TEXTILE REINFORCEMENTS WITH SPREAD AND COMMINGLED YARN STRUCTURES

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ABSTRACT: For the reinforcement of concrete building members, different types of fabrics are used. The variety of reinforcement structures results from the different applied high-strength yarns and the successive development of appropriate 2D- and 3D- textile structures and from their high impact on properties of the building member considering applicable loads. To improve the bond performance and thus the load-bearing capacity of structural elements made from textile reinforced concrete, intensive research on the development of appropriate yarn structures is carried out at the Institute for Textile Technology (ITA) at the RWTH Aachen University in the last few years. In this paper, the influences of the applied reinforcement yarns and textile manufacturing parameters on the load-bearing capacity of textile reinforced concrete (TRC) elements are presented.

1 REINFORCEMENT YARN STRUCTURES

In the context of the collaborative research project SFB 532 different reinforcement yarn structures were applied. These are mostly rovings but also high-strength yarn structures made of alkali-resistant (AR) materials like AR-glass, carbon etc.

In order to activate a larger number of filaments within a single roving and thus to improve the load-bearing capacity of TRC elements innovative opened yarn structures were developed. To these reinforcement structures belong the spread and commingling yarns. The basic concept for a corresponding development, the production technique as well as the bonding and the load-bearing behaviour of these yarn structures in concrete are presented in following.

1.1 Spread yarns – basic concept and production technique

The basic idea by spreading the reinforcement is to break the sizing of the AR-glass roving and to increase the gaps between the single filaments (see Fig. 1.1). Thus a homogeneous and deep penetration of the filament yarn should be achieved.

![Fig. 1.1. Spread yarns as a reinforcement of concrete – basic concept [Heg08]](image)

To spread the studied AR-glass, an air jet texturing technique was used (see Fig. 1.2). An important aspect of the research activities was the achievement of the highest possible opening degree by minimum damage of the brittle glass filaments. Therefore, the influence of relevant process parameters, like overfeeding, air jet pressure, and process speed, on the mechanical properties of the produced yarn structures was investigated in extended test series.
A set of process parameter was determined and used for the further investigations in the context of the project.

Fig. 1.2. Air jet texturing test equipment [Kra08]

1.2 Commingling yarns – basic concept and production technique

The commingling yarns are hybrid structures. These consist of high strength AR-glass fibres and water soluble PVA-filaments. After embedding the reinforcement structure in the concrete, the PVA-filaments are being dissolved due to the alkaline matrix. Thus, hollow spaces are generated between the glass filaments. The concrete matrix is now able to flow into these cavities and to penetrate the internal filaments of the reinforcement (see Fig. 1.3).

Fig. 1.3. Commingling yarns as a reinforcement of concrete – basic concept [Kra09]

PVA is used not only as placeholder, to enhance the penetration of the high-strength fibre due to the concrete. Previous research has shown that the PVA component improves also the microstructure of the concrete matrix, by intervening in the nucleation and the crystallization of the mineral components of the concrete.

Within the presented researches, AR-glass roving, CEM-Fil® from OCV Reinforcement, with linear densities of 1200 tex was used as a high-strength component. As placeholder, commercially available water-soluble PVA-fibres Solvron® was provided by the company Nitivy CO, Ltd., Japan. Both components are fed simultaneously in mixture ratio 95/5 (Glass/PVA) to an air jet nozzle. Due to the air jet vibrations are being initiated into the multi-filament yarns. These provide hybrid structures with a random distribution of the different components in the cross-section. The hybrid yarn is taken up from the air jet nozzle by a godet unit and finally wound onto bobbins by a winder with open-loop control (see Fig. 1.4).
DEVELOPMENT AND PRODUCTION OF TEXTILE STRUCTURES

Depending on the respective application and the manufacturing process different types of knitting patterns are used in the production of 2D- and 3D-reinforcement structures. Non-crimp 2D-fabrics with pillar stitch (Fig. 2.1 (a)) offer opened grid reinforcement structures. These grid textiles are very suitable for the production of concrete elements by using the casting process, where highly liquid concrete mixtures are used. Due to the openings within the fabric the concrete mix can flow through the fabric layers to fill the formwork. However, very thick reinforcement yarns with a titre up to 2400 tex or even 3600 tex provide a poor penetration of the single filaments in the roving core when bundled with a surrounding knitting yarn as a consequence of the chosen warp knitting pattern (Fig. 2.1 (b)). The contact surface between the concrete and the reinforcing roving is low due to the circular shape of the roving [Roy07]. To achieve an equal distribution of the external forces through the whole yarn cross-section in this case, the reinforcement structures are often being impregnated with polymers, usually using thermo-set resins. As a consequence to the activation of all filaments in the roving the load-bearing capacity of the building members with coated reinforcements is higher than with not coated reinforcement using the same textile structure [Glo09].

Non-crimp 2D-fabrics with a tricot stitch embed the rovings with a flat ribbon shaped cross section into the textile structure (Fig. 2.1 (c, d)). Due to the flat shape of the roving the contact surface between the filaments and the concrete increases. Also in comparison to a round shaped filament bundle the minimal penetration depth decreases by almost 50%. The minimal penetration depth is hereby defined as half of the smallest diameter of the filament bundle within the concrete matrix. For the depicted cross sections in Fig. 2.1 the minimal penetration depth for the pillar stitch roving equals approx. 440 µm and for the tricot stitch roving only approx. 225 µm. Thus reinforcement structures are produced which can be easily penetrated by the concrete matrix providing a good bond of the filaments to the concrete.

Hence specimen reinforced with textiles with a tricot pattern show higher load-bearing capacity than specimen reinforced with pillar stitch textiles (Fig. 2.2) [Heg08, Roy07]. However, the spacing width of the textile between the individual rovings decreases due to the ribbon shape of the reinforcement yarn and the closed mesh of the knitting yarn (Fig. 2.1 (c)). For this reason these reinforcement structures are further processed to structural parts mainly by lamination or spraying. Using these manufacturing techniques the bond can be further increased by mechanically working the concrete into the reinforcement by means of rollers.
The influence of the warp knitting pattern of each of the described textiles in respect to the roving cross section is depicted in detail in the following Fig. 2.2. When using regular AR-glass rovings the material is taken from the center of a large bobbin cake and then fed to the warp knitting machine. During this process the bobbin is not moving in the creel. Due to this takeoff procedure the roving gets a low twist. Usually the twist from the takeoff is not visible in the textile. The yarn tension for the reinforcement rovings is kept low and on a steady state in order to produce a homogenous fabric structure and to reduce filament damage to a minimum.
Opened yarns are usually provided on smaller bobbins after processing. The material is taken from the spools in a tangential direction. Due to the tangential takeoff no more twist is added to the yarn but the whole spool with the opened yarn material is moving in the creel. During yarn takeoff from the spool into the machine also the spool and yarn weight has to be compensated regarding yarn tension for the takeoff and feeding process. Apart from the fact, that further filament damage due to the textile processing has to be eliminated keeping yarn tension of opened yarns low is even more important than for usual reinforcement yarns. This is because opened yarn structures tend to lose their opened structure due to the tensile strain of high yarn tension which leads to a re-compaction during textile processing.

3 BONDING BEHAVIOUR AND LOAD-BEARING CAPACITY

The bonding behavior of the spread and commingled yarns was investigated at the Institute of Building Materials Research of the RWTH Aachen University, Germany (ibac), on double-sided pull-out-tests. The test specimens were made by embedding the reinforcement yarn into two concrete elements, which are separated from each other by a thin foil [Heg06]. The two concrete parts are clamped in the testing device and then pulled apart. The concrete parts transfer the tensile forces to the reinforcement yarn. During the pull-out-tests, the force needed for pulling out the reinforcement from the concrete matrix is determined. Fig. 2.5 shows a comparison between the characteristic stress-crack opening displacements-curves of the conventional roving and the developed opened reinforcement yarns. These characteristic curves are determined by testing of four different samples.

In comparison to the raw material, the new commingling yarns show about 80 % higher load-bearing capacity than the AR-glass roving. In case of the spread yarns, the achieved improvement of the mechanical was even higher than 300 %.

For the investigation of the load-bearing behaviour of the new opened yarns, 2D-non-crimp fabrics were produced and embedded into a fine grained concrete with a particle size smaller than 2 mm. For preparation of the test specimens a special formwork developed in SFB 532, was applied. Fig. 1.8 shows the geometry of the samples and the test arrangement, which are described in detail in [Heg06].

A comparison between the load-bearing capacities of reinforcement structures made of opened yarns and the reference made of 2400 tex AR-glass roving shows Fig. 3.3.
Fig. 3.1. Pull-out behavior of different reinforcement yarns [Heg08]

Fig. 3.2. Sample geometry and test arrangement by the tensile stress tests

Fig. 3.3. Load-bearing behaviour of different reinforcement yarns
As it can be seen in Fig. 3.3 the load-bearing capacity of the TRC elements made of spread yarns is approx. 30% higher than the reference (AR-glass roving). For the reinforcement structures made of commingling yarns, an improvement of approx. 80% was achieved.

4 CONCLUSIONS

The experimental works in the context of SFB 532 have clearly shown, that the type of the reinforcement yarn structure as well as the design of the fabric have a significant impact of the load-bearing capacity of TRC building members. The influence of the knitting pattern on the mechanical properties but also of the concreting technique was also presented in this paper. Further, a new strategy for the improvement of the bond between the reinforcement structure and the concrete matrix was described. The approx. 80% to 300% higher tensile stress measured in the accomplished pull-out-tests indicate the better penetration of the concrete into the cross-section of the reinforcement yarn. Another evidence for the positive effect from the application of opened yarn structures are the presented results of the tensile-stress-test on TRC specimens. It was shown, that the load-bearing capacity of TRC elements reinforced by opened yarn structures is 30% to 80% higher than the reference with the common AR-glass rovings.

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REFERENCES


