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# Effect of short, dispersed glass and carbon fibres on the behaviour of textile-reinforced concrete under tensile loading

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ABSTRACT

This paper addresses the influence of the addition of short, dispersed fibres made of alkali-resistant (AR) glass and carbon on the fracture behaviour of textile-reinforced concrete (TRC). A series of uniaxial, deformation-controlled tension tests was performed to study the strength, deformation, and fracture behaviour of thin, narrow plates made of TRC with and without the addition of short fibres. Furthermore, multifilament-yarn pullout and single-fibre pullout tests were carried out to gain a better understanding of the crack-bridging behaviour which suppresses growth and widening of cracks. Pronounced enhancement of first-crack stress was achieved, the value increased by factors of 1.5 and 2 due to the addition of glass and carbon fibres, respectively. While more and finer cracks were observed on the specimens with short fibres added, a moderate improvement in tensile strength was recorded. Water-to-binder ratio influences the matrix–fibre bond quality and thus fibre failure mode. While fibre fracture dominated behaviour when matrix M030 (low water-to-binder ratio of 0.30) was used, pronounced pullout behaviour was observed for fibres embedded in the matrix with a higher w/b ratio (M045). Furthermore, it was found that short fibres can also improve the bond between multifilament-yarns and the surrounding matrix by means of new cross-links.



## 1. Introduction

Textile-reinforced concrete (TRC) is a composite material consisting of a finely grained cement-based matrix and high-performance, continuous multifilament-yarns made of alkali-resistant (AR) glass, carbon, or polymer. The major advantages of TRC are its high tensile strength and pseudo-ductile behaviour, which is characterised by large deformations due to its tolerance of multiple cracking. With its excellent mechanical properties this material can be highly appropriate to many applications both for new structures and for the strengthening or repair of old structural elements made of reinforced concrete or other traditional materials [1,2].

Under tensile loading textile-reinforced concrete exhibits very favourable stress–strain behaviour, showing high load-carrying capacity; maximum tensile strength, attained at relatively high deformations, is accompanied by the formation of a considerable number of fine cracks [3]. Such large deformations prior to material failure are crucial in respect of both structural safety and energy dissipation in the case of impact loading [4]. However, that high strength levels can be only reached at high deformations means that for the service state, where only small deformations are acceptable, the design load-bearing capacity of TRC must be much lower than its tensile strength. Moreover, relatively wide cracks observed at high deformations are undesirable.

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The bond and failure mechanisms in fibre-reinforced concrete are presently being investigated widely by many researchers. Marshall et al. [5], for example, analysed fracture processes in brittle-matrix fibre composites and defined the approximate crack dimension over which the transition from short-crack behaviour to steady-state crack opening occurs. Li [6] presented a theoretical study of stress–displacement curve for cementitious materials reinforced with randomly distributed and oriented fibres. Additionally, the author confirmed the validity of the theoretically derived relationships by comparisons with experimental data. Carpinteri et al. [7] presented a theoretical analysis of single-fibre pullout behaviour in cement-based, short-fibre composites. The embedded length of the fibre was divided into two zones: a sliding zone, where the frictional bond stress is constant, and a non-sliding zone, where the fibre is bonded to the surrounding matrix. Based on the development of these zones by increasing the force applied, the pullout behaviour of single-fibre under monotonic loading in pre- and post-peak stages can be described.

In recent years researchers have performed several test series to investigate the influence of short fibres on various properties of textile-reinforced concrete [8,9]. However, the mechanisms inherent in the joint action of short fibre and textile reinforcement are still not fully understood. In order to gain more and better insight into the specific material behaviour of the finely grained concrete with such hybrid reinforcement, a new investigative programme has been initiated by the authors at the TU Dresden. In this paper the influence of adding short, dispersed glass and carbon fibres on the fracture behaviour of textile-reinforced concrete is presented. Uniaxial tension tests on thin, narrow plates made of TRC constitute the core of the experimental programme. Special attention is directed at the course of the stress–strain relationship, crack pattern development, and fibre failure behaviour.

To provide detailed insights into the various failure mechanisms observed in the experiments, the bond behaviour between short fibres and the finely grained concrete as well as between the yarn surface and the matrix was studied by performing multifilament-yarn and single-fibre pullout tests. Furthermore, visual inspections of the specimens' surfaces and microscopic investigation of the fracture surfaces were performed and evaluated. On the basis of these data, the mechanisms of the interaction between continuous fibres and short fibres in cement-based composites are discussed.

## 2. Typical behaviour of TRC

The stress–strain behaviour of TRC under tensile loading can be subdivided into three states [3], 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 behaviour 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 behaviour 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 [10] as well as on the volume proportion of the fibres 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.

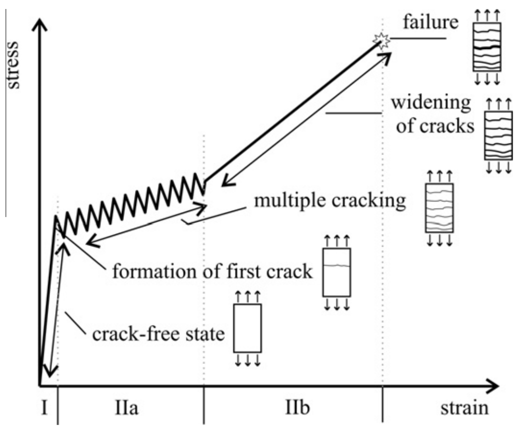


**Fig. 1.** Schematic representation of a typical response of a TRC specimen subjected to uniaxial tensile loading with indication of cracking states.