CU Bau specialist network (*Managing Director Roy Thyroff*) **in the Composites United e.V.**

Description: Das Bauwesen ist eine Branche, bei der das Thema Hochleistungs-Faserverbund einerseits noch nicht etabliert ist, andererseits jedoch ein enormes Anwendungspotential besteht. Um das Thema für unsere Mitglieder weiter aufzubereiten, zu vertiefen und gemeinsam voranzutreiben, dient das Fachnetzwerk CU Bau als nationale und internationale Plattform.

The construction industry is an industry in which the topic of high-performance fiber composites is not yet established on the one hand, but on the other hand there is enormous application potential. In order to further prepare, deepen and jointly promote the topic, the CU Bau network serves as a national and international platform.

Vision: Our vision is that the entire construction industry – builders, architects, planners, approval bodies and construction companies – uses construction products with fiber-reinforced concrete and polymer matrix with confidence and material requirements with appropriate approvals out of knowledge and conviction.

Mission: As a supra-regional specialist network of Composites United e.V. for its members from industry and science, our mission is to promote the acceptance and widespread use of fibre-reinforced materials in the construction industry.

Five working groups are currently active in CU Bau: * Fiber composites for new construction (Neubau) and rehabilitation (Sanierung), * Processes, procedures and digitization, * Design (Entwurf), planning, design dimensioning (Bemessung, Auslegung) and design verification (Nachweis), * Sustainability, health and circular economy and * Education, public relations and cooperation with authorities.

The author, practically, was founder of the CU- Bau specialist network and would like to present here some innovation about some present fiber-reinforced bridges.

80% of all German steel-reinforced concrete bridges are damaged, half should be replaced as soon as possible. But there is some hope to improve the situation.

Carbon fiber reinforcements have several decisive advantages over conventional reinforcing with a rusting steel: 4 x lighter (ρ = 1.8 compared to 7.8 g/cm^3 of steel), uni-axially about 6 x higher tensile strength (3000 instead of 500 N/mm^2) and no rust anymore. This results in a concrete cover of only 15 mm, so that components can remain extremely slim and thus material savings are a further advantage. Hence, the reinforcement made of carbon can be expected to have a service life that is far higher than that of reinforced concrete and thus represents a resource-saving and sustainable alternative in the construction industry. The longer service life is be taken into account especially when building new bridges. The future maintenance costs are significantly reduced by the non-rusting reinforcement. A necessary replacement is also due to the longer service life not expected, where much more than 50 years are the goal. No other material seems to be better suited for road bridge construction than carbon concrete (partly from [*Solidian, Christian Kulas*]).

Two problems faced in steel-reinforced concrete constructions such as bridges: *[partly Wikipedia]*

The alkali-silica reaction, colloquially known as concrete cancer (Betonkrebs oder Betonfrass), is the chemical reaction between alkalis of the cement stone in the concrete and aggregate (Gesteinskörnung) with so-called alkali-soluble silica. It occurs when the concrete is exposed to moisture and has been made with gravel containing too much soluble silica. → The chemical reaction between alkaline and acidic elements leads to the undesired flaking.

Under the action of water and oxygen, steel forms a slightly peeling, porous iron oxide, commonly referred to as rust. If the reinforcement begins to corrode, the associated increase in volume can lead to the concrete spalling over the corrosive steel. The reinforcement in reinforced concrete is protected against corrosion by the high alkalinity of the pore water with pH values between 12.5 and 13.5, since at such pH values a passive layer forms on the steel surface, which practically prevents anodic iron dissolution. This passive corrosion protection can be lost by chloride action such as road salt. → As corrosion progresses, the loss of substance at the reinforcement can endanger the load-bearing capacity of the structure. Statically tension-loaded steel may face under a corrosive environment (sulphide, chloride) a sudden failure due to growing micro-scopic fracture. This failure is termed Stress Corrosion Cracking SCC (Spannungrisskorrosion). Such an effect is the more faced under vibration, termed corrosion fatigue cracking (Schwingungsrisskorrosion), encountered in the dynamically-loaded bridges. Here, a further advantage of carbon-fibers comes in: Its excellent fatigue properties beside the non-corrosion.

One problem of the carbon concrete is the too low operational temperature for some application cases. This is caused by the Polymer in the FRPm (Fiber-Reinforced Polymer matrix) reinforcement element. Therefore of high importance is to replace in the next future the polymer matrix by a Mineral matrix one, obtaining a FRMm bar reinforcing element etc.

Sustainability: Another problem faced is to achieve extremely low-clinker binders, which would result in a CO_2 reduction of two thirds. There is also currently a search for a replacement of the binder cement.

1 Foot Passsenger Bridges in Albstadt, Germany

Albstadt-Lautlingen: In 2010, the longest textile-reinforced concrete bridge was opened. It is still reinforced with glass fibers, in which the breaking stress of 1000 – 1500 N/mm² is significantly lower than with carbon fibers. It is designed as a plate-beam type with a steel pre-tensioning. Two other textile-reinforced concrete bridges of this type are still standing in Oschatz and Kempten. One idea was to get away from additionally pre-tensioning.

While slab-beam bridges are linearly reinforced by bars and often pre-tensioned, here should be reinforced mainly by 2-dimensional ‘textile fiber-grid mats’ (also possible are ‘bar-grids’ from pultruded rods). The mat reinforcements are four layers in the slab and two layers in the cheeks as close as possible to the surfaces.

The design of such bridges is not yet regulated by the building authorities in Germany, which means formulated in a standard and therefore ‘approval process in single case’ (*Zustimmung im Einzelfall ZiE*) must be obtained.

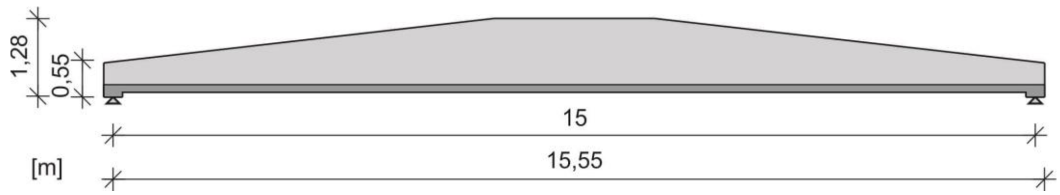
For this purpose, a design method had to be created that is based as analogously as possible on the well-known process of reinforced concrete. *This design method in reinforced concrete analogy was then to be validated by static tests. (Institut für Massivbau an der RWTH Aachen (IMB), Sergej Rempel).* While carbon behaves linearly elastically, steel becomes plastic before failure, which had to be adapted in the reinforced concrete analogy.

Albstadt Ebingen 2018

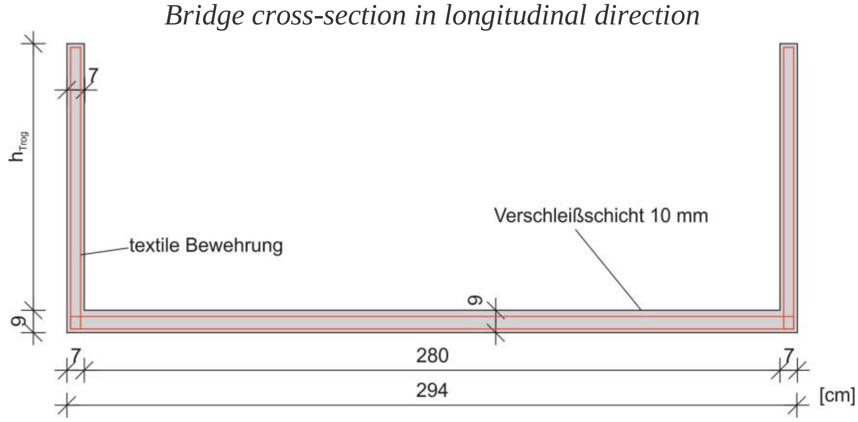
Completely without steel, the world's first carbon concrete bridge reinforced purely with carbon fibers spans 15 m. The engineering office Knippers-Helbig designed the pedestrian bridge, created the static calculations and accompanied the approval process. The lightweight construction with minimized use of materials does not require intensive maintenance, which should reduce maintenance costs and increase service life.

Passenger bridge, Albstadt Ebingen 2018: Length 15 m, width 3 m, mass 14 t.
Erection during one night ! [courtesy Solidian]

The bridge deck is designed as a trough-shaped single-span girder with a fixed and a sliding longitudinal bearing. The cheeks of the trough are 70 mm thin, their height is affine to the bending line of the beam. The railings are connected directly and flush on the walls via recessed sleeves. For the floor, 90 mm is enough. One can live without the covering, because the reinforcement does not corrode, and also without the sealing, so that the maintenance will not cause any significant costs in the future. The opening in the applied mat dictates the maximum diameter size of the aggregate in the concrete, here 8 mm. (*Thanks to Sergej and Christian*).



Bridge cross-section in longitudinal direction



Cross-section of the bridge in perpendicular direction. Carbon textile reinforcement, wear layer 10 mm

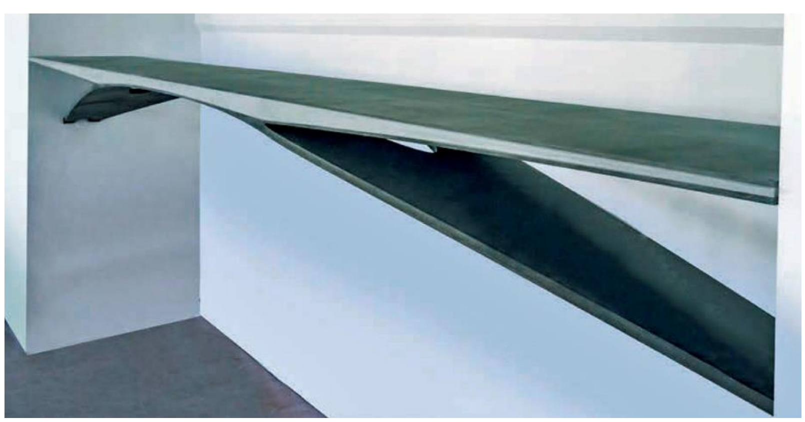
1. Rempel, S.; Will, N.; Hegger, J.: *Zukunftsweisende stahlfreie Fußgängerbrücke aus Carbonbeton*. In: Tudalit Magazin, Tudalit e.V., Nr. 15, 2016, S. 11.

2. Helbig, T.; Rempel, S.; Unterer, K.; Kulas, C.; Hegger, J.: *Fuß- und Radwegbrücke aus Carbonbeton in Albstadt-Ebingen*. Die weltweit erste ausschließlich carbonfaserbewehrte Betonbrücke. In: Beton- und Stahlbetonbau (111), 10/2016, S. 676-685. DOI: 10.1002. ISNN: 0005-9900.
3. Rempel, S.; Kulas, C.: *Fußgängerbrücke in Albstadt. Brückenbau im 21. Jahrhundert*. In: Beton Bauteile Edition 2017. Bauverlag BV GmbH, Gütersloh. 2016, ISBN: 978-3-7625-3676-5

View of the finished reinforcement cage.
From („Zukunftsweisende stahlfreie Fußgängerbrücke aus Carbonbeton". Dr.-Ing. Sergej Rempel , now Professor at Augsburg)

2 CarboLight Bridge Demonstrator (see *figure*)

The *CarboLight Bridge* Demonstrator, an ultra-lightweight construction made of carbon reinforced and infra-lightweight concrete ILC. It is a non-tensioned (slack) exhibition bridge for the bridge construction department of the Deutsches Museum in Munich. (*Courtesy: Text and figures from Marc Koschemann & Silke Scheerer, Institut für Massivbau, TU Dresden. subprojects Curbach in SPP 1542 and Stefan Gröschel, Institut für Massivbau).*



Shape-optimised CarboLight Bridge (Deutsches Museum). [Source: Ansgar Pudenz]

"Cross-section adaptation for bar-shaped compression components" and "Lightweight floor oder **slab** ? structures made of layered high-performance concretes". In addition, a structure was to be designed where the flow of force (load path) is clearly recognisable to any observer from the external shape and whose design follows the principle of form follows force. Raw density $\rho = 800$ kg/m^3. An area approximately 9.5 m long and approximately 2.0 m deep between two walls was available to present the demonstrator in the museum as an eye-catcher for construction engineers and public-relation for CarbonFiber-Reinforced Concrete CFRC. Realistic design load cases were applied.

A fully parameterized 3D model of the bridge was created with the software programmes Grasshopper in conjunction with Rhino. By programming an interface to the FEM programme RFEM, it was also possible to transfer the geometry and material data as well as loads from Grasshopper quasi-simultaneously into a FE beam model in the sense of building information modelling BIM. Trade-off studies on variants were performed. Schematic representation of the assembly steps for erecting the CarboLight bridge using the support structure; the temporary supports were height-adjustable and horizontally movable *[Source: Marc Koschemann]*.

Important findings and experience regarding concrete consistencies, processing times and formwork preparation were gathered during the fabrication and the erection of the demonstrator. Even minor deviations in the manufacturing process can influence the quality of the concrete surface. One goal was optimizing the concrete mixtures by testing various curing methods in combination with different impregnation systems. After 28 days, the supporting structure was removed. To minimize cracks due to shrinkage, surface reinforcement was provided for the columns on the bottom and top sides.

Superstructure (Brückenüberbau):

As carbon reinforcement textile SITgrid 040 (Wilhelm Kneitz Solutions in Textile GmbH) was chosen. The goal was to achieve compression stresses over the whole cross-section for all load combinations. For the superstructure with a biaxially curved underside, a sandwich three-layer structure consisting of two 20 mm thick carbon reinforced concrete face layers and a core layer of ILC.

The superstructure was mainly calculated for bending and shear force. The uniaxially oriented carbon textile SITgrid 040 was chosen for the underside, mainly because of the dominating curvature in the transverse direction. This textile has a reinforcement cross-section of 141 mm^2/m in the longitudinal direction and 28 mm^2/m in the transverse direction, which ensures the required fexibility of the reinforcement mesh. The characteristic yarn tensile strength is 2,200 N/mm^2 [4]. The upper, flat carbon reinforced concrete layer was reinforced with one sheet of solidian GRID Q95/Q95-CCE-38. This textile has a higher inherent stifness and thus offers advantages for positionally accurate installation in plane sections. The calculated load-bearing capacity could be provided with sufficient certainty for both reinforcement layers.

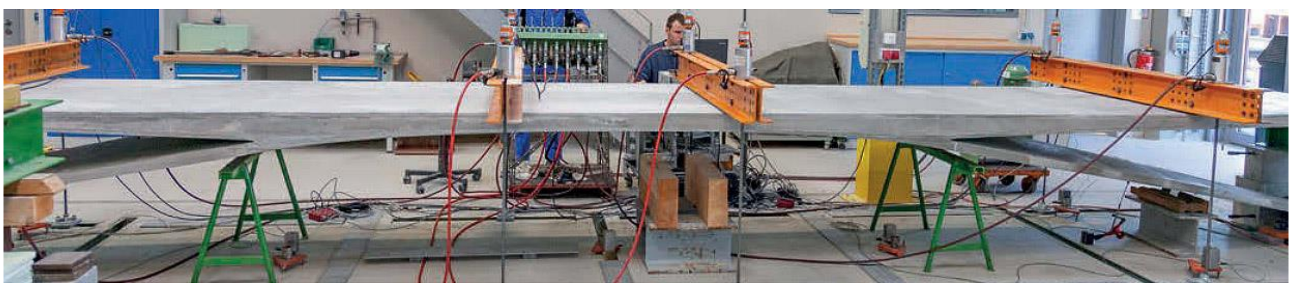
Regarding the sandwich core, the load-bearing capacity of the interface between the layers had to be verified.

The formwork planning was based on the 3D model of the demonstrator. The production of individual formwork parts from solid plywood panels using 3D milling technology was carried out by the HICONFORM company.

Fabrication: The mortar mixture had to guarantee a dense and pore-free structure as far as possible, had to be pumpable and flowable and remain workable for at least 30 min Problems similar to SMC fabrication and the path-oriented, extrusion head-placed mortar strand process. The workability of usually pumped concrete has a slump (Ausbreitmaß) between 50 mm and 100 mm. A concrete of less than 50 mm slump is impractical for pumping, and in the case of a slump above 125 mm, the aggregate will segregate from the mortar and cement paste. Setzverhalten, Konsistenz). To maintain the concrete cover of about 10 mm, DistTex spacers were used

Compression-loaded inclined plates, (Druck-Scheiben): Column kann man nicht nehmen. Verstehen andere Ingenieure nicht.

Filigree FRC parts: Bending superstructure width 1.20 m, 3.0 side spans, 3.6 m center span. 2.1 t Buckling endangered compression columns, inclination 17.5 °. Quelle © Ansgar Pudenz: Self-compacting mortar



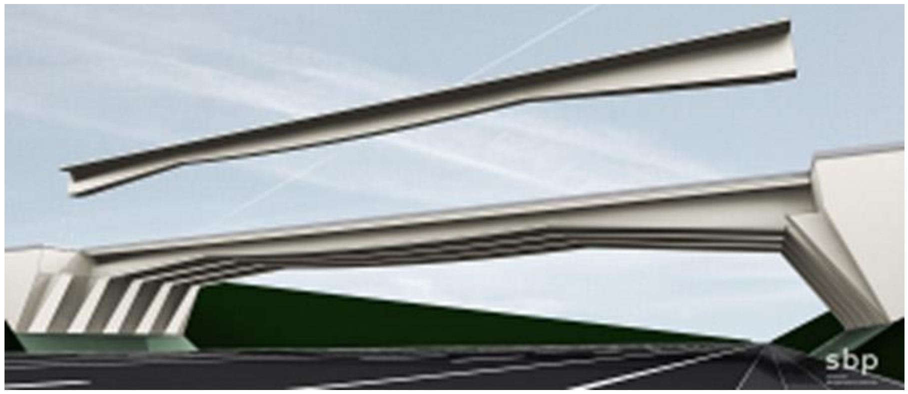
Testing of the bridge at Dresden

3 First integral pre-tensioned carbon concrete bridge

At the TU Berlin (*Mike Schlaich, Professor of design and construction, civil engineering, partner in bureau sbp*), the world's first integral pre-tensioned carbon concrete bridge was built for research purposes. This exhibition bridge is the neighbouring bridge.

To pre-compress concrete (*official term is pre-stress*) in order to better exploit the concrete material so-called tendons are used. A tendon is basically a cable or a multi-roving fiber strand used in pre-compressing structural elements such as beams, columns, plates. According to the construction method, there are generally three types to pre-stress concrete: (1) Pre-tensioned Concrete (*tendons are tensioned from the beginning, then concrete is poured),* (2) Un-bonded Post-tensioned Concrete and (3) Bonded Post-tensioned Concrete (*concrete is poured first, tendons are then tensioned*).

TEXT Konstruktionsdetail fehlten „Herr Gröschel. Gibt es da offizielle Literatur?“ . Echtes Foto noch. Welches Vorspannverfahren?



3D-visualization of the integral overpass bridge built of semi-finished pre-tensioned carbon concrete parts © sbp. (Deutsches Museum)

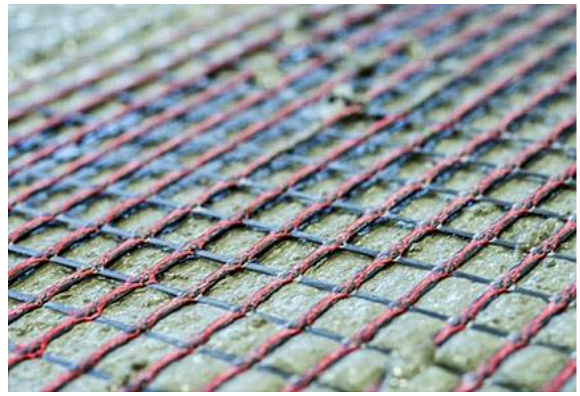
4 Release Bridge Rplacement (Ersatzneubau) in Wurschen, Landkreis Bautzen, 2022

A replacement of the bridge of the state road S 111 near Wurschen (district of Bautzen) was opened to traffic. The former steel-reinforced concrete structure from 1934 was replaced by the first carbon-concrete bridge in the Saxon road network. The bridge is therefore also approved for heavy goods traffic with a vehicle weight of more than 40 tons. The findings gained within the framework of the project substantiated by continuos measurements shall be incorporated into future projects. The use of carbon concrete leads to a significant saving of raw materials and thus represents a sustainable alternative in the construction industry. The superstructure of this bridge consists exclusively of carbon concrete

The reinforcement consists of both rods and mats made of carbon fiber reinforced plastic and is non-rusting The reinforcement consists of both rods and mats made of carbon fiber reinforced plastic and is non-rusting. Both rods and mats made of carbon were used for the bridge.

The C³-Association initiated the project together with the Saxon State Ministry of Economic Affairs, Labour and Transport (SMWA), the State Office for Road Construction and Transport (LASuV) and the LISt Gesellschaft für Verkehrswesen und ingenieurtechnische Dienstleistungen mbH. The planning, execution and supervision was carried out by the members of the C³ association: CARBOCON GMBH, Curbach Bösche Ingenieurpartner, Hentschke Bau GmbH and Technische Universität Dresden. The carbon reinforcement was supplied by Action Composites Hightech GmbH and solidian GmbH.

The very load-bearing, carbon reinforcement can be expected to have a service life that is far above today's reinforced concrete constructions and thus represents a resource-saving and sustainable alternative in the construction industry. Due to the longer service life with considerably lower maintenance costs in the future, there are corresponding cost advantages



Bridge Wurschen: (left) *Superstructure made exclusively of carbon concrete, shell construction. (right) Textile FRP mats in the super-structure) (Foto: Stefan Gröschel, IMB,TU Dresden)*

Besseres FOTO Brücke im Verkehr??

Bridge Wurschen: (left) *Shell construction from top.*
(right) Truck on the ready bridge) (*Foto: Sächsische SZ de,* © Uwe Menschner) Besseres Foto??