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SIMULATION BASED DEVELOPMENT OF PROFILED CARBON ROVINGS FOR CONCRETE REINFORCEMENTS

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ABSTRACT

Textile reinforcements are increasingly establishing their position in the building industry due to their high tensile properties and corrosion resistance. However, in contrast to ribbed monolithic steel bars with a defined form fit effect, the bond force of conventional carbon rovings are transmitted primarily by an adhesive bond (material fit) between the textile surface and the surrounding concrete matrix. Hence, relatively large bonding lengths are needed to transmit the bond forces, which results in an inefficient material utilization. New solutions involving tetrahedral profiled rovings and braided yarns promise significant improvements in the bonding behavior of textile reinforcements by creating an additional mechanical interlock with the concrete matrix, yet maintaining the high tensile properties of the carbon fibers. In order to increase the transmittable bond force and bond stiffness of the profiled rovings through a defined roving geometry, a simulation-based development was conducted. Hereby geometry and material models were developed and tensile tests as well as pull-out tests were simulated. The results of simulation and characterization enable the optimization of the geometry parameters of the tetrahedral profiled rovings and braided yarns to achieve better bond and tensile properties.

KEYWORDS

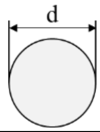
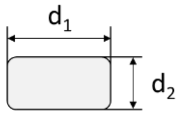
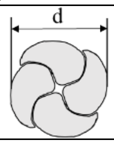
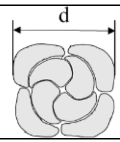
Carbon reinforced concrete, bond behavior, bond simulation, profiled roving, braided yarns.

MATERIALS AND METHODS

In order to compare different profiled rovings and to evaluate the influence of the profile type on tensile and bond properties, four different roving configurations made of Carbon Fiber Heavy Tows [1] are produced, tested and simulated. Rovings with the tetrahedral profile [2,3] are produced using a laboratory unit at ITM [4,5]. Braided yarns were produced with an VF 1/4-32-140 variation braiding machine from Herzog GmbH (Germany). As a reference structure, straight rovings were produced. All rovings were consolidated with the polymeric dispersion TECOSIT® CC 1000 (50% solid content), produced by CHT Germany GmbH, Germany. An overview of the investigated roving properties as well as an illustration of the different rovings is given in Tab. 1.

In order to generate a realistic geometry model of the tetrahedral profiled roving, which can be used for simulation of tensile and bond tests, 3D scans of real rovings were created and evaluated. Based on this a parametric model was approximated, that enables the variation of different profile parameters for further parametric studies. Models of braided yarns consisting of multiple rovings were generated using the braiding software of TexMind UG (Germany) [6]. The idealised, compressed geometry was converted into a realistic, outstretched braided yarn by applying a fictitious thermal strain on the filaments using the simulation software LS-DYNA, from DYNAmore GmbH (Germany). The yarn's surface was derived and converted into a solid structure following the procedure described in [7] (Fig. 1). The models were validated by comparing the results of virtual tensile tests and pull-out simulations with experimental results.

Table 1. Material properties of the developed and investigated roving types as well as the reference.

Properties	Roving with no profile (reference)	Tetrahedral profiled roving	Braided yarn	Vario braided yarn
Roving material	1 × TohoTenax®-E STS40 F13 48K 3200 tex	1 × TohoTenax®-STS40 F13 48K 3200 tex	4 × TohoTenax®-E STS40 F13 12K 800 tex	8 × TohoTenax®-J STS40 E13 6K 400 tex
Total Fineness	3200 tex			
Impregnation agent	Polymeric dispersion TECOSIT® CC 1000 (50% solid content)			
Profiling typ	Circular with no profile	Tetrahedral with $d_1/d_2 \sim 1{,}7$	Braiding structure flat, 4-strand braid	Vario braiding structure
Schematic cross-section				
			a) Roving with no profile	
			b) Tetrahedral profiled roving	
			c) Braided yarn	
			d) Vario braided yarn	

For determination of tensile properties different profiled rovings were tested on the basis of DIN EN ISO 10618 [8]. The test specimens consist of 450 mm long single rovings with resinated ends for the clamping area. The rovings were clamped with 35 bar between two metal clamps Demgen (steel file cut 50 × 60 mm) and a free clamping length of 200 mm. All tests were conducted at the testing machine Zwick 100, from ZwickRoell GmbH & Co. KG (Germany), with optical elongation and a test speed of 3 mm/min.

For the analysis of the bonding behavior, this study focused on pull-out test results, which is an established method for classifying bond strength and stiffness of single rovings. Pull-out specimens for testing purposes were created by embedding different profiled carbon rovings in a fine concrete drymix (binder compound BMK 45-220-2) in a cube formwork at the Institute of Construction Materials of the Technische Universität Dresden. The embedment length was set to 50 mm with a concrete cover of 40 mm. To determine the characteristic bond-slip relationship pull-out strength was measured by a single-sided pull-out through a defined yarn fixing in the lower concrete block with an increased embedment length of 90 mm with a controlled quasi static load. The specimens were tested at 20°C 28 days after embedment.

RESULTS AND DISCUSSION

The developed geometry simulation models of the different profiled rovings, which are used to simulate tensile and bond test, are shown in Fig. 1. Hereby the tetrahedral profile roving consists of a single 3200 tex roving, whereas braided yarns consist of multiple rovings (highlighted with different colors) with a total fineness of 3200 tex.

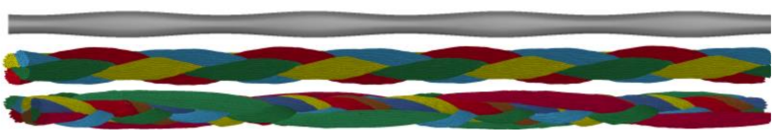


Figure 1. Simulated geometry model of different profiled rovings (all 3200 tex).

The following two diagrams show the mean-values of tensile strength (Fig. 2 left) and Young's modulus (Fig. 2 right) with the single standard deviation of the different series of roving types compared to results of a simulated tensile test (cross-hatched). For each test series, a minimum of seven single specimens were tested. The tensile strength refers to the dry filament area with approximately 1.8 mm^2.

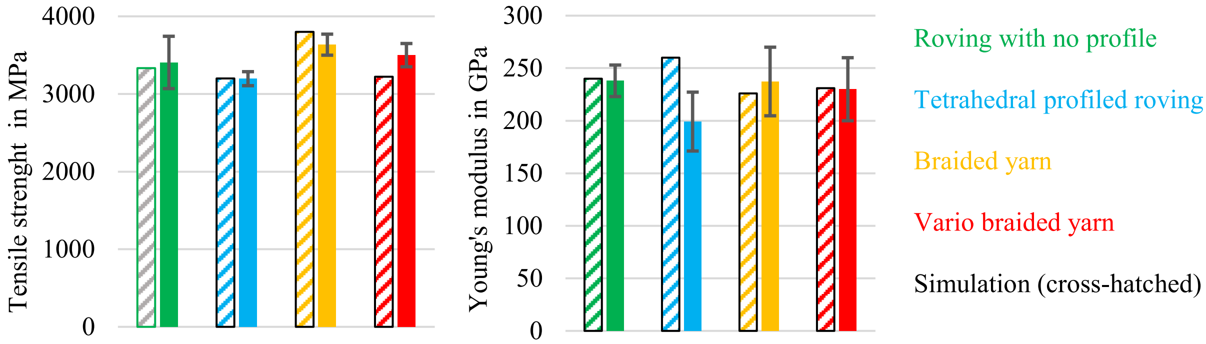


Figure 2. Tensile strength (left) and Young's Modulus (right) of different profiled rovings determined in tensile tests and compared to simulation (cross-hatched).

The diagrams in Fig. 2 show, that the profiled rovings achieve almost the same test results as straight rovings. Due to an adapted braiding process with a reduction of roving ondulation through a tension regulation system and consolidation of the roving structure, tensile stiffness of braided yarns compared to straight rovings is not reduced. The results could be reproduced in simulated tensile tests, although simulated tetrahedral profiled roving shows a deviation in tensile stiffness. One possible reason is the great challenge to consider all aspects of the complex tetrahedral roving shape with its inhomogeneous material properties within the simulation model. A major challange in this context is especially the variation of the impregnation proportions due to the changing cross sections along the roving axis and its influence on the roving properties, such as transversal contraction due to elongation. New test methods for characterizing the inhomogenous properties are part of future reasearch.

The characteristic bond behavior of the investigated carbon rovings with different profiling typs (Tab. 1 b-d) in concrete is shown in comparison with an unprofiled roving (Tab. 1 a) in Fig. 3 as mean value curves of five single tests each. Results from a simulated pull-out test on basis of [9] for each roving configuration is shown as dashed lines.

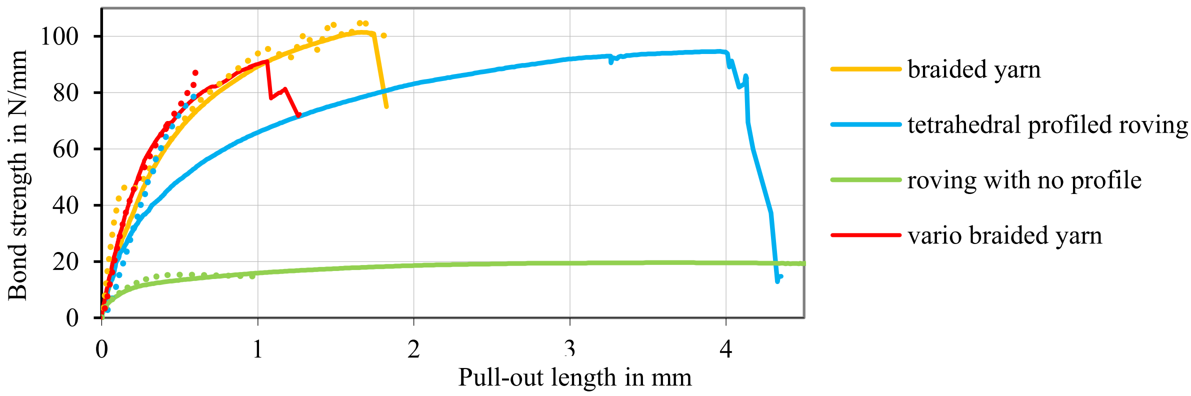


Figure 3. Bond behavior of different profiled rovings determined in pull-out test and simulation (dashed).

Due to improved mechanical interlock of profiled rovings, resulting bond strengths are well above that of rovings with no profile. Braided yarns and tetrahedral profiled rovings transmit almost five times higher bond strengths than rovings with no profile. They even achieve their breaking strength resulting in a failure of the roving, indicated by the sudden drop of the bond strength. Therefor the embendment length of 50 mm is enough for a complete anchoring of the roving. The simulation fits almost the curves of the determined bond behavior. Only tetrahedral profiled rovings has a higher bond stiffness in simulation than in test results. A possible reason could be a wedging effect of the tetrahedral shape with the surrounding concrete matrix before the full mechanical interlock is achieved in the tests. In addition to that, transverse contraction of the profile as well as an inhomogenous occurrence of interface friction could influence the pull-out performance. These effects will be analyzed in further studies e.g. by characterizing resistance of the roving profile to stress (longitudinal and transversal) in order optimize the the roving geometry as well as the consolidation process to achieve a higher bond stiffness.

CONCLUSION

The results show that the developed profiled carbon rovings are able to transmit much higher pull-out loads and demonstrate a significantly improved bond-slip behavior. Compared to straight carbon rovings with no profile the profiled carbon rovings transmit up to five times the maximum bond strength, yet maintaining their high tensile properties making them particularly suitable as concrete reinforcement. Hereby the simulation-based development and simulated bond tests enable an optimization of the profile properties in order to enhance bond behavior and material efficiency. Furthermore, the simulation is an important step for a fundamental analysis of the bonding mechanisms between roving geometry and concrete matrix in addition to a better understanding of inhomogenous material properties and resistance of the profile geometry under stress. The simulation based studies enable perspectively reduction of practical tests and hence costs, material and time for further developments. New and adapted test setups for characterization of profiled roving properties will be developed in future research studies. For a production of profiled, grid-like textile reinforcement structures for concrete applications the conventional textile manufacturing processes needs to be further developed in continuing investigations.

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REFERENCES

[1] Teijin Carbon Europe, *Produktdatenblatt - Tenax® Filament yarn*, online, https://www.teijincarbon.com/ fileadmin/PDF/Datenbl%C3%A4tter_dt/Product_Data_Sheet EU_Filament_DE_.pdf [access: 26.01.2022]

[2] Waldmann M., Rittner S., Cherif C., *Bewehrungsstab zum Einbringen in eine Betonmatrix sowie dessen Herstellungsverfahren, ein Bewehrungssystem aus mehreren Bewehrungsstäben sowie ein Betonbauteil*, Technische Universität Dresden. DE 10 2017 107 948 A1. 12.04.17.

[3] Cherif C., *Neuartige Profil-Carbonrovings für die Betonbewehrung*, Proceedings of 11. Carbon- und Textilbetontage 24-25.09.2019, Dresden 2019, pp.18–19.

[4] Penzel P., May M., Hahn L., Cherif C., Curbach M., *Tetrahedral profiled carbon rovings for concrete reinforcement*, Proceedings of AUTEX 2021, Book of Abstracts, 2021, pp.142–143.

[5] Hahn L., Cherif C., *Fortschritte bei Fertigung von profilierten Carbonpolymergarnen mit höchsten Verbundeigenschaften*, TUDALIT-Magazin 2020, vol. 22, no 1.

[6] Kyosev Y., *Machine configurator for braided composite profiles with arbitrary cross section*, Proceedings of ECCM16 - 16th European conference on composite materials, 22- 26.06.2014, Seville 2014, pp. 1–8.

[7] Huang L., Wang Y., Miao Y., Swenson D., Ma Y., Yen C.-F., *Dynamic relaxation approach with periodic boundary conditions in determining the 3-D woven textile micro-geometry*, Composite Structures 2013, vol. 106, pp. 417–425.

[8] DIN EN ISO 10618:2004-11. Kohlenstofffasern - Bestimmung des Zugverhaltens von harzimprägnierten Garnen. 2004.

[9] Seok S., Haikal G., Ramirez J.-A., Lowes L., Lim J., *Finite element simulation of bond- zone behavior of pullout test of reinforcement embedded in concrete using concrete damage- plasticity model 2 (CDPM2)*, Engineering Structures 2020, vol. 221, pp.1–20.