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Textile reinforced concrete multiscale mechanical modelling: Application to TRC sandwich panels

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ABSTRACT

The present study establishes a numerical strategy for describing the textile/concrete bond behaviour in textile-reinforced concrete (TRC) composites that separates the cohesive and coulomb friction contributions.

The textile-concrete bond approach, validated on an existing pull out test in the literature, has been used to calibrate the textile-concrete bond slip law of an existing TRC tested in tension by an innovative inverse approach thanks to its pull-out mode of failure.

The calibrated bond slip law has been used as an input parameter to produce an enhanced TRC multiscale numerical model that is based on the nonlinear behaviour of its constitutive components (concrete, textile, and textile-concrete bond slip law) and takes into account all the damage mechanisms of TRC, which are mainly characterized by matrix cracking and yarn pull-out. The model has been validated on the basis of the previous TRC experimental tensile test.

Two approaches have been used to account for the mechanical behaviour of a textile-reinforced concrete sandwich panel under a four-point bending test: a macroscopic 3D finite element approach, which considers the composite TRC with its macro tri-linear stress – strain relation under tensile solicitation, and the proposed TRC multiscale 3D finite element approach which, involves definition of the textile-concrete interaction bond slip law. More accurate results have been achieved with the multiscale approach; furthermore, the experimental mode of failure of the sandwich panel has been captured.

1. Introduction

Sustainable development continuously grows in the building industry. In this context, composite structures and non-traditional materials have widely emerged.

Textile-reinforced concrete (TRC) consists of a fine-grained concrete reinforced by a high-strength textile made of alkali-resistant glass, carbon, etc., which allows it to combine the high compressive strength of concrete structures with the tensile resistance and non-corroding behaviour of the textile fibres. TRC offers an alternative to fiber-reinforced polymer (FRP), which has the constraint of cost and criteria of sustainable development to strengthen or repair concrete structures [1]. Moreover, TRC composites also emerge in modern building construction such as in light-weight sandwich panels [2,3], light-weight roofs, etc., which represents a serious alternative to thick corroding steel-reinforced concrete structures.

TRC differs from ordinary steel-reinforced concrete by its more complex structure. In addition to the nonlinear behaviour of the heterogonous concrete material, non-coated textile reinforcement yarn also consists of numerous filaments that exhibit heterogeneous penetration of the fine-grained concrete matrix between the filaments. Consequently, the core filaments have less contact with the matrix compared to the outer filaments, which are in direct contact with it [4]. For coated textile yarn, the impregnation of the inner filament is improved [5]. However, the heterogeneous distribution of the coating along the textile causes the damage to still be localized at the textile concrete bond. Therefore, the complex behaviour of TRC has become the driving force for the development of analytical models [6,7] that can predict the behaviour of the composite starting from single-yarn pull-out tests up to tensile tests with multiple concrete cracking. However, analytical models are not qualified to solve this multiscale problem with reasonable effort, especially if bond failure events and cracking have to be considered. Furthermore, the stress distributions can only be determined for basic configurations e.g, single-crack

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bridges. Consequently, they are not appropriate for the complex kinematics that must be taken into account for TRC [8].

The design of TRC structures can be simplified by establishing material models available in commercial finite element software, particularly in the case of accurate simulation of the nonlinear behaviour due to cracking of the matrix and textile-matrix debonding. Actually, the few contributions to TRC modelling focused on the TRC as a composite material with macro stress-strain behavior. Cuypers [9] uses the ANSYS program (2D element PLANE 82), to model a TRC sandwich panel subjected to a four- point bending test considering TRC as one entity obeying a tri-linear stress- strain relation. Truong [10] establishes a numerical model of reinforced concrete beams that are repaired with TRC also using a macroscopic constitutive law for the composite TRC identified experimentally. The macro models established for TRC are efficient for establishing a qualitative global behaviour for the composite. However, they are not always able to take into account the evolution of some local parameters such as the degradation of the bond strength (textile-mortar) due to alkalinity and hydration kinetics as described in [11] and the degradation of the mechanical characteristics of the textile itself due to an alkali attack [12]. Moreover, they are unsuited for predicting local failure mechanisms within the yarn in the bonding layer and in the cementitious matrix.

For all these reasons, the main objective of this paper is to develop a 3D finite element model that can reproduce either global or local behavior of TRC structures starting from single-yarn pull-out (micro-scale) up to TRC tensile tests (meso-scale) and finishing with a TRC sandwich panel (macro-scale) (Fig. 1).

In the first part of the present paper (micro-scale), a numerical strategy for describing the textile-concrete bond behavior has been validated on the basis of a pull out test.The established textile-concrete bond model has been used to calibrate the bond slip law of an existing TRC tested in tension by an inverse approach, taking advantage of its pull out mode of failure. Then, the calibrated textile-concrete bond slip law has been used as input to establish an enhanced model of the composite TRC (meso-scale), taking into consideration all the possible failure mechanisms of its constitutive materials (concrete cracking, concrete -textile debonding and textile failure). The proposed model has been validated on the previous TRC tensile test. In the third part of the paper (macro-scale), the performance of the proposed enhanced TRC model has been compared with a macroscopic approach for reproduction of the global and local mechanical behaviours of an existing textile-reinforced concrete sandwich panel.

2. Micro-scale: numerical modelling of the textile-concrete debonding process

2.1. Introduction

In the first part of the present paper, a numerical approach (the cohesive-friction contact model) has been proposed to model the yarn-concrete debonding process in TRC composites. The proposed approach will be used to produce an enhanced TRC model that considers either the concrete multicracking behavior or the yarn-concrete debonding at further stages.

Considering the detailed description of the double sided pull out test available in Ortlepp's investigation [13], the result obtained using the cohesive-friction contact model is compared with data from the pull-out test [13] in terms of force transmitted vs crack opening to verify the relevance of the proposed approach.

In the double-sided pull-out test, a TRC sample with a predetermined crack is prepared, such that a yarn embedding length of $L_{E,0}$ = 18 mm can be gradually pulled out from the concrete-matrix (Fig. 2).

An adherence length of 240 mm is chosen in the lower part of the TRC (Fig. 2) to ensure the anchorage of the textile, which consisted of coated carbon filament yarns with a fineness of 800 tex (0.65 mm in diameter) in the matrix, which consists of a high-strength concrete mixture with a maximum grain size of 1 mm and a Young modulus of 30 GPa [13].

2.2. Numerical model

ABAQUS/Implicit [14] is used to model the textile-concrete debonding process. An Abaqus C3D8R element is employed to model the concrete and the yarn material (yarn is a bundle of a huge number of fibres; however, in this research, coated yarn is used which can be considered as a single entity). A simplified rectangular section for the yarn with an equivalent round section is assumed to avoid meshing problems (without changing the physical problem), and a fine surface mesh (0.5 mm approximate size) is ensured along the contact direction.

A cohesive-friction bond slip law (corresponding to the bond slip evaluated experimentally in [13], available in (Fig. 4) is introduced between the slave surface (yarn) and the master surface (concrete), while a perfect superposition is ensured between every two opposite nodes belonging to the master and slave surfaces. A displacement-controlled analysis is performed, increasing the displacement applied

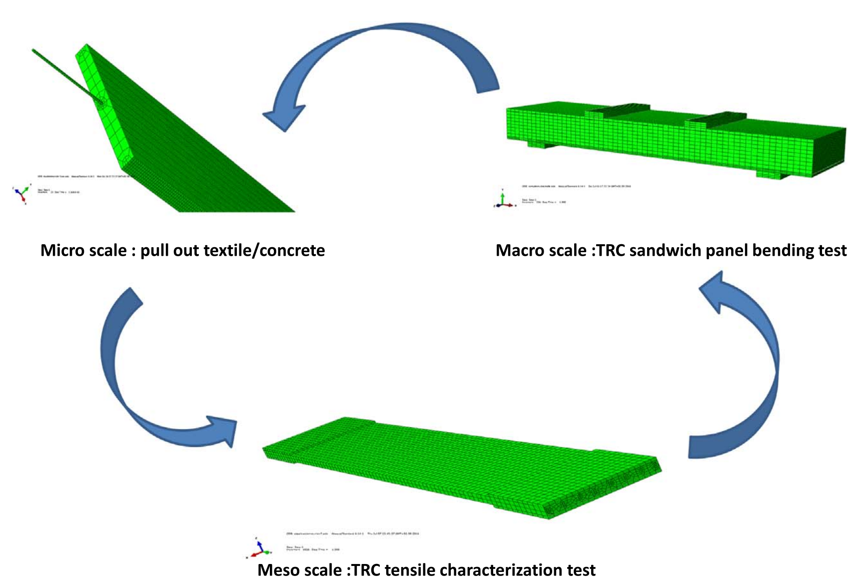

Fig. 1. Multiscale TRC study approach.