Composite Structures 194 (2018) 178–187

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Implants for load introduction into thin-walled CFRP-reinforced UHPC beams

Benjamin Kromoser[a,b,*], Oliver Gericke[c], Werner Sobek[c]

[a] Research group for Biobased Design, University of Natural Resources and Life Sciences, Vienna, Peter-Jordan-Straße 82, 1190 Vienna, Austria
[b] Institute of Structural Engineering, TU Wien, Karlsplatz 13/E212-2, 1040 Vienna, Austria
[c] ILEK – Institute for Lightweight Structures and Conceptual Design, University of Stuttgart, Pfaffenwaldring 14, 70569 Stuttgart, Germany

ARTICLE INFO

Keywords:
UHPC
CFRP reinforcement
Thin walled concrete
Load introduction in thin walled concrete
Implants for engineering

ABSTRACT

Combining two high-performance materials – viz. ultra-high performance concrete (UHPC) as the matrix, and carbon fibre reinforced polymers (CFRP) as the reinforcement – opens up new possibilities of achieving concrete elements with thin walls and minmial weight. This strategy, however, results in a higher degree of material utilisation, which impedes load transfer from such thin-walled concrete elements to auxiliary constructions such as superordinate load-bearing systems. The authors present a solution for the load transfer from very slender CFRP-reinforced UHPC beams to its supports via steel implants (Sobek and Mittelstädt, 2012; Kobler, 2013; Mittelstädt, 2015). In this paper, the conceptual design of three different types of implants is presented. The geometry of the implant and especially the connection of the CFRP reinforcement to the steel implant are examined in detail. For this paper the authors tested beams with three different types of implants and three different configurations of the textile CFRP reinforcement serving as structural and shear reinforcement.

1. Introduction

Composites made from *ultra-high performance concrete* (UHPC) and *carbon fibre reinforced polymers* (CFRP) have a high potential for realizing light and efficient structures in the built environment. Due to the higher loads applied to such structures, regions of structural or force discontinuity, such as supports or load introduction points, need to be considered carefully. The occurrence of peak stresses and deviation forces in these regions can result in the structure not achieving its full potential. Using the example of a thin-walled CFRP-reinforced UHPC beam, the authors propose using embedded steel elements at the supports to achieve an effective load transfer. These so-called *implants* are designed to uniformly distribute the arising stresses to the concrete.

When used in lightweight structures, CFRP-reinforced UHPC has two advantages compared to conventional steel-reinforced concrete: first, both CFRP and UHPC exhibit a significantly higher strength to weight ratio than the steel and concrete normally used for reinforced concrete structures. Secondly, the concrete cover of carbon fibres only needs to be thick enough to ensure a proper bond [4]; the concrete cover of steel reinforcement has to be thicker in order to protect the steel from corrosion, thus increasing the weight of the structural components.

The efficiency of CFRP-reinforced UHPC components may be increased further by prefabrication in a controlled environment. The resulting improvement in concrete quality [5] leads to a further decrease in the mass required for the desired structural behaviour. According to [6], prefabricated concrete components should be designed to minimize expenditures for transportation and on-site assembly, thus increasing the economic advantages of this fabrication method. An example of an easily mounted concrete component is a dapped-end beam whose crack distribution is shown in Fig. 1. A comparison of the size of the elastomer support and the dimensions of the beam suggests that stress concentrations at the supports are to be expected. Given the high loads on CFRP-reinforced UHPC structures, support regions are critical in the design of such components.

In order to avoid stress concentrations, deviation forces, and the resulting need for additional material in load introduction areas, researchers of the Institute for Lightweight Structures and Conceptual Design (ILEK) of the University of Stuttgart have further developed the implant technology for concrete components which was originally invented by Werner Sobek [1–3]. The geometry and the material of these implants are chosen to ensure a homogeneous transfer of high loads into the concrete elements and to avoid stress concentrations in the concrete. Furthermore, the high-strength nature of the implants permits the use of point connections, which are easy to mount and demount. Fig. 2 shows an implant designed to transfer high compressive forces

* Corresponding author at: Institute of Structural Engineering, TU Wien, Karlsplatz 13/E212-2, 1040 Vienna, Austria.
E-mail address: benjamin.kromoser@boku.ac.at (B. Kromoser).

https://doi.org/10.1016/j.compstruct.2018.03.044
Received 24 November 2017; Received in revised form 14 February 2018; Accepted 12 March 2018
Available online 13 March 2018
0263-8223/

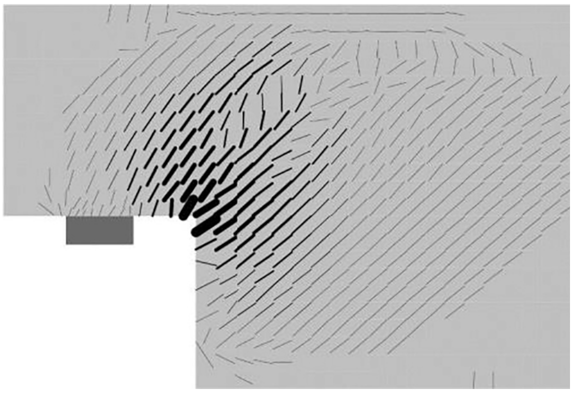

Fig. 1. Crack distribution of a dapped-end beam subjected to self-weight and uniformly distributed load.

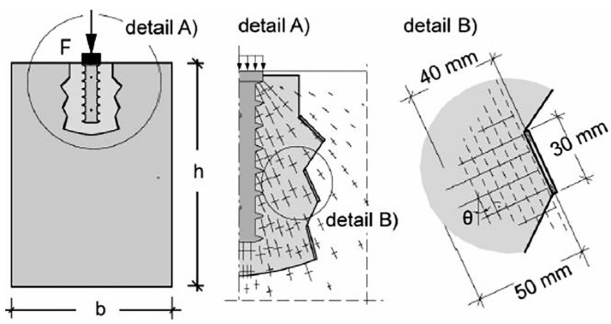

Fig. 2. Example of a steel implant for the introduction of high compressive forces into a thin-walled UHPC component (left). Principal state of stress used as the basis for the design of the implant geometry (centre, right). .
Source: [1]

into a thin concrete wall. The implant consists of two main components: a tooth bar for introducing the compressive forces and a fan with fins for reinforcement against lateral tensile forces. According to [3], the concrete component with the implant is able to resist a load 3.9 times higher than that sustained by a similar part without an implant.

This paper describes implants for transferring high shear stress from a CFRP-reinforced UHPC beam to a point support. First, the design of the implants will be described. In Section 3, a series of experimental investigations is performed at TU Wien presented, the results of which are described in Section 4. The paper will conclude with a summary of the results and an outlook towards future research.

2. Conceptual design of the implants

2.1. Design approach

The geometry and the material of the implants were chosen to avoid critical peak stresses within the concrete and to allow a homogeneous load introduction into the beam. The design of implants is always based on the stress state for a given load case. Therefore, a first analysis had to be carried out on an idealised system (Fig. 3). The design was conducted in two stages:

1. Preliminary design
   The material and the approximate dimensions of the implant are chosen.
2. Refined design
   The geometry of the implant–concrete interface is based on the stress fields obtained from the analysis of the idealised beam in the preliminary design stage.

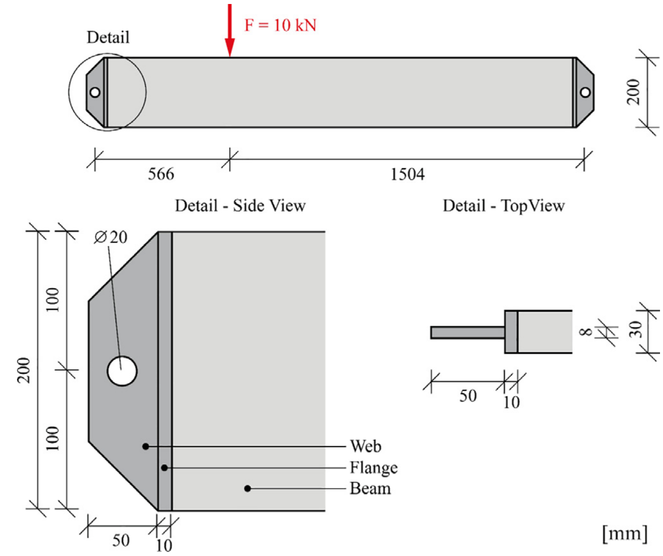

Fig. 3. Preliminary design of the concrete beam with implant. The bond between the steel flange and the concrete beam is idealised as a perfect bond to obtain results for the detailed design.

2.2. Preliminary design

The implant was designed to serve as a support connection for a 2070 mm long beam with a rectangular cross section (30 mm wide and 200 mm high). The beam was subjected to a single force positioned to cause high shear stresses near the support. A bolted connection was chosen to join the beam to the supports so as to allow easy installation on site.

The implant consisted of an 8 mm thick steel web and a flange of the same width as the concrete beam (30 mm, see Fig. 3). In the preliminary design stage, the bond between the implant and the beam was idealised as a perfect bond. The interface properties were adjusted in the second stage of the design.

Stainless steel X5CrNi18-10 (1.4301 according to EN 10088-1) was chosen for the implant. Due to its high compressive and tensile strength and its isotropic material behaviour this material was expected to exhibit efficient structural performance with respect to stress concentrations and deviation forces at the support.

2.3. Refined design

In this design stage, the preliminary design of the beam (Fig. 3) was analysed and the interface between the implant and the beam was refined according to the determined stress field. For the analysis, the single force F was defined as 10 kN. The left support is defined as a pinned support, the right support as a sliding support. The material parameters of stainless steel X5CrNi18-10 were used for the implant, while the material parameters of the UHPC described in [3] were assumed for the beam, since the parameters of the UHPC to be used were still unknown during this phase. For the design of the presented implants a linear analysis using linear material parameters was conducted. The results of the analysis are shown in Fig. 4 (left). The principal stress field shows a superposition of bending stresses and high shear stresses. Based on these results two changes were made to the implant geometry: the interface surface between the implant and the beam was adjusted to facilitate a uniform transfer of the compressive stresses, and additional steel components were added to transfer tensile forces to the implant.

It was assumed that a uniform transfer of the compressive stress from the beam to the implant occurs if a frictional connection between the two components exists. According to [7] a frictional connection between two components exists if the criterion