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Article

Contribution of Carbon Concrete Construction to the Circular and Resource Economy

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Abstract: Fibre-reinforced composites are used in many industries. In the construction industry, for example, the building material carbon concrete is increasingly being used successfully. Although the demand for fibre-reinforced composites and fibre-reinforced plastics made of carbon fibres has risen continuously by approximately 11% per year over the last 10 years, there is currently still no coherent integration of fibre-containing waste into the corresponding material cycles. In addition, there are ever-increasing requirements for environmental and climate protection, which necessitate a transformation from linear waste management to a cycle-oriented recycling and resource management overall. Carbon concrete construction is already providing an important impetus for the construction industry. The use of reinforcement made of mat or grid-shaped and bar-shaped carbon fibres basically makes a significant contribution to the conservation of resources, and ultimately a reduction in CO2 emissions of up to 80% is possible. In connection with recyclability, it is demonstrated that with today's common facilities, both the deconstruction and dismantling of components and structures made of carbon concrete and the collection and sorting of the demolition material using camera-based sorting with a grade purity of 98% are already possible. In addition, the article provides an outlook on the project WIRreFa | WIR! recyceln Fasern (We recycle fibres) and its approach to closing the material cycle of fibre composites.

Keywords: carbon concrete composite; fibrous waste; construction industry; carbon concrete construction; fibre composite; carbon fibre; circular economy; recycling; material cycle; secondary raw material; transformation

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1. Introduction | Importance of Returning Fibre-Containing Secondary Raw Materials to the Material Cycle

Fibre-reinforced composites and fibre-reinforced composites plastics are becoming increasingly popular in Germany and worldwide and are used in all areas of life. Depending on the area of application, different raw materials such as carbon (CFC), glass (GFC) or basalt fibres are used. The spectrum ranges from ultra-light spectacle frames to household and leisure appliances (21%), wind energy (14%), the automotive and marine industries including transport (24%), the aerospace industry including defence (36%) and increasingly the construction industry with the use of carbon concrete (5%) [1].

Carbon concrete is a composite material consisting of concrete and a non-metallic reinforcement made of carbon or carbon fibres (carbon). The reinforcement in turn consists of a carbon-based fibre, coating and impregnation. The decisive factor is that the design of the reinforcement is both mesh or grid-shaped and bar-shaped, while short fibres mixed into the concrete are not part of the carbon concrete. The highly load-bearing, non-rusting carbon fibre reinforcement can be expected to have a service life that is far longer than today's reinforced concrete structures and therefore represents a climate-neutral alternative in the construction industry. The carbon concrete construction method also allows low maintenance costs over the entire life cycle of a building, savings of up to 80% in raw materials, a reduction in CO_2 emissions of up to 50% and a filigree design in concrete construction. The carbon concrete construction method ultimately helps to significantly reduce the impact of concrete construction on the environment and people.

For all industries, the annual demand for carbon fibres in Europe alone has risen from 19,000 t (2011) to over 52,000 t (2021). The annual demand for glass fibres has also risen from 2,369,000 t to 2,910,000 t in the same period [2]. At the same time, the quantity of fibre waste has been increasing significantly for years. It can be assumed that more than 34,000 t of carbon fibres and more than 1,594,000 t of glass fibres will be recycled across Europe in 2025 alone (Figure 1) (inspired by [2]). Glass fibres have also seen an increase in annual demand from 2,369,000 t to 2,910,000 t over the same period [2]. At the same time, the quantity of fibre waste has been increasing significantly for years. It can be assumed that in 2025 alone, more than 34,000 t of carbon fibres and more than 1,594,000 t of glass fibres will be recycled across Europe (Figure 1) (inspired by [2]).

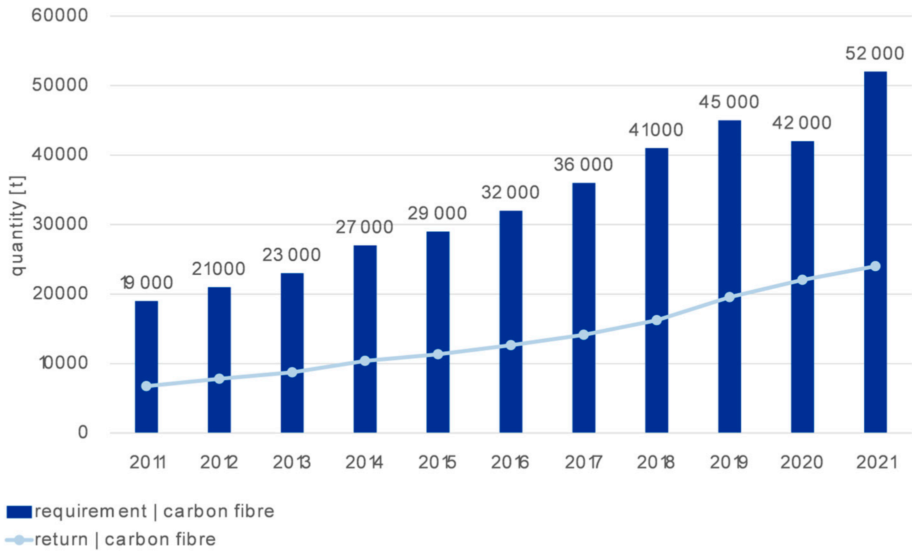

Figure 1. Development of the annual demand and the annual amount of waste containing carbon fibres in Europe from 2011 to 2021, inspired by [2].

Fibre-containing waste is generated as soon as components of fibre composites cannot be directly reused. Waste is generated not only at the end of the use phase but also during the production of fibres and yarns, the manufacture of semi-finished products and the fibre composites themselves. This fibre-containing waste is not yet an integral part of a closed material cycle, so these available and at the same time still high-quality secondary raw materials have so far remained unused. There is a lack of suitable recycling routes.

In order to establish the use of recycled fibres in the sense of high-quality material recycling on a nationwide basis, the technical and organisational processes for the material cycle must be created. This also includes offering further marketable products made from recycled fibres. There is still a need for development here. In the specific case of carbon fibres, the construction industry is already providing decisive impetus with the carbon concrete construction method so that the transformation from linear waste management to a circular economy can succeed in Germany.

2. Challenges and Knowledge Gaps in Returning Fibre-Containing Secondary Raw Materials to the Material Cycle Using the Example of Carbon Concrete Construction

Since the 2010s, the advantages of fibre composite have increasingly been used in concrete construction. The carbon concrete construction method combines concrete and non-metallic reinforcement. The reinforcement usually consists of a carbon-based fibre, a coating and an impregnation and can be either mat or grid-shaped and bar-shaped. In contrast, short fibres are not added to concrete [3].

The use of carbon concrete can already contribute to climate-neutral buildings (Figure 2), both in new constructions and in renovation, repair and reinforcement. Compared to reinforced concrete, up to 80% of the material (sand, water and cement; in some cases, no surface protection system is required) is saved, and the costs for loading and transporting the materials or prefabricated parts are significantly reduced. In addition, components and structures made of carbon concrete are said to have a service life of up to 200 years. When refurbishing existing structures with the use of carbon concrete, objects in need of refurbishment in building construction and civil and structural engineering can also be structurally preserved. Other refurbishment methods cannot usually be used due to additional weight requirements or monument protection. In these areas of application, a reduction in CO_2 emissions of up to 80% is already possible with carbon concrete [4]. This is also important because the construction of buildings and infrastructures and their management alone release around 37% of energy- and process-related CO_2 emissions worldwide [5].

Figure 2. Applications of carbon concrete in building construction and civil and structural engineering, © C^3 Verband.

With the political ambition of making the building stock in Germany climate neutral by 2045 [6], such climate-neutral approaches will become increasingly important in the construction industry, especially since there are currently no alternatives to concrete as a construction material that can meet society´s demand across the board. For example, the construction industry cannot switch completely to wood as a construction material because the world's forests cannot grow back sustainably to a sufficient extent [7]. Irrespective of this, according to the Kreislaufwirtschaftsgesetz (KrWG, Closed Substance Cycle Economy Act), natural resources must be conserved and people and the environment must be protected in the generation and management of waste [8]. The resulting measures determine the political direction of the coming years. The Freistaat Sachsen (Free State of Saxony) and its subordinate political levels have therefore committed themselves in accordance with § 10 SächsKrWBodSchG to contribute in an exemplary manner to achieving the goals of the circular economy, even if this results in additional financial costs and reductions in insignificant use properties to an acceptable extent [9].

At the same time, the topic of sustainability is increasingly becoming the focus of social discussion, which goes hand in hand with a higher environmental awareness in society. This leads to an increasing demand for sustainable products that can be reused even after the end of their initial use phase. Products that do not have a viable recycling potential will have difficulty remaining on global markets in the future. If it is not possible to establish reliable concepts for recycling and the use of recycled fibre products in the market, the fibre composites companies will face economic challenges in the medium and long term. This also applies to carbon concrete construction, which is currently growing strongly.

Finally, stakeholders from the construction industry in particular must expect that in the future, climate-neutral construction methods will be increasingly demanded or promoted both in public tenders and in private contracts. It can also be assumed that life cycle assessments will be required for certifications (for example for a sustainable building through BNB or DGNB certification). Thus, decisions on climate-neutral construction materials or constructions will have to be made at an early stage of planning [4], which would also have a decisive influence on the proportion of reinforcement made from (recycled) carbon fibres.

Within the framework of the research project $C^3 \mid C^3$—Carbon Concrete Composite (duration 2014 to 2022) [10]—the most advanced research and development work in the construction industry to date—it was shown that the essential prerequisites for the circular and resource economy approach already exist in Germany. However, the technical-scientific status in the individual phases of the material cycle of carbon concrete is still at different stages of development [11,12]:

- Production phase: On the economic side, this phase is characterised by a high degree of maturity, which is reflected, for example, in the extraction of fibres from different starting materials (basalt, carbon, glass, etc.), the manufacturing of fibres with different morphological structures (AR glass, pitch- and PAN-based fibres, etc.), the production of semi-finished products with organic and inorganic surface coatings (epoxy resin, styrene-butadiene rubber, thermoplastics, etc.) and the production of semi-finished products and fibre composites with various structures and shapes (mat- or grid-shaped and bar-shaped, fleeces, etc.) as well as products (semi-finished and finished components for building construction and civil and structural engineering). On the other hand, on the scientific side, there are topics such as the sustainable extraction of carbon fibres based on the renewable raw material lignin, extracting CO_2 from the air, production from polyethylene or by generating lipid-rich algae biomass, development of fire-resistant coatings and the production of components made of carbon concrete from recycled materials.
- Use and application phase: Stakeholders from the economy already have different applications for materials in new construction projects (floor slabs, façades, precast garages, etc.) and in refurbishment, repair and reinforcement (of structures, bridges, canalisations, etc.), which ultimately determines the requirements for the materi-

als. The characteristics of the materials depend on the production process. At this point, stakeholders from the scientific community are focusing on the advancement of processes for approval and the creation of guidelines.

- Demolition and recycling phase: This phase again depends on the quality of the previously used materials. The state of the art for carbon concrete construction is essentially based on the state of the art for the recycling of conventional materials made of plastic, wood and mineral components. In contrast, the state of the art goes a step further, as evidenced by the demonstrable dismantling and deconstruction of constructions with fibre composites, the successfully practised collection and sorting of fibre composites in the construction industry (camera-based sorting, etc.) and the processing of the fibre composites (pyrolysis, solvolysis, combination with thermoplastic fibres, etc.) for reuse in the manufacture of new semi-finished products and products (production of yarns from recycled carbon fibres, etc.).

The major challenge and knowledge gap is to transfer the new results and knowledge into practice and to make them sustainable. This also means that the previous individual solutions of the stakeholders from the industry (isolated solutions) must be brought together. In particular, the upstream and downstream processes between the individual phases of the material cycle must be coordinated with each other, whereby initial points of contact have already been successfully created in recycling, for example. Solving the knowledge gap is a necessary prerequisite for the recycling of carbon concrete to be implemented in construction practice in the future and for the cycle to be closed.

3. Characteristics of the Recycling of Fibrous Secondary Raw Materials Using the Example of Carbon Concrete Construction

For a good introduction to the topic "Recycling of carbon concrete", it is necessary to define the term recycling and to delineate it as a fixed process. In a broadly interpreted view, the recycling of construction materials can include the following substeps:

- Collecting the waste materials (for example in special waste containers);
- Carrying out necessary pre-treatment measures (for example, shredding or pre-sorting the waste);
- Preparation of the materials (for example by sorting); and
- Processing these secondary raw materials into a new product (for example, adding the recycled material to the production process) [13].

At this point, however, the term recycling is considered more narrowly and is based on the definition according to the German KrWG [14]. According to this, recycling means

> "... any recovery operation by which waste is processed into products, materials or substances either for the original or for other purposes; it shall include the processing of organic material, but shall not include recovery of energy and processing into materials that are to be used as fuel or for backfilling."

This means that the incineration of waste should generally not be considered as recycling. Rather, after recycling, all waste should ideally be usable at the same material quality level that existed in the course of the first material use. In the construction industry, the same material quality level is achieved by the direct reuse of components that have been dismantled without damage in other constructions with the same function. However, this is only very rarely possible. For example, it is very rare for entire wall or ceiling components to be dismantled and reused as elements in the same form in new constructions [15]. If a component cannot be dismantled without causing damage and then be reused, the construction material should be recycled. In the case of material recycling, the properties of the material are used again. Therefore, the crushing and the processing of the materials as well as the pure separation of the material fractions are of great importance [16].

In addition, further measures are necessary in the recycling process, such as keeping the waste separate at the point of origin. This can be ensured on the construction site, for example, by using different waste containers for metal or wood or, in this specific case, for waste containing fibres. The aim of all these measures is to keep the quality level of the material at the highest possible level during recycling and to prevent so-called downcycling. Downcycling means that waste is processed into recycled material that has a much lower material quality or processability compared to its first use as a material [17]. Another example of downcycling is the use of a high-grade recycled material in low-grade applications where the material properties are not fully utilised. This applies, for example, to high-strength recycled concrete material used for backfilling underneath roads.

If the conventional metallic reinforcement for concrete construction is at least partially replaced by mat- or grid-shaped and bar-shaped reinforcement made of carbon fibre, this will have a direct influence on the conventional process for demolition and recycling. The processes used in the recycling of reinforced concrete are well known and have been tested in practice. In particular, the separation of metallic reinforcement from demolished reinforced concrete components is efficiently implemented with magnetic separators [18]. The constructions already built from carbon concrete and the annually increasing consumption of carbon fibres and carbon fibre-reinforced plastics (see Section 1, predicted annual growth rate in the construction industry is around 10%) show that large quantities of carbon fibres will be used in construction in the future.

The largest quantities of building material waste are generated when demolition work is carried out on buildings or construction components. Demolition then often means the demolition of the entire building at the end of its life cycle with the removal of all technical or structural installations without leaving any residue [16]. Demolition work, however, is not limited to the removal of structures at the end of the building's life cycle or during the conversion of a building but also concerns the actual construction-related process of the building when, for example, concrete drilling and cutting technology are used to make openings in the structure. All of these processes already generate waste in the manufacturing phase that has to be recycled. As a result, waste is already being generated from carbon concrete construction activities. This waste material must be recycled. In order to implement high-quality recycling, the goal must be to use the already existing efficient techniques and technologies for recycling, which have been developed in the fields of waste management and primary raw material extraction [18].

There are legally required recycling quotas for recycling. For example, non-hazardous construction and demolition waste must be recycled at 70% by mass [19], and plastics must be removed at 85% by mass [20]. In order to meet these requirements, the carbon fibres must be detached from the concrete by suitable treatment processes and separated from the concrete in a subsequent treatment process. For the recyclability of the construction material carbon concrete, it is therefore very important that its components, concrete and reinforcement made of carbon fibres, can be efficiently separated from each other.

With regard to the recycling of carbon concrete, until now the commercially available equipment for demolition and crushing has been used. When buildings made of carbon concrete have to be removed, the demolition and crushing of the carbon concrete construction components results in precrushed fragments of carbon concrete and partly already separated fragments containing reinforcement (1st preparation; Figure 3a). For further crushing, the material has to be processed by a crusher (2nd preparation). In order to be able to pour the fragments into a processing plant, the fragments have to be crushed to a defined size (Figure 3b). For further crushing, a jaw crusher with an integrated magnetic separator can be used, which was also used in the presented research design for the processing of reinforced concrete material. In a practical test, the fragments were crushed to a maximum size of 56 mm. The crusher has a capacity of about 100 tonnes per hour. The resulting crushed stone in the size 0/56 can be used to produce crushed stone base layers and frost protection layers. For high-quality recycling, however, the material must be further processed, and the concrete must be separated from the reinforcement made of carbon fibre. The maximum grain size of 0/56 is well suited for further tests on the separation of fractions.

Figure 3. (**a**) Demolition with a concrete pulveriser, (**b**) pre-shredded demolition material made of carbon concrete, (**c**) result of camera-based sorting of carbon concrete containing demolition material, © Jan Kortmann.

As a result of the crushing, the carbon fibres were dissolved from the concrete in a heterogeneous heap. The little fraction of metallic material, such as transport anchors or connecting bolts, could be separated in the jaw crusher with the magnetic separator. The fear that a large part of the fragmented reinforcement made of carbon fibres would remain connected to the concrete was not confirmed. This material fraction of concrete with still bonded reinforcement made of carbon fibres is present only very sporadically and has a mass fraction of less than 1% of the total mass. For the further process of recycling, the experimental proof is thus provided that the reinforcement made of carbon fibres can be completely disconnected from the concrete matrix with a conventional mobile crushing plant. As a result of the tests, a disconnection separation result of more than 99% was determined.

For the sorting of the still-mixed demolition material, numerous sorting methods were examined in experiments for their suitability for the separation of residues containing reinforcement from the demolition material. The resulting data were used to objectively and verifiably evaluate the separation processes within the framework of a utility value analysis. The methods investigated included cross-flow sifting, eddy current sifting, floating-sink sorting, manual picking, near-field infrared sorting and camera-based sorting. In the following, a method for the successful separation of reinforcement from carbon fibres from the mix, which was deemed particularly suitable after the evaluation, is presented [21].

Camera-based single-grain sorting is presented as a best practice example. The separation process of camera-based single-grain sorting was carried out in an experiment at the company TOMRA Sorting GmbH. The aim was to answer the question of whether the residues containing reinforcement can be removed from the demolition material. Various criteria, such as colour, shape and composition, were used as distinguishing features. In the event that the target fraction (reinforcement-containing residues) was successfully identified, this material was then blown out of the demolition material by means of directed compressed air pulses in a targeted and sorted manner. In this case, the "geometric shape" was defined as a distinguishing feature. The characteristic "geometry" promises a high degree of reliability for material recognition, since external influences (excessive dust accumulation etc.) do not lead to a falsification of the results. This would be the case, for example, with the feature "colour".

For the definition of characteristic shape values, a representative sample of the 0/56 material was added to the camera sensor. In the recognition software, a minimum boundary line in rectangular format was virtually modelled around each recognised body, with the help of which the characteristic values "toolbox width" and "toolbox length" were determined. The geometric differentiation of the fractions is very well possible. The particles of the concrete are specimens with a particle size of less than or equal to 0.125 mm up to concrete lumps with a size of up to 56 mm. This particle group shows a compact cubature in the detection. The width-to-length ratio is in the 50% quantile with a balanced ratio of 90%. The fraction containing carbon fibre residues is comparable to a pencil-shaped specimen and is generally elongated in one dimension. The ratio of particle width to particle length is at the 50% quantile with a low ratio value of 9%. In the first sorting run, a very good sorting result of 97.7% was achieved without pre-treatment (Figure 3c).

The result of the investigation is in line with the literature on the performance of camera-based sorting systems. For example, a purity of up to 99.7% can be achieved when sorting white glass from mixed glass waste [22]. The throughput capacity of camera-based sorting systems is given in the literature for particle sizes from 3 mm to 250 mm with 2 tons/h to 10 tons/h [18]. A throughput of 10 tons per hour of demolition material containing carbon concrete can be achieved in the tested plant with consistently good quality. For higher throughput rates, camera-based sorting machines from the processing of primary raw materials from the mining industry can also be used, which work with a chute feed and double-sided detection. With these sorting machines, significantly higher throughputs could be achieved than with the tested belt machine.

With the best practice example, it was demonstrated that the demolition of components made of carbon concrete can be implemented in construction practice and that the crushing with the almost complete disconnection of the fragments containing reinforcement from the concrete matrix is successful with conventional machine technology. Processes for separating the fractions by type also exist and fulfil the necessary requirements for large-scale implementation.

For complete recycling, the separated fractions must be recycled. According to the guideline of the Deutscher Ausschuss für Stahlbeton e. V. (DAfStb; German Committee for Reinforced Concrete), "Concrete according to DIN EN 206-1 and DIN 1045-2 with recycled aggregates according to DIN EN 12620" [23] and up to a volume share of 45%, the crushed mineral concrete can be added into the production of fresh concrete. The fine fraction of the concrete up to 0.15 mm can also be recycled to a high quality [24]. The fraction from carbon fibres is first processed by means of pyrolysis or solvolysis. The recycling scenarios for the processed carbon fibres range from simple injection moulded components to the production of fleece and high-quality staple fibre yarns with a proportion of recycled carbon fibres. The results refer to the use of bar-shaped and lattice-shaped reinforcements made of carbon. Short-fibre concretes are not the subject of the investigation. The investigation also refers only to carbon reinforcements with an epoxy resin matrix. Soft matrices made of elastomers are not the subject of the investigation.

According to the results, recyclability is already basically possible with the existing technical plants and processes. The separation of the individual components and the subsequent sorting of the mineral and fibrous waste is practicable. Accordingly, the secondary raw materials could be returned to the material cycle. However, the results also show that the technology readiness level (TRL) of the individual plants is not yet all at a comparable level. Another complicating factor is that the processes are not yet coordinated. Consequently, there may be material shortages that are neither suitable for recycling nor for thermal recovery. Furthermore, there is currently often a lack of sufficient quantities of recycled materials that are economically viable. Ultimately, this in turn complicates measures to optimise the technology and processes and to bring the stakeholders together.

Nevertheless, it can be concluded from the evaluation of the results that the use of non-metallic reinforcement and, more specifically, mat- or grid-shaped and bar-shaped reinforcement made of carbon fibres is a sustainable approach for the construction industry. On the one hand, its use in building construction and civil and structural engineering can significantly save resources and reduce CO_2 emissions. On the other hand, the recyclability of this construction method offers all the prerequisites for returning the materials to the material cycle. In view of the new legislation in the Federal Republic of Germany, this opens up new perspectives for making building more sustainable.

4. Approach to Closing the Material Cycle of Carbon Concrete via the Project WIRreFa | WIR! Recyceln Fasern (We Recycle Fibres)

In order to close the existing knowledge gap in the material cycle, the stakeholders involved in the project WIRreFa | WIR! recyceln Fasern (We recycle fibres) are committed to closing the material cycles that are still open (Figure 4) [25]. The region "Elbtal Sachsen (Elbe Valley Saxony)" will be the model region for carbon and glass fibre-reinforced material waste for the Freistaat Sachsen and the neighbouring regions. Against the background of a high concentration of regional know-how, the region "Elbtal Sachsen" offers an optimal basis for the development of a sustainable alliance for the circular and resource management of fibre-reinforced materials. It is characterised in particular by its openness to innovations and adaptability in the textile, mechanical engineering and lightweight construction technology sectors. Since the end of the 20th century, a targeted process of restructuring of the industry has been taking place since the resident stakeholders from business and science have concentrated on the knowledge-intensive field of technical textiles and also, specifically, on carbon concrete construction.

In the sense of structural change, the stakeholders are gradually creating new impulses for regional development in the areas of business, science, politics and society, in particular through new areas of application for the sustainable use of recycled carbon fibres (Figure 5). Against the background of the continuously increasing demand for fibre composites made of carbon fibres and the resulting increasing amounts of fibre-containing waste (Section 1), with a simultaneous increase in the requirements for environmental and climate protection in the construction industry (Section 2), the technological and process-related achievements in recycling (and reprocessing) in recent years (Section 3) require an even more coherent approach. Furthermore, there is still a lack of regulations, approvals, and links between the intermediate steps in the material cycle and the networking of relevant stakeholders for the integration of secondary raw materials and, more specifically, recycled fibres. The project WIRreFa is initially focused on the construction industry and the use of recycled fibres for carbon concrete construction. The construction industry's efforts to be able to build in a more climate-neutral way in the short term are decisive. In addition, the requirements for products made of fibre-reinforced composites with regard to mechanical properties and aesthetic appearance are more flexible than in other sectors.

Figure 4. Phases of the material cycle of carbon concrete including examples of technological availability, © C^3 Verband.

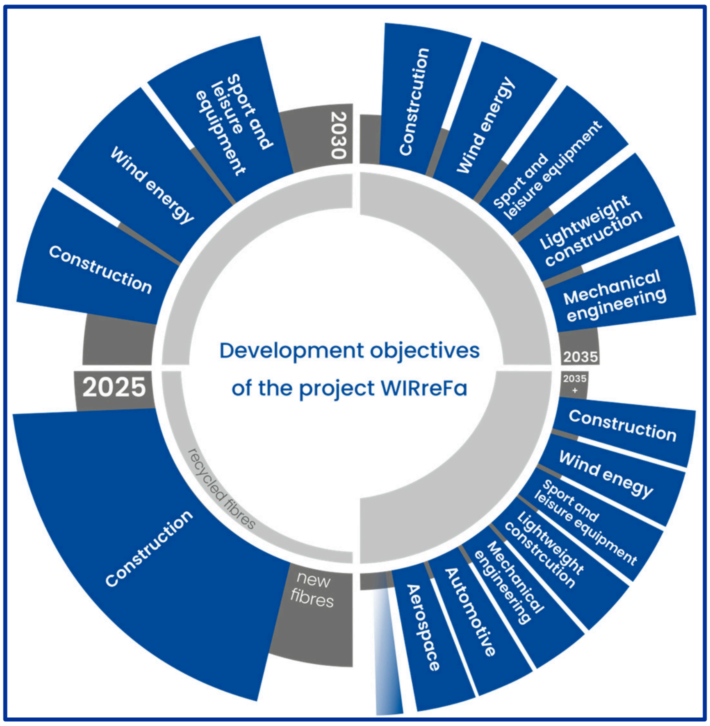

Figure 5. Development objectives of the project WIRreFa (short-, medium- and long-term), © C^3 Verband.

In the first phase of the project WIRreFa, waste containing fibres will be processed in such a way that recycled fibres can already be used in the short term for practical and thus marketable constructions with a narrow range of requirements. In this way, they can already make their contribution to reducing CO_2 emissions and the primary raw materials required in the construction industry. Mat- or grid-shaped and bar-shaped reinforcement made of carbon fibres, which are used in concrete construction mainly because of their resistance to corrosion, must be load-bearing and durable. However, there are no visual requirements or demands for low weight for the time being. Even a reduced load-bearing capacity of the recycled fibres can be easily compensated by a higher number of fibres and thus an increase in the cross-section. In the end, however, a structure should be created that closely links the processing of recycled fibres and the development of products from recycled fibres.

In the medium term, recycled fibres will be used in the second phase of the project WIRreFa for constructions whose requirements profile is significantly higher than for the constructions in the first phase. For example, optical requirements will be met by a combination of new fibres on the outside and recycled fibres on the inside of the construction. Further-developed recycled fibres with an increased load-bearing capacity should enable use in constructions where a clear focus is placed on the reduction in weight (constructions for railways etc.).

At the end of the project WIRreFa (third phase), the application of recycled fibres will be extended to as many areas as possible—including those with the highest demands and thus analogous to new fibres (wings of aircraft, etc.). High-quality and materially pure recycled fibres are needed that can be used to substitute primary raw materials. This includes the material quality of the waste fractions and the authority to act through securities within the regulatory framework.

Finally, the circular and resource economy for fibre composites developed in the region "Elbtal Sachsen" strengthens local development opportunities by complementing existing processes in the circular value chain and initiating new developments instead of outsourcing them from the region "Elbtal Sachsen". This improves regional (economic) resilience and variability and creates long-term prospects for growth and employment in Germany.

To summarise, it can be concluded that the current work carried out to recycle carbon-reinforced concrete provides a valuable basis for initiating and establishing an economic material cycle for recycling. The practical realisation of the cycle is to take place with the WIR project that has been launched. The results that will be developed as part of the research project to close the cycle will put carbon-reinforced concrete construction on a sustainable base and serve to increase its use.

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