DETERMINATION OF DEVELOPMENT LENGTHS OF TEXTILE REINFORCEMENT USING AN ADAPTIVE TESTING METHOD

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Abstract

The development length for textile fabrics located within a fine-grained concrete matrix was determined based upon specific filament yarn pull-out tests. The purpose of this research was to eliminate the possibility of failure due to fabric pull-out from the matrix in practical applications. An adaptive test specification was developed for the investigations, allowing the anchoring lengths to be adjusted during the execution of a test series depending on the pull-out behaviour of the strengthening textile.

Textile fabrics made of alkali-resistant glass (AR-glass) fibres, as well as carbon fibres, were tested. Findings indicated that conventional AR-glass fabrics required large anchoring lengths for practical applications. The research further showed that an additional application of a polymer suspension coating to textile fabrics greatly increased the reinforcement's resistance to pull-out. Carbon fibres have a substantially higher strength than AR-glass fibres and a different bond behaviour. Recommendations for optimizing bond properties of configurations of textile reinforcing fabrics are derived from the test results.

Keywords: textile reinforced concrete, strengthening, development length, pull-out

1. Introduction

For many years applications of shotcrete reinforced with additional steel have been used to improve the the load-carrying capacity of reinforced concrete members. Textile-reinforced concrete (TRC) represents an ongoing development in the field of strengthening and retrofitting of concrete (Brameshuber [1], Brameshuber and Hinzen [2], Ortlepp [3]). TRC is a composite material of layers composed of high-strength, fine-grained concrete and textile reinforcement. Less than 2 mm of concrete thickness are needed between textile layers, as only a maximum aggregate diameter of 1 mm of fine-grained concrete matrix is required. The use of extremely thin TRC strengthening layers limits the increase of the dead load resulting from additional strengthening, while generally maintaining the original geometric dimensions of the structural member. Slabs and beams in bending (Brückner et al. [4]), as well as beams and T-beams in shear (Brückner et al. [5]), can primarily be strengthened with TRC. In these cases, considerable increases in the load-carrying capacity have been observed.

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Knowledge of the tension force that the TRC layer can bear and its related deformation behaviour is crucial for developing appropriate cross-sectional models necessary for designing the strengthening of reinforced concrete (RC) members. Various bond specimens were studied to examine the force transfer from the textile-reinforced strengthening layer into the aged concrete (Ortlepp et al. [6]).

Over the course of these experimental investigations, it was discovered that a failure of the internal bond between the filament yarns of the textile fabric and the surrounding fine-grained concrete matrix also occurred with the use of certain textile fabrics (Ortlepp and Curbach [7]). In this case, the interface between the aged concrete substrate and the strengthening layer did not fail because the shear or adhesive tensile load-carrying capacity were exceeded (Fig. 1a,b). Instead the bond itself within the strengthening layer has already failed (Fig. 1c). The filament yarns of the textile reinforcing fabric were “pulled out” of the fine-grained concrete matrix of the strengthening layer. Findings indicated that in particular conventional carbon fabrics required large anchoring lengths for practical applications. Since this failure mode can also cause a failure in the anchorage range, it was necessary to examine this failure mechanism separately.

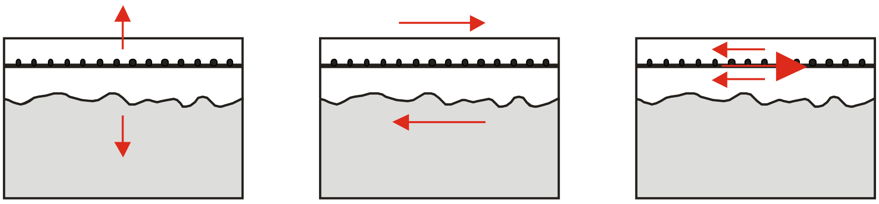


Fig. 1: Bond failure modes of a TRC strengthening applied to a RC surface

There are lots of existing test setups that were developed for testing single yarns, e.g. Banholzer [8], [9], Aljewifi et al. [10], Butler [11]. But these are not sufficient for the development length because they do not consider the influence of the textile structure. In contrast to simple pull-out tests of individual filament yarns, the conducted tests analysed the influence of cross-reinforcement on pull-out forces. According to Krüger [12], this is particularly important for impregnated (coated) textiles since the node resistance is changed and the yarn cross-section is strongly affected along its axis by the coating. For instance, the stitching fibre, which connects the longitudinal and cross yarns of the textile, has a significant influence on the force transmission between filament yarns and the surrounding fine-grained concrete matrix.

This paper discusses the experimental investigations used to easily determine the development lengths of textile reinforcement in a fine-grained concrete matrix.

2. Experimental investigations

2.1 Adaptive test setup

The experimental setup for investigating the development length of the textile (Fig. 1) was developed on the basis of the uniaxial tension tests recommended by RILEM TC TDT (Hinzen and Brameshuber [13]), as well as bond tests concerning end-anchoring of textile-reinforced strengthening described by Ortlepp et al. [6]. The specimens have a width of 100 mm. In the case of the uniaxial tension tests, the load was introduced at the upper and lower ends of the specimens by clamped anchorage, which was chosen to attain the maximum tensile load of the fibres while avoiding a pull-out failure from high lateral pressure. Because no lateral pressure but rather adhesive tensile stresses exist in the region of the end-anchorage (Ortlepp et al. [6]), the author designed a pull-out test setup simulating these adhesive tensile stresses that arise within the range of the end-anchorage of a TRC strengthening layer (Fig. 2). For this reason, a load introduction by means of glued steel plates was selected at the lower end of the specimen, where pull-out was expected to occur (Fig. 2 and 3).

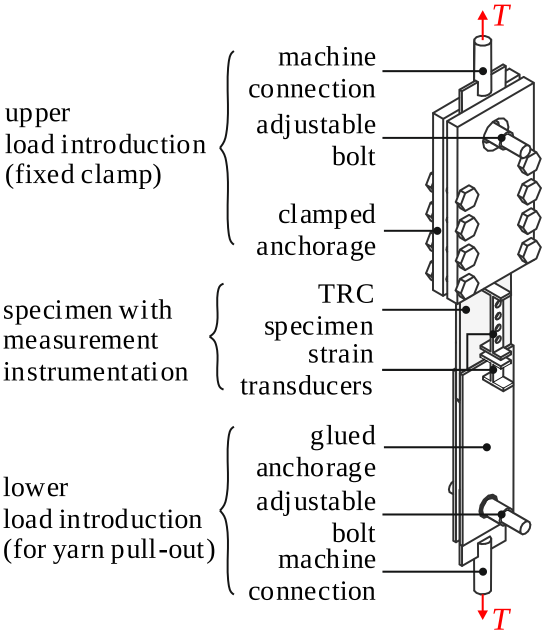


Fig. 2: Test setup for the development length of the textile (textile pull-out test)

The clamping length at the upper end of the specimen was made equal to or greater than that of the glued anchorage to ensure that pull-out failure occurred at the lower end of the specimen in additional testing. The adhesive bond length at the end of the specimen can vary depending on the bond properties of the tested textile, i.e. it may adapt to the previously estimated development length to be measured (Fig. 3).

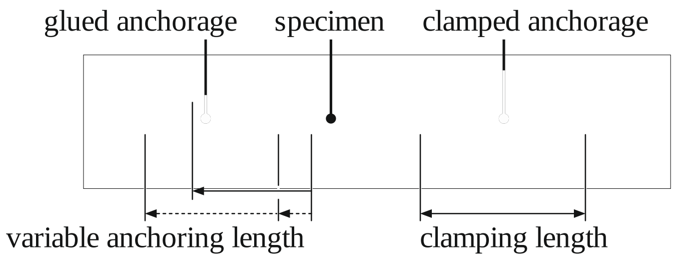


Fig. 3: Specimen for adaptive testing of textile's development length

The anchoring length of the textile was varied within each series. A test series consisted of up to 8 specimens. The specimens came from one and the same concrete charge, which ensures the comparability of the individual partial experiments under the decrease of the diffusion of the concrete and compound characteristics. The idea was to minimize the number of specimens in a testing series. Therefore, the specimens no. 2 ff. of a series were not equipped with the anchorage plates before the test of the previous specimen.

At first, the anchorage plates were glued onto the first specimen over a medium length. Depending on the ensuing test result, the anchorage plates of the next specimen were glued over a smaller or longer length in the hope of finding the development length in this tested interval. If one of the tests showed a pull-out failure (Fig. 4a) and the other one a tensile failure (Fig. 4b), the development length lay in the interval and had to be found by further tests using the interval bisection method. If not, the anchoring length was increased (in case of two pull-out failures) or decreased (in case of two tensile failures) again, until each failure mode had occurred once. Finally, the development length was found using the interval bisection method.

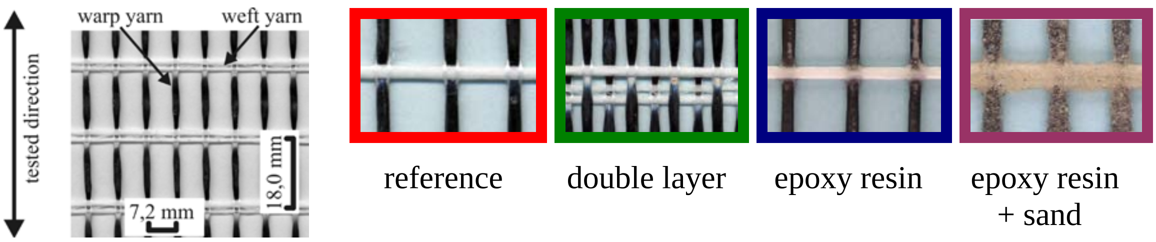
(a) pull-out failure (b) tensile failure

Fig. 4: Failure modes

2.2 Experimental program

The influence of applying an additional coating on the bond behaviour of the textile fabrics was the primary parameter of this investigation. The influence of transverse reinforcement on the anchorage in textile-reinforced meshes must be taken into consideration in the case of steel-reinforced concrete constructions. But the connection between longitudinal and transversal threads is more flexible in a textile fabric than in a welded reinforcing steel mesh. Clarification is thus required concerning the effect of the connection of the longitudinal to the transversal threads with different coatings on the development length for warp-knitted fabrics.

For the matrix, a high strength concrete mixture with a maximum grain size of 1 mm was used. The compressive strength of the TRC layer amounted to 76.3 N/mm². The reference textile consisted of carbon filament yarns with a fineness of 800 tex and a fibre strength of 1.032 N/mm² in warp direction (Fig. 5a) as well as of alkali-resistant glass fibres with a fineness of 640 tex in weft direction. It was modified with a coating on a polymer basis.



(a) reference textile (b) modifications

Fig. 5: Textile

The reduction of the development length was analysed using different possibilities. Thus, specimens with double-layer textile, specimens with an additional epoxy resin coating as well as specimens with epoxy resin and sand coating were examined (Fig. 5b).

2.3 Experimental results

The results of the tests carried out to determine the development lengths are represented in Fig. 5. Reductions of the development lengths of 50 to 60% were achieved in comparison with the unmodified reference textile as a result of the bond-improving measures.

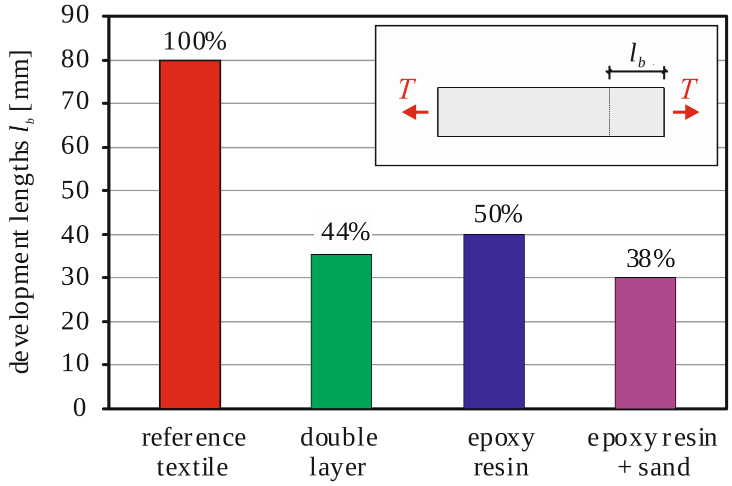


Fig. 6: Comparison of the development lengths

As can be seen in Fig. 5, simply using a second textile layer to increase the percentage of reinforcement decreases the development length significantly. Furthermore, an additional application of an epoxy resin coating with or without sand to the textile fabrics greatly increases the textile's resistance to pull-out.

3. Conclusions

The developed test setup allows quick and easy testing of the development length of textiles embedded in a fine-grained concrete matrix. Carbon fibre textiles with a normal coating have quite large development lengths compared to AR-glass textile fibres. While carbon textiles can be used for flexural strengthening or as helical reinforcement, shorter development lengths are needed for other applications such as shear strengthening of T-beams.

The results of the investigations showed a high potential to enhance the textile fabrics' bond properties. Subsequently applied coatings enhance the internal bond of textiles within a fine-grained concrete matrix. The tested coating techniques are very suitable for reducing the development length of carbon fibre textiles.

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