Challenges in the Production of Carbon Reinforced Concrete

Klaus Holschemacher

Abstract Carbon reinforced concrete (CRC) is an innovative building material where carbon-based meshes, partially in combination with solid carbon fiber reinforced polymer (CFRP) bars, are used as reinforcement in concrete members. In comparison to ordinary steel bar or steel mesh reinforced members there is no danger of corrosion of reinforcement. Therefore, concrete cover may essentially be decreased resulting in reduced dimensions of the member. However, CRC is not only characterized by application of carbon-based reinforcement, but it additionally allows the realization of new design principles like thin wall or free-form structures. By this, CRC contributes to the reduction of cement consumption and is helpful for improvement of sustainability issues in civil engineering. Application of carbon-based reinforcement requires new production technologies. The paper reports on the development of specialized concrete placement methods and reinforcing technologies and methods. Special consideration is needed to prevent the change of position of carbon reinforcement during placement and compacting fresh concrete. It is demonstrated that adequate production technologies are important precondition for application of CRC in construction practice.

Keywords Carbon reinforced concrete · Sustainability · Production technology

1 Introduction

1.1 Sustainability of Reinforced Concrete Members

Reinforced concrete (RC) is the dominating building material of our era. It is a material combining many advantageous properties, like outstanding load-bearing behavior for reasonable costs, high fire resistance and the possibility to produce

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C. Ha-Minh et al., (eds.), *CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure*, Lecture Notes in Civil Engineering 203,
https://doi.org/10.1007/978-981-16-7160-9_83

concrete elements in wide variety of shapes. Otherwise, RC has some weak points. The production of Portland cement, as one of the main components in ordinary concrete mixes, contributes to a large extend to greenhouse emissions. It is estimated that cement industry causes about 8% of global carbon dioxide (CO_2) emissions [1].

Another problematic topic is the fact that steel reinforcement must be prevented before corrosion. To achieve this objective there are specified requests for the minimum and nominal concrete cover in the codes depending on exposure conditions. For unfavorable conditions, e.g. environmental class XD3, according to fib Model Code 2010 [2] the minimum cover is 45 mm for non-prestressed reinforced concrete. Considering the design allowance for deviation Δc_{dev} the nominal cover c_{nom} results in a value of 60 mm. For the tensile zone of a section it means that the 60 mm depth concrete cover has no load-bearing function but is needed only for durability reasons. That is a significant part of the total section and, therefore, unfavorable in the context of sustainability.

Application of non-metallic reinforcement may improve this issue and result in essential reduction of concrete cover for reasons of durability and improved sustainability of reinforced concrete members.

1.2 Carbon Reinforced Concrete

Carbon reinforced concrete (CRC) is intensively investigated in the German research project C^3—Carbon Concrete Composite, funded by German Federal Ministry of Education and Research (BMBF) [3]. In the sub-project C3–V.1.1 the production technology for CRC was explored. Some of the results are reported in the next chapters.

CRC is characterized by the application of carbon-based reinforcement in concrete members. Typical in this context are very filigree members, small concrete covers, low spacing between adjacent reinforcement layers, and minimal mesh width of textile reinforcement. In general, two types of reinforcement are used in CRC: textile meshes and/or solid bars. Textile meshes consist of impregnated carbon fibre strands. Impregnation materials are epoxy or polyacrylate-based resin. Usually, carbon fibre strands are arranged in biaxial direction forming a rectangular grid (see Fig. 1) or as multiaxial meshes.

Solid CFRP-bars are available in various sizes and in different kinds of surface preparation (e.g. deformed surface, sand-covered surface, wrapped with fibre strands). The last issue is of high importance for the bond behavior of the CFRP-bars in concrete [4]. CFRP-bars are often applied in combination with CFRP-meshes (Fig. 2).

In CRC members the application of fine-grained high-performance concrete is preferred to ensure a good penetration of textile meshes by the concrete. The maximum grain size depends on clear distance between fibre strands, application field and casting technology, but it is normally no more than 8 mm. Mostly fine-grained concrete with maximum grain size of up to 2 mm is used. Casting

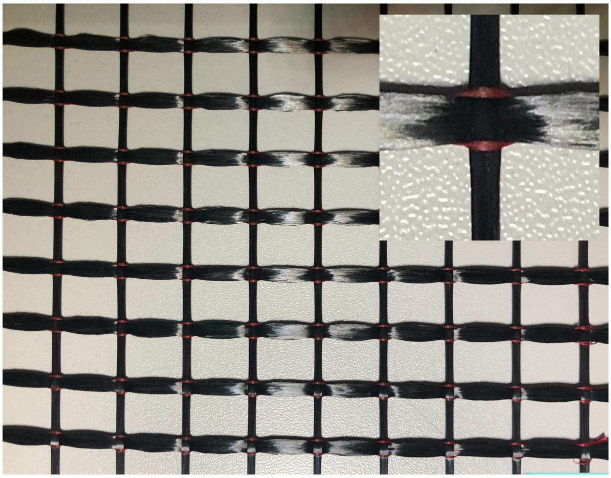

Fig. 1 Example for carbon-based mesh reinforcement

Fig. 2 Example for combined CFRP bar and mesh reinforcement

technology influences also the demands for fresh concrete properties (flowability, compactability).

2 Production of CRC Members

2.1 General Remarks

Main reason why production processes of CRC members may differ from those of ordinary RC members are the particularities of applied concrete composition and carbonbased reinforcement. Thus, aiming on high-quality construction with CRC, the development of suitable manufacturing processes and processing strategies is necessary. Because of the fact that manufacturing costs have a bigger share at total expenses as material costs, it becomes clear that the investigation and implementation of appropriate production processes is of high importance for the successful application of CRC in construction practice.

There are three main application fields of CRC: strengthening of existing concrete or masonry members, precast concrete members and in-situ cast concrete members. Depending on application there are different requests on manufacturing methods that are described in the following sections.

2.2 Processing of Carbon-Based Reinforcement

Basically, carbon-based reinforcement is sensitive to pressure in lateral direction. This fact requires special attention for transport, storage and arrangement of reinforcement.

Reinforcement must be packaged transported and stored. Package should be protected against mechanical damaging. Grinding during transport process, contact to oils and solvents and storage at transport zones is to avoid. Furthermore, protection against weather effects, heat and pollution is needed. No sharp-edged objects may be arranged on the reinforcement. Entering by reinforcement fixing staff must be prevented.

Mesh reinforcement may be planar or pre-formed. It is possible to shape two-dimensional (2D) and three-dimensional (3D) textile structures (Fig. 3). Apart from special processing technologies, 3D textile structures are pre-formed before delivery to site.

Due to low density of CFRP components in comparison to concrete density, measures are needed that prevent a lifting of CFRP reinforcement when concrete is casted. Conventional spacers for steel bar or steel mesh reinforced concrete are not applicable because of differences in bar and fibre strand sizes as well as cover. For this, specialized spacers systems have been developed considering the particular requirements of carbon-based reinforcement. They may be divided regarding their dependence of the production process of the textile reinforcement. Independent of the production process are plastic spacers that are fixed on textile reinforcement by clipping or gluing. Applicability for different sizes and cross-sectional shapes of

Fig. 3 Pre-formed mesh reinforcement

fibre strands must be met. Furthermore, textiles shaped in square, circle or semi-circle geometry are well usable as spacer system [5].

On the other hand, production of spacers may be included in the fabrication process of textile reinforcement or CFRP bars. It is possible to arrange spacers during the pultrusion process of CFRP bars in a defined position. In the result, the spacer is directly connected to the CFRP bar, the need for fixing spacers at the site disappears. Another opportunity is the arrangement of CFRP bars between adjacent layers of textile meshes ensuring the required distance between them. This procedure can be done during the weaving process of textiles.

Meanwhile, there are manifold spacer types available, such as point (e.g. star shaped), lining and two-dimensional elements. Figure 4 illustrates the importance of suitable spacer systems for the positional accuracy of textile reinforcement [6]. A typical plastic spacer system is shown in Fig. 5.

For the connection of shells in prefabricated double wall elements, special anchor sticks were developed under consideration of the required thermal insulation. It

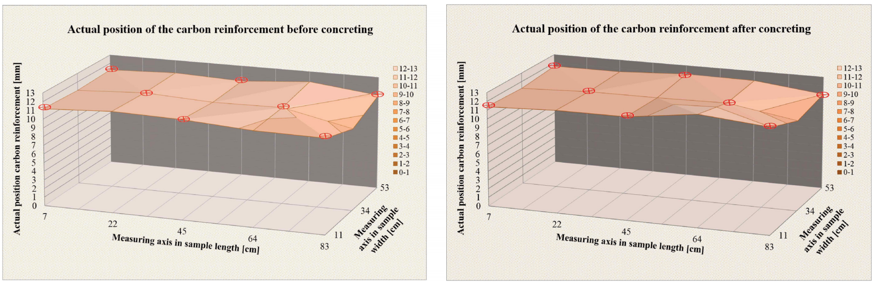

Fig. 4 Position of textile reinforcement before and after casting in case of insufficient spacers [5]

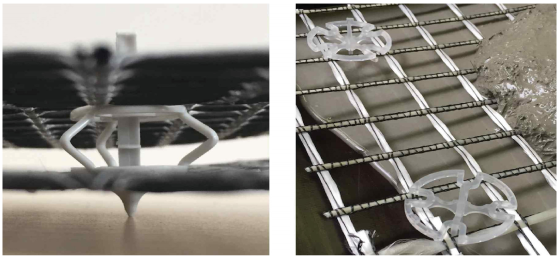

Fig. 5 Typical spacer system for carbon-based mesh reinforcement

enables the application of these precast members as part of outer building envelope without loss of the walls' heat insulation capacity [7].

Sometimes, CFRP meshes must be shortened at the site. It is recommended to use a suitable saw (band saw or coping saw) for this procedure. For cutting of CFRP bars there are no special demands in comparison to ordinary steel bar reinforcement, a usual abrasive grinder may be used.

3 Concrete Placement

For placement of concrete, various methods have proved in the different application fields, e.g.: Laminating; Casting; Spraying; Injection; Extrusion.

A further new and promising technology is 3D printing enabling an automized production of CRC members. There are also very specialized manufacturing procedures, e.g. the centrifugal process for production pipe, masts and piles.

3.1 Laminating

Laminating is the typical concrete placement process for strengthening and revaluation of existing structures. One or more thin CRC-layers are added at the surface of the existing members resulting in a small increase of the section. Increase of load-bearing capacity is mainly achieved by reinforcement inside of the strengthening layers. First, concrete matrix is applied by trowel or comparable tool to the surface of the existing member. In the next step, carbon-based reinforcement is carefully installed in the concrete layer. These steps may be repeated until the intended number of layers is achieved. The final one is always a concrete layer that covers the last assembled reinforcement layer. Laminating procedure is also usable for construction of new members. In this case, the first layer is applied at surface of formwork. The laminating process is a relatively easy procedure enabling high reinforcing ratio. There is no need for spacer systems. Disadvantageous are the high manual workload and the time and space consuming efforts. 3D textile reinforcement structures are normally not applicable (Fig. 6).

Fig. 6 Laminating process for confinement of a concrete column

3.2 Casting

For in-place casting the carbon reinforcement is assembled in the formwork in the first step. Suitable spacers must ensure the required concrete cover and the clear distance between adjacent reinforcement layers as well as positional accuracy during the casting process. In the last step the formwork is filled with concrete. Concrete composition must be designed in a way that textile reinforcement is well penetrated by the concrete. Therefore, adjustment of fresh concrete properties with regard of characteristics of applied textile reinforcement (mesh width, number of layers) is needed. High-flowable and self-compacting concrete may provide a good solution in this context (see Fig. 7). In-place casting is the often-preferred manufacturing process in precast concrete industry [8]. Some remarkable structures were realized with this method [9]. The main advantages of in-place casting are fast manufacturing process, high accuracy and low tolerances, good surface quality, and possibility of application of 3D reinforcing meshes. Problems may arise if there are too much reinforcement layers because of the increasing danger of imperfections (concrete pores and cavities, insufficient embedment of textile reinforcement in concrete).

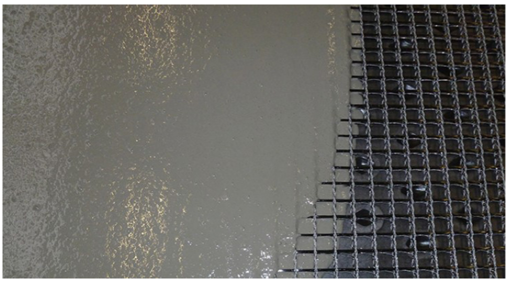

Fig. 7 Flowing of fine-grained concrete during in-place casting process

Fig. 8 Strengthening of a column with spraying method

3.3 Spraying

Spraying of concrete is proven technology for strengthening of existing structures and for tunnel construction. Gained experience is well transferrable to CRC. In general, it is to consider that enough space for spraying process must be available. Furthermore, a high level of dirt and residues is occurring (Fig. 8). Similar to in-place casting the spraying process is done layer by layer. The pressure on carbon-based reinforcement layer caused by spraying must be limited to avoid damages in the reinforcement. The huge benefit of the spraying procedure is the high operation speed. Even big areas may be covered with CRC in comparatively reduced time.

4 Summary and Outlook

CRC combines outstanding load-bearing behavior caused by high tensile strength of carbon fibres with excellent durability resulting in lower dimensions and reduced ownweight of CRC-members. In this way, CRC contributes to better sustainability and resource-saving constructions. Precondition for successful application of CRC are suitable and economic manufacturing processes. In the paper some particularities in manufacturing processes of CRC members are reported. It is to expect that in future automatization of production processes become very important. Combination of automized concrete placing like 3D printing with assembling of carbon-based reinforcement by robotic will essentially improve the quality of concrete structures. Already done steps in this direction are very promising [10].

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