Zukunft Bau

STRUCTURE / OUTLINE SHORT REPORT

Title

Development of the fundamentals for the application of a novel cement-bonded high-performance material in building construction with aligned carbon fibers and high tensile strength

Motive / Initial Position

For a long time there have been intensive efforts to further develop the economically extremely important composite reinforced concrete and, above all, to increase the tensile strength of concrete. Using the production process developed at the University of Augsburg, in which the alignment of mixed carbon fibers can be specifically adjusted by means of a nozzle, it has been possible to achieve a significant increase in the ratio of tensile strength and compressive strength in cement stone samples with commercially available starting materials and practice-oriented processes.

Matter of the Research Project and Conclusion

In the material development studies, it was shown that the high strength of fiber-reinforced test specimens can be achieved even with shorter fibers and thus better workable mortars of the same strength can be produced. A more cost-effective system could be realized without loss of strength by replacing expensive new fibers with cheaper recycling products. It could be clearly shown that the orientation of the fibers must take place in a narrow angular range, even deviations of about 10 ° lead to a noticeable loss of strength. The compressive strength of the systems does not appear to be directly related to fiber orientation. The strength development of the fiber-reinforced systems is fast, the decisive factor seems to be the rate of solidification and hardening of the cement matrix, possible post-curing effects do not seem to play a major role. The formulations used so far are designed for the use of CEM I 52.5 R; however, it could be shown that with relatively simple adjustments, other types of cement can be used without greatly changing the performance of the system. The resistance to fatigue is significantly increased by the fiber reinforcement, with the same ratio of upper tension in the cyclic test to breaking stress increases the number of load cycles to break by orders of magnitude.
The feasibility of introducing fillers for further price reduction has been demonstrated and has provided promising results. By using fine-grained quartz flours, a recipe could be found that delivers well-extrudable mortar systems with a comparatively low water-cement-ratio. This mortar mix shows better bending tensile strengths at lower fiber contents than the cement paste recipe; at fiber contents above 2% by volume, the strength drops slightly compared with the cement paste formulation. The system can easily be printed by an extrusion process and thus has high potential for applications in additive manufacturing ("3D printing").
The flexural strength of the mortar system was tested up to a fiber volume content of 2% and corresponds to the high values of the previously used cement paste formulation. By a specific adaptation of the water-cement-ratio to the fiber volume content mixtures could be created, which were well extrudable by hand and thus have significant potential for automatic printability.

Initial manual tests of scaling up the technique developed for small-sized test specimens to align carbon short fibers in a cement paste matrix have shown that similarly high bending tensile stresses can be reached even on larger specimens. After developing a 3D printer for carbon short fiber concrete, first results for standard prisms were able to measure slightly lower strengths than for the miniature specimens produced at the University of Augsburg. Various nozzle geometries and concrete pumping pumps were examined with regard to concrete workability, economy and specific suitability. It has created the basis for the use of a multi-nozzle. By using the previously developed mortar mixture it could be shown that due to the high water-cement-ratio curing of the specimens has no influence on the flexural tensile strength.
Extensive investigations on the load bearing behavior were carried out with centrically loaded samples and under uniaxial bending. In the area of tensile stress a very ductile behavior was observed, which is similar to that of steel. In the compression range, the typical linear elastic behavior of high-performance concrete was determined. These load-bearing properties can be transferred to the more complex stress state in bending tests and a conclusive design concept could be developed. Basically, a very high load capacity could be achieved without the use of conventional steel reinforcement.
Examinations of the fatigue behavior showed the material’s extraordinarily high potential. The good-natured behavior of the carbon fibers as individual transmits very well to the composite material, which opens up new possibilities for the use in the area of crane runways, bridges or wind energy plants.
Even with long-term loads, it has been shown that no fiber pullout occurs due to the omission of the facing optimized for CFRP, which is applied ex works to the carbon fibers and is thermally removed during the oxidation process. In this context there have often been poor results in recent studies on the bonding of carbon in concrete.

In the fire test, no satisfactory solution could be found to prevent component failure even at "low" temperatures. Deeper investigations are necessary.

Basic Information

Short title: Cement-based Carbon Fiber Reinforced High Performance Material

Researcher / Project Manager:

Technical University Munich
Chair of Concrete Structures
Prof. Oliver Fischer
Philipp Lauff, M.Eng.

University of Augsburg
Chair of Solid State and Materials Chemistry
Prof. Dirk Volkmer
Dr. Manuel Hambach
Matthias Rutzen, M.Eng.

Total Costs: 278.526,00 €

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Project Term: 30 months

PICTURES / IMAGES:

Picture 1: 1 kl. 3D-Drucker.jpg
Extruder for the production of small specimen

Picture 2: 2 kl. Hohlraumproben.jpg
Smallsized, porous specimen (left: topview, middle: diagonal cut with mortar filled cavities (dyed red), right: diagonal cut through a bigger specimen)

Picture 3: 3 REM.tif
Scanning electron microscopic image of carbon fibers, sticking out of the concrete

Picture 4: 4 Kartuschenpresse.JPG
First upscaling-attempts with a catridge press

Picture 5: 5 gr. 3D-Drucker.JPG
Specifically developed 3D-printer for the production of large-sized specimen

Picture 6: 6 Druckprozess.jpg
Extrusion of carbon short fiber reinforced concrete during the printing process

Picture 7: 7 Freiform TUM.JPG
Due to waiver of formwork it is possible to produce specially formed parts