

# **CARBOrefit® - STRENGTHENING WITH CARBON REINFORCED CONCRETE – SUSTAINABLE, RESOURCE-EFFICIENT AND DURABLE**

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Global events have shown that climate protection is the issue of the moment - also for the construction sector! In order to initiate the change that is now urgently needed, future-oriented processes are required. The material carbon reinforced concrete offers a promising possibility. With carbon reinforced concrete, sustainable and resource-saving constructions are possible not only in the area of new construction, but also in strengthening. This has already been demonstrated several times. Especially in the field of renovation and strengthening of existing structures, carbon reinforced concrete has immense potential to strengthen and maintain structures and thus save them from demolition. The preservation of existing structures - as opposed to demolition and replacement - must always be strived for; this is the only way to achieve truly long-term ecological constructions. A new and improved approval with the name CARBOrefit® - Process for Strengthening Reinforced Concrete with Carbon Reinforced Concrete makes it possible to reinforce structures more efficiently and thus to save material. As a result, buildings are not only protected from demolition, but can also continue to be used sustainably. A recent comparison to a conventional shotcrete reinforcement has shown that with the use of carbon reinforced concrete more than 50 % of CO<sub>2</sub> emissions and 85 % of material can be saved.

*Keywords:* Approval, Carbon grid, Innovative technology, Change in construction.

## **1 INTRODUCTION**

The topics climate change, environmental protection, sustainability, and the use of resources are universal. In many industries around the world, innovative solutions are being developed and forward-looking approaches are being demonstrated. Carbon-reinforced concrete is one of the key technologies in the construction industry that can be used to initiate change and make construction more sustainable. In 2016, the technology was awarded the German Future Prize. This award honors outstanding technical, engineering and scientific achievements that lead to application-ready products. Carbon reinforced concrete has enormous potential especially in the area of strengthening or refurbishment, to restore existing structures in a resource-saving and efficient way. Construction projects such as the strengthening of a highway bridge at the Frankfurt A648/A5 intersection over the Nidda (Steinbock *et al.* 2021) and the strengthening of the landmarked *Hyparschale* in Magdeburg (Hentschel *et al.* 2019, Riegelmann *et al.* 2020) show that the transfer of the high-performance material into application has taken place. A normative regulation for the area-wide application has been lacking until this day. With the issuance of the

new general technical approval 31.10-182 CARBOrefit® - Method for the reinforcement of reinforced concrete with carbon concrete (abz / aBG 2022) by the *Deutsches Institut für Bautechnik* (German Institute for Construction Technology - DIBt), architects and planners are now provided with a tool that enables sustainable, stock-protecting and economical solutions.

## 2 THE PRINCIPLE OF STRENGTHENING WITH CARBON REINFORCED CONCRETE

The composite material carbon reinforced concrete combines the two high-performance materials concrete and carbon reinforcement. In the specific case of refurbishment or reinforcement, this results in a perfect symbiosis. The carbon grids transfer the tensile stresses and, due to their corrosion resistance, the reinforcements require only minimal concrete cover to transfer the bond stresses. The fine-grained concrete in the reinforcing layer ensures adhesion to the old concrete and the transfer of forces from the carbon grids to the old concrete. Moreover, carbon reinforced concrete can be used to strengthen the compression zone/area of existing steel reinforced concrete structures. In this case the fine-grained concrete increases the load capacity of the compression zone.

In the case of structural reinforcement, fine-mesh carbon grids are generally used. Figure 1 shows the basic structure of a carbon concrete reinforcement.

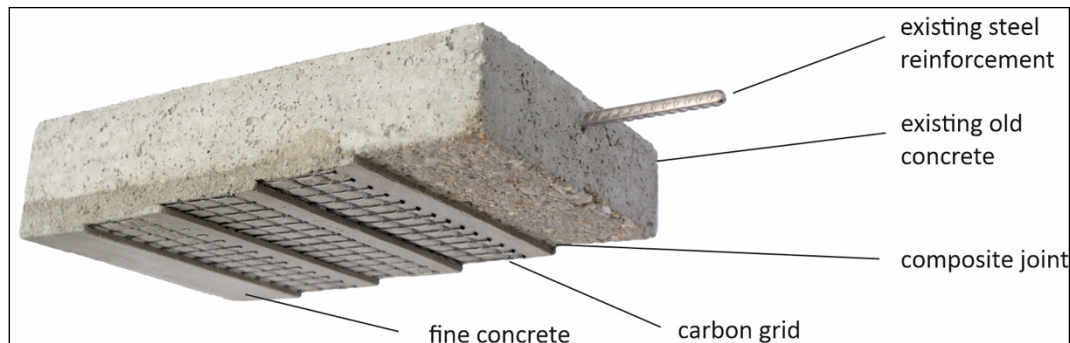


Figure 1. Structure of a reinforcing layer with carbon reinforced concrete (Photo: C. Gärtner, TU Dresden).

In the reinforcement process, the carbon grids are applied to the concrete surface in layers alternating with the fine-grained concrete. First, a layer of fine-grained concrete (generally 3 – 5 mm thin) is sprayed on and the carbon grid is worked in. The process is repeated until the desired number of layers is achieved. The existing surface is pretreated in advance using established methods until a sufficiently roughened old concrete surface is obtained. In contrast to conventional shotcrete, there is no need to dowel the joint, which is why a sufficiently roughened and pre-branched surface must be ensured for carbon reinforced concrete so that force transmission in the composite joint is guaranteed. Depending on the static requirements, up to 6 layers (Steinbock *et al.* 2021) of carbon grids can be applied. As a rule, however, 1-2 layers of carbon grid are sufficient to restore existing buildings in structural engineering, which corresponds to a total strengthening thickness of 10 - 15 mm. Thicker concrete covers are not required, as the carbon reinforcement does not need to be protected from corrosion even at higher exposures. Its high durability, a service life of more than 100 years, a fast construction process and a reinforcement method that is gentle on the existing structure (by dispensing dowelling) are just some of the advantages of reinforcing with carbon concrete and makes it more than

competitive compared with conventional reinforcement measures, not only technologically but also economically.

### 3 THE FIRST GRANTED APPROVAL BY THE BUILDING AUTHORITIES

In 2014, the DIBt issued the general building authority approval (*allgemeine bauaufsichtliche Zulassung abZ*) with the number Z-31.10-182 and the designation "Method for reinforcing steel concrete with TUDALIT® (textile-reinforced concrete)". The granting of the first approval for the reinforcement of structural elements with textile concrete in 2014 was a significant milestone for carbon reinforced concrete, as the approval was preceded by years of basic research. The 2014 approval allowed for measures in interior areas with up to 40 °C and 65 % humidity. The reinforcing layer was only to be applied in the tensile zone and for reinforced concrete components that do not require shear reinforcement in terms of calculation. The characteristic adhesive tensile strength of the old concrete had to be at least 1.0 N/mm<sup>2</sup>. The old concrete had to be a normal concrete with a strength class of less than C50/60.

Under the old approval, a special kit consisting of a fine-grained concrete and one carbon grid was approved by the building authorities. The previous restrictions on the use of carbon concrete as a reinforcement material exist only at the formal level. With the help of approval in individual cases (*Zulassung im Einzelfall ZiE*), carbon concrete can already be used in exterior applications. This is demonstrated, for example, by the reinforced hypar shell in Magdeburg. These formal limits are to be successively eliminated with the aid of the extension of the general approval and the approval for outdoor use extended.

### 4 NEW CONSORTIUM AND NEW APPROVAL FOR STRENGTHENING WITH CARBON REINFORCED CONCRETE

In June 2021, a strong consortium of 8 highly competent and experienced companies in the field of carbon concrete joined forces to significantly advance the development of carbon reinforced concrete for the reinforcement of existing components. In the course of this, the "old" approval was transferred to its new applicant CARBOCON GMBH (coordinator and contact person for the approval in the new consortium).

Further companies are project or associated partners in the consortium from 2021:

- CHT Germany GmbH (impregnation manufacturer)
- Hitexbau GmbH (grid manufacturer)
- Lefatex-Chemie GmbH (impregnation manufacturer)
- PAGEL® Spezial-Beton GmbH & Co. KG (concrete manufacturer)
- Wilhelm Kneitz Solutions in Textile GmbH (grid manufacturer)
- Teijin Carbon Europe GmbH (fiber manufacturer, associated partner)
- TUDATEX GmbH (grid manufacturer, associated partner)

In the course of the new consortium and the takeover of the old approval, the aim was to define a new, more versatile and thus better applicable approval to further exploit the potential of carbon reinforced concrete in the field of strengthening or refurbishment. The approval was also renamed into "CARBOrefit® - Process for strengthening reinforced concrete with carbon reinforced concrete" (abz / aBG 2022).

Once the new approval was granted by the DIBt at the end of 2021, new, higher-performance carbon grids can now be used by building authorities and efficient solutions can be planned. In addition to the extension of the approval to additional material combinations, one of the fundamental changes of the new approval is that the planner can plan and design according to

fixed properties in the same way as for reinforcing steel and can select the most suitable carbon grid for the respective construction project. The carbon grids listed in the approval are classified into 3 predefined types, which in turn have fixed properties.

For the user, this means that he can select the most suitable carbon grid for the respective construction project and carry out the necessary verifications with the specified characteristic values of the carbon grid types. As a result, an individual decision can be made depending on the application, e.g., whether a soft or a stiffer carbon grid is required, and the most economical solution can be found. The following Table 1 shows the material properties of each grid type.

Table 1. Summary of important mechanical parameters.

Grid type	Type 1	Type 2	Type 3
Tensile strength (char. value)	$\geq 1550 \text{ N/mm}^2$	$\geq 1950 \text{ N/mm}^2$	$\geq 2250 \text{ N/mm}^2$
Design value of tensile strength	$768 \text{ N/mm}^2$	$967 \text{ N/mm}^2$	$1300 \text{ N/mm}^2$
Bond strength (char. value)	$\geq 4.0 \text{ N/mm}$	$\geq 7.0 \text{ N/mm}$	$\geq 10.0 \text{ N/mm}$
Design value of bond strength	$0.564 \text{ N/mm}$	$2.6 \text{ N/mm}$	$4.7 \text{ N/mm}$
Anchorage length at full design value	2450 mm	670 mm	500 mm

In addition to the classification of the carbon grids into the three types, the prescribed grid geometry has been eased in the new approval. Thus, in addition to the already established standard design, further special designs may be used. This allows even more individual and economical solutions for the respective construction projects, e.g., by selecting a carbon grid with a smaller cross-sectional area for a lower load factor. Figure 2 shows an example of the standard design and a possible special design. The option of choosing between a standard or special design applies to all three types. Depending on the requirements, the grids can be produced with a main bearing direction, usually the warp direction, but also for a biaxial bearing direction. A biaxial design of the carbon grids is not permitted in the current approval status, but in the long term it will be part of the approval.

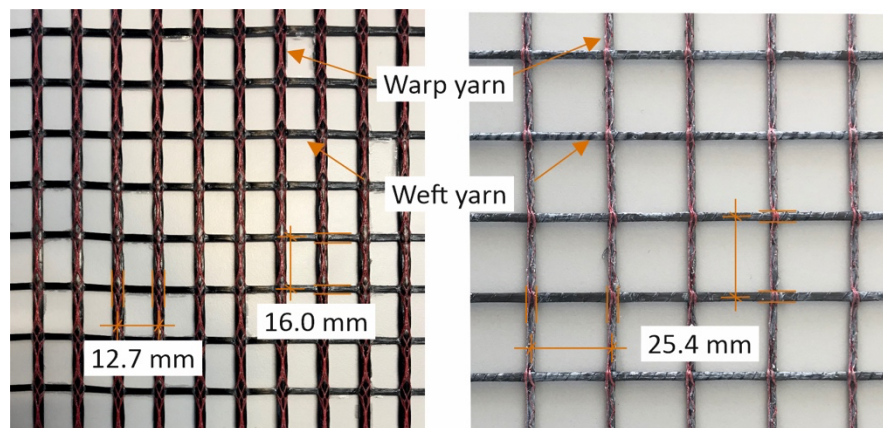


Figure 2. Structure of a reinforcing layer with carbon reinforced concrete (Photo: M. May, CARBOCON GMBH).

The new and extended CARBOrefit® approval provides more options for all parties involved in the use of carbon reinforced concrete in the field of refurbishment and strengthening. Compared to the previous approval, three different carbon grid types with different properties are

regulated. This means that the planner can, for example, take into account the specific conditions of the existing structure and select the type of grid that represents the most economical and efficient solution for the project in question. At present, the scope of the CARBOrefit® approval covers the uniaxial flexural reinforcement of the tension zone of reinforced concrete members that do not require any shear reinforcement. Several layers of carbon reinforced concrete can be used to reinforce the bending tension zone. The number of layers depends primarily on the existing load-bearing capacity deficit and the type of carbon mesh used.

Furthermore, currently only interior components under predominantly static load may be reinforced up to a maximum temperature of 40 °C and a relative humidity of 65 %. The components to be reinforced must have an adhesive tensile strength of at least 1.0 N/mm<sup>2</sup> (char. value) and the properties of the old concrete must be in the range of a concrete strength class ≤ C50/60.

As far as the concrete is concerned, the *abZ* regulates the use of the fine-grained concrete TF10 from the manufacturer PAGEL®. The fine-grained concrete produced as dry mortar consists of cement, silica fume, fly ash and quartz sand and has a maximum grain size of 1 mm. The following Table 2 shows the material properties.

Table 2. Properties of the fine-grained concrete (DIN EN 196-1 2005).

<b>Char. Compressive strength (28 d)</b>	<b>Char. Flexural strength (28 d)</b>	<b>E-Modul (28 d)</b>
≥ 80 N/mm <sup>2</sup>	≥ 6 N/mm <sup>2</sup>	≥ 25,000 N/mm <sup>2</sup>

## 5 MONITORING OF CARBOrefit®-COMPONENTS AND EXECUTION

To guarantee the quality of strengthening measures with carbon reinforced concrete in the context of the approval, the entire process is monitored and controlled from material production to execution.

The manufacturers of the carbon grids and fine-grained concrete are certified by a testing institution and can then manufacture the products regulated by the approval. In order to continuously check reproducibility, the manufacturers carry out a factory production control. The properties of the products are compared with the required characteristic values of the approval and are marked with a symbol of conformity. The certified testing institute carries out external monitoring at the manufacturer's premises every six months. The results of the factory production control are checked on the basis of random sample tests and the quality of the materials is independently assessed and confirmed.

In addition to the monitoring of the kit components, the approval and the DIBt also regulate the monitoring of the companies carrying out the execution. Before companies and their construction staff are allowed to process the reinforcement system in real construction projects, they have to pass and successfully complete an obligatory qualification test. The applicant for approval (CARBOCON GMBH) trains the companies in a 2-day seminar. In the theoretical part, the basics of the composite material carbon reinforced concrete, the principles of dimensioning and instructions for application are explained. In the practical part, the participants are taught how to handle the components of the kit as well as the spraying equipment necessary for the application of the fine-grained concrete. A certified inspection authority assesses the execution of the reinforcement work and checks the quality of the carbon concrete reinforcement. By using different test methods, material parameters are determined and compared with the required characteristic values. After successful training, the executing companies and their employees receive a certificate proving their suitability. The certificate is issued for 3 years and can be



extended by attending a refresher course and listing practical projects in which carbon reinforced concrete was used.

Quality control on the construction site is guaranteed on the one hand by self-monitoring of the executing companies and on the other hand by external monitoring by a certified inspection authority. The companies keep a report on the progress of construction and record relevant material parameters themselves or through subcontracted companies. The inspection authority monitors the execution and checks whether the required characteristic values have been achieved. With the constant quality assurance and improvement of the technology, further important points are being researched and optimized parallel to the granted approval. Currently, the separation of the components of the composite material is already technically possible. Further studies are now to optimize the recycling of carbon concrete beyond separation to the use of the waste for further circular economy. The handling of higher temperatures and the overall material performance are also to be further improved.

## 6 CONCLUSION

Sustainable and resource-saving technologies are needed to drive the transformation of the construction industry. Carbon reinforced concrete has excellent mechanical properties and is corrosion-resistant. In the application area of strengthening, renovation and maintenance of existing structures, this potential is being tapped and the change initiated. With the new, revised and supplemented approval, planners and architects can develop efficient solutions in the area of strengthening, with the use of carbon reinforced concrete, the climate goals can be achieved and a long-term security of existence can be guaranteed. Construction projects such as the reinforcement of the highway bridge over the Nidda (Steinbock *et al.* 2021), the *Hyparschale* in Magdeburg (Hentschel *et al.* 2019) and the historic footbridge *Thainburg* in Naumburg/ Saale have shown that the transfer of carbon reinforced concrete as a material has taken place and that economical solutions can be implemented.

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