Increased performance and sustainability through the use of profiled textile reinforcements for concrete applications

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Abstract

Building in a resource-saving way and still exploiting a high performance potential, is that even possible? At the Institute for Textile Machinery and High Performance Material Technology (ITM) at the TU Dresden, such composite optimized profiled textile reinforcements for concrete applications and the related manufacturing technology were developed as part of the research project IGF 21375 BR. On the basis of braiding and forming technology, a new generation of profiled reinforcement yarns was developed with the help of simulation-based investigations. Like ribbed steel reinforcements, these profiled yarns have a very high bond with the concrete matrix, but despite the profiling they almost fully exploit the performance potential of the carbon fibers in terms of tensile properties. In this way, the bond length required for complete force transmission between the textile reinforcement and the concrete can be reduced to just a few centimeters, and up to 80 % of the component-dependent oversizing of the textile reinforcement can be saved. The further development of the multiaxial warp knitting technology for the requirement-based and fiber-friendly processing of the profiled yarns into grid-like reinforcement structures enables the production of profiled textile reinforcement structures with the highest bond properties for use in carbon-reinforced concrete components with maximum material and resource efficiency.

Initial situation and problem definition

As is generally known, climate change is the greatest challenge of the 21st century, which can only be successfully overcome by consistently saving resources and CO_2 emissions. Since the construction industry, with a share of approx. 38 % of global CO_2 emissions, has made a significant contribution to global warming to date, in particular due to the enormous cement consumption [1], a change to more energy and resource efficiency as well as a growing awareness of sustainability is absolutely necessary. In the course of this, a resource-efficient carbon concrete, consisting of a corrosion-resistant textile reinforcement in combination with a significantly reduced concrete cover, is established in the construction industry as a convincing alternative to conventional steel reinforced concrete [2,3].
Due to the high load-bearing capacity of the textile reinforcement with the smaller concrete cross-sections required, the bond between the textile and the concrete is extremely important. So far, R&D has focused on the development of impregnations and impregnation systems for improved material bond with the concrete matrix [4]. However, only small forces with a shear flow of about 5 - 40 N/mm can be transferred, an efficient utilization of the textile reinforcement is not possible. Solutions with profiling of the yarn surface promise significant improvements in the transmission of bond forces [5]. Therefore, new technologies for the continuous and reproducible production of profiled textile high-performance fiber yarns and their further processing into reinforcement structures were developed within a research project at the ITM of the TU Dresden. These innovative, profiled reinforcements are characterized by their ability to transmit significantly higher bond forces in concrete [6,7]. In particular, this was realized by a form-fitting effect between the textile and the concrete, that meets the specific requirements

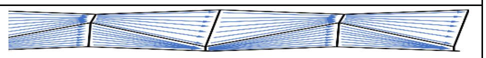
of a stiff and symmetrical surface profile of the reinforcement yarns in order to guarantee a constant and high force transmission. To generate the yarn profiling, solutions based on braiding technology and forming processes were developed and implemented with the help of simulation-supported studies. The premises were a permanently stable textile structure and a profile with a symmetrical structure. The realization of grid-like reinforcement structures, consisting of the profiled reinforcement yarns, was carried out using the multiaxial warp knitting technology. This was developed further on a modular basis with regard to the existing processes (yarn feeding, weft yarn insertion, knitting process, impregnation and winding) in accordance with the necessary adaptation measures for the fiber-friendly and requirement-based further processing of the profiled reinforcement yarns into grid-like structures.

Development of the innovative profiled reinforcement yarns

For the development of bond optimized profiled reinforcement yarns for concrete applications, a simulation-supported yarn development was carried out on the basis of braiding and forming technology. In particular, the main challenge was to realize profiled yarns with minimal structural elongation, so that, an initial force transmission of the textile reinforcement is possible and the concrete crack widths are minimized [3] if the concrete matrix fails at approx. 0.2 % elongation. For this purpose, a new type of varying braiding structure was developed. Moreover the braiding technology was further developed to enable a low-undulation and pre-stabilization of the braiding yarn structure during the braiding process, yet still ensuring further textile processing. As a result, it is now possible to implement novel vario braiding yarns as well as conventional packing braided yarns, consisting of carbon fibers with nearly eliminated structural elongation, minimal fiber damage and the required pre-stabilization of the yarn structure (see Table 1).

New profile yarns with a patented tetrahedral geometry were developed with a laboratory unit for the production of profiled carbon rovings at ITM (see Table 1).

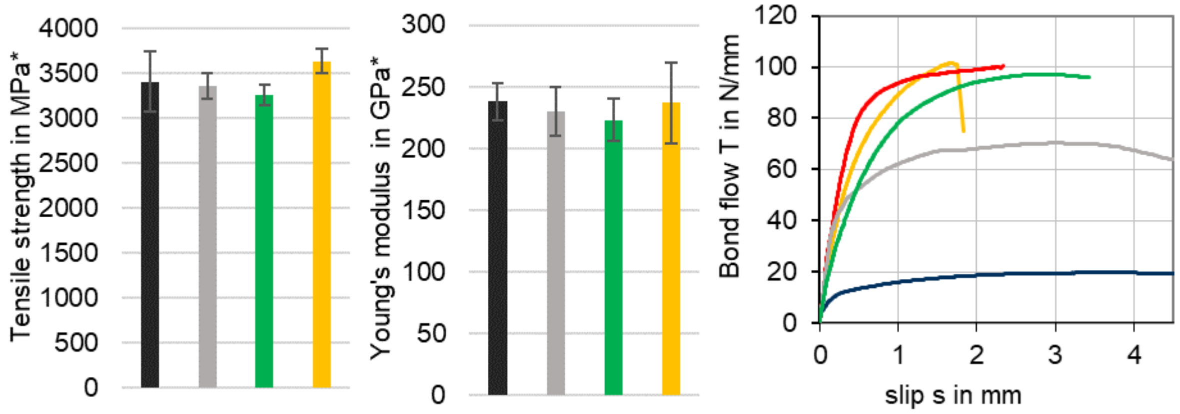
Table 1: Representation of unprofiled and profiled reinforcement yarns (3200 tex)

Yarn type	Depiction	Geometry modell
Unprofiled roving		-
Reference textile		-
Profiled roving		
Braiding yarn		
Vario braiding yarn		

In order to optimize the profile geometry and fiber arrangement, the force-strain behavior and the yarn pull-out tests were simulated too, for which corresponding geometry and material models of the new reinforcement yarns were developed and validated (see Table 1) [8].

Performance potential of the new profiled reinforcement yarns

The newly developed profiled reinforcement yarns are characterized by nearly unchanged tensile properties, yet up to 500 % higher bond properties compared to carbon rovings without profile or rovings extracted from reference textiles (see Figure 1). In addition, they do not show any noticeable structural elongation, so that an initial force transmission is possible without additional crack opening after the failure of the concrete matrix. However, an increase in bond strength of more than 500 % from approx. 20 N/mm of the carbon rovings without a profile to over 100 N/mm of the profiled reinforcement yarns was achieved, which is accompanied by a significant increase in material efficiency (see Figure 1). The vario braiding yarns in particular are characterized by very high bond stiffness, which is of particular interest for an initial force transmission. The packing braiding yarns and the profiled rovings with tetrahedral geometry have almost the same bond properties. The bond stiffness is marginally lower compared to the vario braiding yarns, whereas their production is more productive than the vario braiding yarns.



Unprofiled roving **Reference textile** **Profiled roving** **Packing braiding yarn** **Vario braiding yarn**

* Based on the net filament cross-section (1.81 mm²)

Figure 1: Tensile properties on the yarn and bond flow-slip relationship (in concrete) of unprofiled and profiled reinforcement yarns

Development of the multiaxial-warp knitting process

To process the newly profiled reinforcement yarns into a grid-like reinforcement structure, a biaxial warp knitting machine Malimo 14022 at the ITM and the corresponding sub-processes (yarn feeding, weft yarn insertion, knitting process, impregnation and winding) were adapted and further developed so that on the one hand the pre-stabilized braiding yarns and the consolidated tetrahedral-shaped profiled rovings can be processed further. For this purpose, the weft thread laying process in particular was modified by developing a new type of weft thread guide for the laying of the pre-stabilized braiding yarns. Since the rigid profiled rovings could not be processed with the conventional weft laying process, a new type stick placement system consisting of a stick magazine and a shaft with profile rollers was developed (see Figure 2). The pre-cut sticks were individually inserted via the stick placement system into a transport chain modified with new fixing elements.

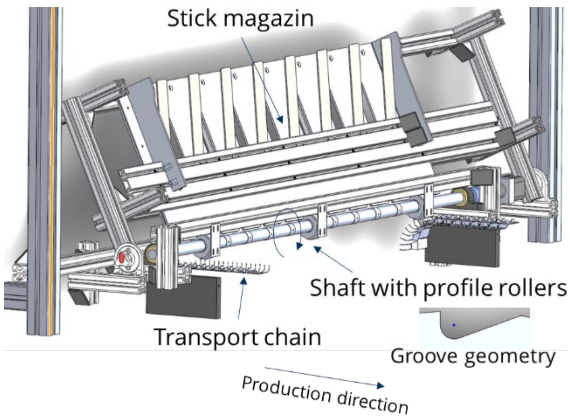


Figure 2: Stick placement system

In order to guarantee textile processing, the pre-stabilized braiding yarns were impregnated and consolidated after the warp knitting process, contrary to the rigid profiled rovings, which do not require any further impregnation.. On the basis of extensive production tests, a new type of impregnation system was developed based on the kiss coater process with an additional coating roller for applying an impregnation agent to both sides of the pre-stabilized braiding yarns. Various reinforcement structures were manufactured and characterized with the implemented system technology. Figure 3 shows a new type of profiled textile reinforcement consisting of prefabricated profiled rovings with tetrahedral shape.

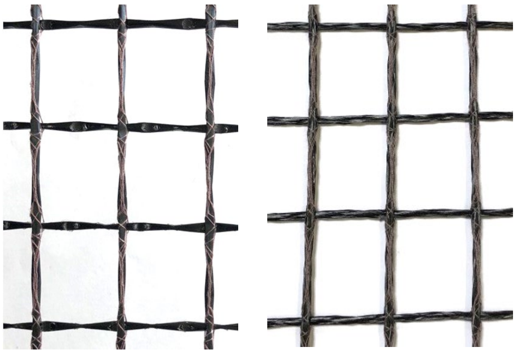


Figure 3: Textile reinforcement structure made of profiled rovings (left) and braiding yarns (right)

Conclusion

At the ITM of the TU Dresden, new, bond optimized reinforcement yarns were developed on the basis of braiding and forming technology, which can transmit up to 500 % higher bond forces in concrete than yarns without profile. The profiled rovings and braided yarns show at a bond length of only 50 mm a full anchoring. With the forming technology developed at the ITM, profiled rovings could be manufactured which, due to the patented tetrahedral geometry, can almost completely exploit the tensile potential of the carbon fibers. In the course of developing the braiding yarns, a new vario braiding structure was developed, with nearly eliminated structural elongation under load. This made it possible to manufacture profiled reinforcement yarns with very high tensile properties, which is a basic requirement for use in concrete. In addition, the multiaxial warp knitting technology has been further developed in such a way that the new bond optimized reinforcement yarns (profiled rovings and braiding yarns) can be processed without damage into profiled, grid-like textile reinforcements. This results in a significantly higher material efficiency of the textile reinforcement, so that previous necessary disproportionate oversizing and large overlapping lengths can be significantly reduced. This is of enormous importance, especially in view of the energy-intensive production of carbon fibers and consequently for the sustainability goal of the future-oriented carbon concrete technology, in order to make concrete constructions of the future resource saving and sustainable.
The project results achieved also represent a significant contribution to the production of extremely resilient textile-reinforced concrete structures with significantly improves bond properties, arising new prospects in the construction industry for component production in the field of renovation and new construction.

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Resources

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