mm were applied as additional reinforcement. Two fiber contents of 1% and 2% by volume of concrete were investigated. The fibers had a density of 7.8 g/cm³ and a tensile strength of 2800 MPa.

2.2. Preparation of specimens and test setup

For uniaxial tensile tests, rectangular plates with 400 mm long, 80 mm wide and 6 mm thick were prepared. First, glass textile sheets were laid and fixed at the end of the moulds and then the matrices spread in and finally smoothed. Schematic view of specimens’ preparation technique and uniaxial tensile testing setup are illustrated in Figure 2.

In addition to the TRC specimens, which were reinforced with 2 layers of glass textile, a series of textile reinforced specimens were also produced containing different contents of micro steel fibers. Specimens were demoulded after one day and then stored in water until reaching an age of 28 days. UHPC specimens were cured through accelerating method for 48 hours in boiling water.

The uniaxial tensile tests on the TRC plates were conducted with a controlled deformation rate of 0.5 mm/min. In order to better transfer the force to the specimens, steel plates with 4 mm thickness were glued to their ends by epoxy resin to avoid the failure at the connection during the uniaxial tensile
Deformation was measured using two linear variable differential transformers (LVDTs). The connection between the plates and the testing machine was designed as hinges to eliminate bending moment in the specimens (Figure 2).

![Figure 2. Schematic representation, testing device setup and specimens’ preparation of TRCs subjected to uniaxial tensile test](image)

3. Results and discussion

The stress-strain behavior of TRC specimens made with different matrices containing different volume fractions of micro steel fibers is illustrated in Figure 3. Figure 4 shows the effects of both matrix type and also the use of micro steel fibers on first-crack stress and ultimate tensile strength of TRCs.

As seen in Figure 3 and Figure 4, matrix composition has considerable influence on first-crack stress, ultimate tensile strength and tensile stress-strain behavior of TRC specimens. Tensile behavior of TRC specimens made with commonly used matrices (PZ, M3 and M7) varies considerably. At this series of specimens the maximum increase of app. 50% is observed in first-crack stress of M7-0% in comparison with that of the PZ-0%. The maximum enhancement of app. 31% is seen in ultimate tensile strength of M3-0% when compared with that of the PZ-0%. In fact, lower porosity of matrix in textile-matrix interface at commonly used matrices with lower water/binder ratios results in further bonding between matrix and textile and then improvements in tensile properties and strain-hardening behavior of TRC specimens are achieved.

Strain-hardening behavior of TRC specimens made with UHPC matrix containing different volume fractions of micro steel fibers is clearly observed at Fig 3. Despite an increase in first-crack stress of TRC specimens prepared with UHPC matrix in comparison with that of the specimens made with...
commonly used matrices, the ultimate tensile strength of UHPC specimens is slightly lower than that of the corresponding M3 and M7. It seems that accelerated water curing (in boiling water) of UHPC specimens might be the main reason for this reduction in ultimate tensile strength.

As seen in Fig 4, first-crack stress of TRC specimens made with PC matrix is considerably higher than that of the rest of specimens. Indeed, first-crack stress of PC specimens is approximately 4 times more than that of the PZ specimens. However, in TRC specimens made with PC matrix the first crack stress of PC matrix was even more than tensile capacity of glass textile and then a sudden failure of the specimen was occurred following the first crack and then the strain-hardening behavior was not observed. It seems that the strain-hardening behavior can be achieved at PC specimens by increasing the number of glass textile layers or by decreasing the thickness of specimens’ cross-section.

Figure 3. Tensile Stress-strain curves of TRC specimens prepared with different matrices containing different contents of micro steel fibers
As observed in Figure 4, the first crack stress and ultimate tensile strength of TRC specimens made with different matrices are increased by raising the volume fractions of micro steel fibers. Adding micro steel fibers by 1% volume leads to an increase of about 14% to 35% in first crack stress of TRC specimens prepared by different matrices.

In TRC specimens prepared with commonly used matrices, adding micro steel fibers by 1% volume at PZ-1%, M7-1% and M3-1% results in increases of about 35%, 23% and 25% in first-crack stress, respectively in comparison with corresponding plain specimens. Increasing the micro steel fibers volume content up to 2% leads to an increases of about 44%, 31% and 41% in first-crack stress of PZ-2%, M7-2% and M3-2%, respectively when compared with that of corresponding plan specimens. Increases of about 14%, 15% and 11% in ultimate tensile strength are generated when PZ-1%, M7-1% and M3-1% are compared with corresponding plain specimens, respectively. Moreover, adding micro steel fibers by 2% volume at PZ-2%, M7-2% and M3-2% results in increase of about 19%, 21% and 15% in ultimate tensile strength, respectively when compared with corresponding plain specimens.

Increase of 16% in first-crack stress and 10% in ultimate tensile strength are observed when UHPC-1% is compared with UHPC-0%. An increase of 24% in first-crack stress and 20% in ultimate tensile strength is observed when UHPC-2% is compared with UHPC-0%. First crack stress of PC-1% and PC-2% are increased app. 14% and 20%, respectively in comparison with plain specimens.

As seen in Fig 3, adding micro steel fibers to TRC specimens’ matrix results in a higher number of tensile cracks in all types of matrices. As the improved first crack stress and ultimate tensile strength are along with a higher number of cracks, a considerable improvement in strain-hardening behavior and then a significant increase in area under the stress-strain curves and more energy absorption are observed.

4. Conclusions
At this experimental research, effects of different matrix compositions containing different contents of micro steel fibers on tensile properties and strain-hardening behavior of glass TRC were investigated. Commonly used matrices such as PZ, M3 and M7 and also two innovative matrices of UHPC and PC were used to prepare TRC specimens. Micro steel fibers were added into the mentioned matrices in different contents of 0%, 1% and 2% by volume. The following conclusions can be drawn from the present research work.

- Both the first crack stress and the ultimate tensile strength of TRC specimens were significantly influenced by the matrix composition type. It seems that, different w/b ratio of cement-based matrices was the main factor influenced on bonding of matrix-textile and matrix-steel micro fibers that resulted in significant changes in tensile behavior of TRC specimens.
- Usage of micro steel fibers in matrices led to an increase in first-crack stress and ultimate tensile strength of TRC specimens made with different matrix compositions. The tensile properties of TRC were more improved with increasing the volume fractions of micro steel fibers. A significant increase in number of cracks was observed by adding micro steel fibers to matrices that followed with more improved strain-hardening behavior of TRC specimens.

Figure 4. First crack stress and ultimate tensile strength of TRC specimens prepared with different matrices containing different contents of micro steel fibers.
It can be clearly concluded that tensile properties of TRC specimens are improved by using an appropriate matrix containing micro steel fibers. As the improved first-crack stress and ultimate tensile strength are along with an increase in number of tensile cracks, a considerable improvement in strain-hardening behavior and then a significant increase in area under the stress-strain curves and more energy absorption are observed.

Considering the acceptable tensile performance of specimens prepared by UHPC matrix, textile reinforced ultra-high performance concrete seems to be introduced as an innovative material especially for structural applications which is well worth to be more investigated in upcoming researches.

Acknowledgments
The authors gratefully acknowledge the Solidian company, specially Dr. Ali Shams for their kindly support in providing textile sheets.

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