Application of Textile Reinforced Concrete in Precast Concrete Industry

K Holschemacher

1HTWK Leipzig, Structural Concrete Institute, Karl-Liebknecht-Str. 132, 04277 Leipzig, Germany

E-mail: klaus.holschemacher@htwk-leipzig.de

Abstract. The sales of Germany’s precast concrete industry have been almost 6 billion Euros in 2017. This is only a small part of total construction investments but precast concrete industry traditionally is open-minded for implementation of innovations. Consequently, many new trends in civil engineering have been started in precast concrete industry. Recently, Textile Reinforced Concrete (TCR) has got more and more attention for application in precast members. Basic idea for the development of TCR was the intention to replace the traditional steel bar or steel mesh reinforcement by textile meshes on the basis of alkali-resistant glass fibres, carbon fibres or basaltic fibres. By this method it is possible to avoid the corrosion problem of the steel-based reinforcement and to improve the durability of precast concrete members. However, there was not a real break-through of TCR in construction practice until 2010. Main reason was the preferred usage of glass fibre meshes as textile reinforcement and the limited load-bearing capacity.

The last step in the development of TCR is the application of carbon fibres for the production of mesh and bar reinforcement. Carbon meshes and carbon bars may be used combined or separately as reinforcement resulting in a new construction material called Carbon Concrete Composite. Based on the outstanding properties of carbon fibres it is possible to enhance essentially the application possibilities of TCR. The paper describes the basics of the production and approaches for the design of Carbon Concrete Composite members and reports first applications in construction practice.

1. Introduction

Reinforced concrete (RC) is the worldwide most applied building material for more than 100 years. This situation has been caused by the advantageous properties of RC like high load-bearing capacity and fire resistance. However, there are some disadvantages of this material, especially the insufficient durability when the concrete cover of steel bar or steel mesh reinforcement is too low under harsh environment. By the application of non-metallic reinforcement the danger of corrosion can be avoided resulting in a better durability. In this context a lot of research has been done to develop the so-called textile reinforced concrete (TRC). TRC is characterized by the replacement of the steel bar or steel mesh reinforcement by textile meshes on the basis of continuous carbon, basaltic or alkali-resistant glass fibres. Until the year 2010 there was not a real break-through in practical application of this material. Main reasons have been [1]–[3]:

– Because of the poor stiffness and low density of textile meshes, it is difficult to fix the mesh
position during casting the concrete.

- It is necessary to develop a new production technology for members of TRC. Adapting the traditional methods suitable for steel bar or mesh reinforcement is not possible. Precast concrete technology is traditionally adjusted on materials with magnetic properties like steel. If non-metallic materials are used, new ideas for transportation and assembling of textile meshes are needed.

- The bond between yarn and surrounding concrete is a quite complicate issue. Only the outer filaments of the yarn are in direct contact to the concrete matrix and have a good bond. The inner filaments have only direct contact to other filaments but not to the matrix resulting in a non-uniformly strain distribution over the section of the yarn. Consequently, there is a significant gap between the ultimate strength of one filament and the design strength of the yarn.

- The cross sectional area of usual textile meshes is relatively low because the mesh width must not be to low for sure casting of concrete. Especially for structural members, often more than one layer of textile reinforcement is necessary. But then may arise difficulties in the production of the members. In such cases, a very flowable concrete with low maximum grain size is needed. Otherwise the probability of imperfections in the concrete structure is quite big.

In the years after 2010 the situation changed when meshes on the basis of carbon fibres in combination with reinforcing bars of carbon fibre reinforced plastics (CFRP) were investigated as possible reinforcement. The result is a new building material called Carbon Concrete Composite.

At time, a lot of research results about Carbon Concrete Composite already have been published. Remarkable applications, mainly in the fields of precast industry and strengthening of existing RC members, show that Carbon Concrete Composite is a recognized and attractive building material in construction practice. In the following chapters, basic information about Carbon Concrete Composite and examples for its usage in precast concrete industry is provided.

2. Mechanical properties of carbon mesh reinforcement

Carbon fibres are characterized by high modulus of elasticity and ultimate strength. A comparison with other fibre materials is shown in Table 1. There is a linear and brittle load-deformation behavior of carbon fibres in contrast to steel, see Figure 1.

Table 1. Mechanical properties of typical fibre materials [4].

|                      | Density $\text{g/cm}^3$ | Modulus of elasticity GPa | Tensile strength GPa | Ultimate strain |
|----------------------|-------------------------|----------------------------|---------------------|-----------------|
| Steel fibres         | 7.85                    | 160–210                    | 0.3–3               | 1–10            |
| Polypropylene fibres | 0.9                     | 1.3–10                     | 0.2–0.7             | 5–15            |
| Alkali-resistant glass fibres | 2.68–2.70 | 72–80                     | 1.5–3.7             | 1.5–3.6         |
| Basalt fibres        | 2.6–2.8                 | 90–110                     | 4.8                 | <4.0            |
| Aramid fibres        | 1.44                    | 30–150                     | 0.6–2.9             | 1.8–4.4         |
| Carbon fibres        | 1.6–1.7                 | 240–600                    | 3.0–5.0             | 0.5–2.5         |

The ultimate strength of the carbon mesh reinforcement inside of concrete members is lower than the pure fibre strength. For a typical carbon mesh the tensile strength of the roving is more than 4.000 MPa, the average tensile strength of mesh reinforcement in Carbon Concrete Composite members amounts 3.100 MPa and the characteristic value of the tensile strength is only 2.200 MPa.

If the carbon mesh reinforcement is applied in curved member regions, a further reduction of tensile strength is to consider [5], [6]. Experiments carried-out in the context of strengthening of existing circular reinforced concrete columns showed that there is a strong dependence between the curvature radius and the strength reduction. For a curvature radius lower than 80 mm the tensile strength is rapidly decreasing, see Figure 2.
3. Design for bending
At time there exist no normative regulations for Carbon Concrete Composite members. Therefore, the design and application procedure is to define in Technical Approvals, e.g. [7]. The Technical Approval must provide all information that is needed for design like partial safety factors, characteristic values of material strength, ultimate limit strains, modulus of elasticity, additional reduction factors (considering durability, creep, temperature effects) and nominal values of crack widths.

![Figure 1. Load-deformation behavior of typical fibre materials.](image1)

![Figure 2. Influence of deflection radius on load-bearing behavior of carbon mesh reinforcement [5].](image2)

Principles for bending design of Carbon Concrete Composite sections are quite similar to those of ordinary RC members. However, in the calculation of the design value of the tensile strength of carbon reinforcement some special influence parameters have to be considered. It is well known from research about textile reinforced concrete that reduction factors taking into account effectiveness of textile reinforcement, oblique angle between tensile stress and direction of the yarn and bi-axial...
stresses must be included in the design [8]. These findings must be adapted on bending design of carbon reinforced concrete members.

4. Production of Carbon Concrete Composite members
For the production of Carbon Concrete Composite members the following methods are most suitable: casting, laminating, spraying and injection. The most usual methods are casting and laminating when producing new members. A very high surface quality is achievable with the injection method [9]. For strengthening of existing reinforced concrete structures spraying is preferred.

Caused by the low density of carbon a new spacer generation must be developed. It is a particular problem to hold the mesh reinforcement in place when casting the concrete [10], see Figure 3. Meanwhile, new spacer systems specialized for carbon mesh reinforcement have been developed. An example is shown in Figure 4 [11].

Figure 3. Actual position of the carbon reinforcement after concreting (mean value: 11.65 mm, nominal position: 11.0 mm).

Figure 4. Spacer for carbon mesh reinforcement [11].

A particular problem in precast concrete industry is the fact that the whole technical equipment is only prepared for processing of metallic reinforcement, based on their magnetic properties. When using a non-metallic reinforcement like carbon meshes, there is a demand for new concepts for transport and arrangement of the meshes. A suitable solution consists in the application of robots.
Robots are used for the arrangement of the carbon reinforcement (consisting of meshes and, sometimes, additional bars) on the formwork table, see Figure 5. Based on a digital reinforcement draw it is possible to concentrate the carbon reinforcement by robots at positions where it is really needed for reasons of load-bearing capacity. For this reason, the carbon yarn is taken from a role and positioned by the robot arm at the formwork table. Apertures and other irregularities in the members geometry are much more easy to consider than in case of prefabricated meshes. After positioning of the yarn it is covered with an adhesive by spraying method. By the adhesive cover, the bond behavior of carbon mesh reinforcement is strongly improved. Furthermore, the meshes get a certain degree of bending stiffness preventing a movement during the concrete casting process. First results in this context are demonstrated in [12].

Figure 5. Arrangement of carbon meshes on the formwork table by robotic arms.

5. Examples for application of Carbon Concrete Composite

After a hesitant start, the application of Carbon Concrete Composite has strongly increased in construction practice in the last years. Remarkable examples for usage in precast concrete industry are:

- façade elements (at time mostly produced using alkali-resistant glass fibres)
- balcony slabs [13]
- small bridges
- precast elements like garages [7].

Especially, the construction of a pedestrian bridge in Albstadt-Ebingen/Germany was a milestone in the development of Carbon Concrete Composite [14]. It is the first entirely carbon reinforced bridge worldwide. The bridge has a span of 15 m and a width of 3 m. The applied through section has depth of only 70 mm (through walls) and 90 mm (through slab). Noteworthy is the low weight of the bridge deck with only 14 tons. The bridge was designed for a traffic load of 4,66 kN/m2.

Nowadays, for preparation of Carbon Concrete Composite’s application in other structure types, a lot of research is performed. It is estimated that it will be possible to produce double walls, roof and shell elements from Carbon Concrete Composite very soon.

A complete other topic is the application of Carbon Concrete Composite for strengthening and repair of existing reinforced concrete structures. The topic is not covered by this paper. For more information see [15].

6. Conclusions

TRC has experienced an upgrade to Carbon Concrete Composite, a new building material with outstanding mechanical and durability properties. The most important difference between TRC and Carbon Concrete Composite is the combined application of carbon fibre meshes and CFRP bars as reinforcement. Carbon Concrete Composite enables a reduction of concrete cover resulting in
decreased members’ depth and saves in this way resources and energy. After years of intensive research, Carbon Concrete Composite is on the way to get the status as an accepted and valuable applied building material.

References

[1] Holschemacher K 2017 Application of Innovative Materials in Precast Concrete Structures In: Pellicer E, Adam J M, Yepes V, Singh A and Yazdani S (eds.): Resilient Structures and Sustainable Construction Proceedings of ISEC-9 Conference (Valencia, Spain) ISBN 978-099604374-8

[2] Holschemacher K, Lieboldt M, Schladitz F, Tietze M and Bulgakow A 2019 Carbon concrete: from research to construction practice Russian Academy of Architecture and Building Sciences (RAASN) (Moscow) pp 580–591 DOI: 10.22337/9785432303134-580-59

[3] Holschemacher K 2017 Short fibers and textile mesh as reinforcing precast concrete elements International Conference and Exhibition of Concrete Technology ICCX 2017 (St. Petersburg/Russia) pp 19–24

[4] Holschemacher K, Dehn F, Müller T and Lobisch F 2017 Grundlagen des Faserbetons In: Bergmeister K, Fingerloos F and Wörner J-D Betonkalender 2017 1 pp 381–472 Ernst & Sohn, Verlag für Architektur und technische Wissenschaften (Berlin) ISBN 978-3-433-3123-0

[5] Holschemacher K, Meßerer D and Heiden B 2018 Test method for curvature-dependent tensile strength reduction of textile reinforced concrete (TRC) Proceedings of the 4th fib Symposium (Melbourne, Australia)

[6] Meßerer D, Heiden B, Bielak J and Holschemacher K 2018 Prüfverfahren zur Ermittlung des Krümmungseinflusses auf die Zugfestigkeit von Textilbeton Bauingenieur 93 11 pp 454–462 ISSN 0005-6650

[7] Deutsches Institut für Bautechnik 2018 Allgemeine bauaufsichtliche Zulassung/Allgemeine Bauartgenehmigung Z-71.3-40 (Kleingebäude, Raumzellen (Fertiggarage)) solidian GmbH

[8] Hegger J, Horstmann M, Voss S, Will N 2007 Textilbewehrter Beton Tragverhalten, Bemessung und Anwendung Beton- und Stahlbetonbau 102 6 pp 362-370

[9] Hertwig L, Ulbricht P and Holschemacher K 2018 Hochleistungs-Feinkornbetone im Injektionsverfahren In: Greim M, Kusterle W and Teubert O (eds.): 27 Workshop und Kolloquium Rheologische Messungen an Baustoffen (Regensburg) pp 173–185 ISBN: 978-3-7469-1878-5

[10] Holschemacher K, Mende K and Kieslich H 2017 Positional stability of reinforcement in carbon concrete composite members. 25th Annual International Conference on Composites or Nano Engineering, ICCE-25, Rome, Italy

[11] Wagner J, Mende K, Kraft R, Holschemacher K and Curbach M 2019 Stabanker für dünne Carbonbetonwände Beton- und Stahlbetonbau 114 7 pp 485–494 DOI: 10.1002/best.201800100

[12] Tietze M, Kahnt A, Grauer O, Rittner S, Zuben M and Schurig M 2018 Automatisierte und bedarfsgerechte Carbonbewehrungsherstellung im Fertigteilwerk Betonwerk International 1 pp 192-197

[13] Frenzel M, Lieboldt M and Curbach M 2014 Leicht Bauen mit Beton: Balkonplatten mit Carbonbewehrung Beton- und Stahlbetonbau 109 10 pp 713–725 DOI: 10.1002/best.201400056

[14] Helbig T, Rempel S, Unterer K, Kulas C and Hegger J 2016 Fuß- und Radwegbrücke aus Carbonbeton in Albstadt-Ebingen. Beton- und Stahlbetonbau 111 10 pp 676–685 DOI: 10.1002/best.201600058

[15] Schladitz F and Curbach M 2017 Carbon Concrete Composite. In: Holschemacher K (ed) Neue Herausforderungen im Betonbau (Beuth, Berlin) ISBN 978-3-410-27393-6