THE AUTOMATED MANUFACTURING PROCESS OF BUILDING ENVELOPES USING THE EXAMPLE OF CARBON-REINFORCED CONCRETE

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As a result of climate change, more ecological building materials are continuously developed and find their way into the construction industry. These new building constructions also require new manufacturing technologies. Using examples from research and industry show how partial and complete automation can be used for the practical and individual series production of facade elements made of new building materials such as carbon concrete. The focus is on the complete internal production of some subcomponents. Thus, on the analogy of the production of steel reinforcement on-site in the precast plant, reinforcements made of textile-based materials can also be produced individually in a circulation process down to batch sizes of one without trimming and therefore without waste. The dependence on intermediate product manufacturers can be eliminated and supply bottlenecks avoided. This rethinking of their plant production enables precast producers to manufacture economically and ecologically optimized reinforcements from carbon fibers and integrate them into their circulation process. This adapted production of semi-finished and finished parts made of carbon concrete is implemented similar to the production of precast reinforced concrete elements on existing plant components. Here, too, examples from research and industry are used to demonstrate the need for adaptation in the conventional manufacturing process.

Keywords: Building automation, Textile-reinforced concrete, Facade elements, Sustainable building.

1 INTRODUCTION

Over the past decades, innovations have continuously emerged in materials and component research adopted by the construction industry. Thus, the use of textile reinforcement materials has also found its way into the semi-finished and finished parts industry. The production of conventional components made of reinforced concrete is primarily implemented on automatic production lines. These enable the production of a wide variety of components with individual properties and dimensions. However, it is not possible to use textile formwork as an alternative to steel on these lines. The processes within the production lines have been optimized for steel, and the formwork and concreting processes are designed accordingly as well. Textile-reinforced concrete elements such as curtain wall elements are still produced in manual production (Hülsmeier et al. 2013). The placement of inserts and attachments on the concrete elements is mostly done manually (Tietze et al. 2018). Due to the high proportion of manual labor, the production costs of these facade elements are far higher than those of automated production. This article is intended
to show possible solutions from industry and research for fully automated production of carbon concrete elements for facades. The aim is to produce carbon-concrete elements in a more cost-efficient and material-saving way in the future.

2 INITIAL SITUATION

Manual production — To produce two-dimensional curtain wall elements from textile concrete, the production techniques of manual lamination, casting or concrete spraying are usually used. It is not possible to maintain the required exposed concrete quality continuously at the same level with all these processes. For example, the reinforcement structure can show on the concrete surface in the casting process as shown in Figure 1. The spraying process is suitable for textile concrete, but the shear force can damage the carbon fibers during the spraying. Thus, this manufacturing process is not always the best option. Production by lamination is the most delicate process (Kahnt et al. 2016).

Figure 1. Showing of the reinforcement on the concrete surface.

Figure 2 shows a sketch of the process sequence as it is currently implemented in most cases. At the beginning of the actual concreting, the formwork is produced. In the case of facade design, a large number of different plate geometries are often available. Due to many ‘small batches’, the formwork is mostly made manually of wood. Then the laminating process begins. The concrete and carbon textile are placed in the formwork in layers. This layer structure generates the required component thickness. In a separate step, the carbon gel is cut to the required dimensions. After curing, the facade panel is removed from the formwork, and the attachments for fastening to the structure are fitted either in the factory or on-site. The required fastening points in the facade panel are inserted either during concreting or after curing.

Due to the lack of automation, individual processes—in particular the fabrication of carbon reinforcement—are mainly implemented manually. This has a cost-increasing effect on the final price of the components. Another disadvantage of the current production chain is that the carbon fabrics can only be purchased as rolls or sheets. These circumstances show how quickly a shortage of material can arise. The extremely sensitive carbon rovings can also be damaged during transport to the end-user. For example, as seen in Figure 3, a complete visual inspection of the material quality cannot be done when the rolling stock is delivered. In the worst case, reinforcement sections inside the rolls are unusable due to material damage. This results in follow-up costs due to increased material consumption. In addition, waste is produced while trimming the mesh for the required sizes. The remaining offcuts cannot be reused. This is a far away from ecological and material-efficient production.
Figure 2. The process sequence of conventional production of facade elements made of carbon concrete.

Figure 3. Bent longitudinal fiber.
3 SOLUTION APPROACHES

Automatic production — To achieve the cost- and material-efficient production of facade elements made of carbon concrete, individual process steps have to be reviewed and reevaluated.

Figure 4. The process sequence of automated production of facade elements made of carbon concrete.

Figure 4 shows one possibility for a fully automated process flow. After digital planning of the facade elements, the data are transferred in time with the process steps of formwork and reinforcement production. For the geometric dimensions of the concrete carbon elements (thinner slabs than conventional), newly adapted formwork elements will be used, which can also be handled by formwork robots. The process step for producing the formwork is divided into three sub-processes. A robot is used to create a clamping frame on which the reinforcement is placed. This tensioning frame defines the geometry and the course of the carbon reinforcement yarns. This yarn comes from a carbon yarn spool using a robot. This process involves online coating with the desired resin matrix. When the reinforcement has been placed down entirely, it is subjected to annealing process. This cures the resin, and the carbon fabric achieves its full load-bearing performance. At the same time, the first concrete layer is placed in the formwork. The fixed reinforcement is detached from the clamping frame by a robot and placed on the first concrete layer. A second concrete layer is applied afterwards. The component is now fed into the setting process.
After curing, it is again fitted by a robot with attachments, e.g., for fastening the facade. The automatic manufacturing process is thus completed, and the pieces can be prepared for transport. Within the research of the Institute for Concrete Construction at the University of Applied Sciences, individual solutions for complete automation in carbon concrete production have already been developed in recent years. Here, the focus is also on the production of reinforcement structures directly at the point of use. For example, a coating and clamping module was developed, which can be connected as an attachment tool to various robot kinematics. It can be used to place carbon yarns of different designs in precise positions according to the desired reinforcement layout. The module is equipped with a continuous 2K resin impregnation system. This means that the yarn can be coated online with the desired resin system directly during the placement. Currently, deposition speeds up to 0.5 m/s are possible, and the production speed is optimized.

The yarn is placed via previously positioned deflection points on a tensioning frame. These can be used to set the desired mesh size of the carbon scrim. After the yarn has been placed and the endpoints have been fixed, the scrim is subjected to an annealing process. This gives the scrims dimensional stability and makes them easier to process.

![Mechanical fastening of the flange nuts to the reinforcement by robots.](image)

Furthermore, solutions have been developed for fitting the facade elements with inserts and attachments (see Figure 5). Flange nuts, used for later attachment of facade installation systems, are attached to the carbon scrim directly before concreting (Grauer 2019). The flange nuts are installed at the nodal points of the scrim, which prevents displacement in the x- and y-directions. The threads of the nuts are equipped with plastic blind screws to prevent concrete penetration during concreting. After the concrete has hardened, this reusable screw is removed, and the fastening system can be installed.

4 DISCUSSION

Basically, it can be said that the implementation of such new manufacturing processes for reinforcements directly in the precast concrete plant can increase its productivity. This includes, for example, the new possibilities to quickly produce desired reinforcement geometries on site according to specific orders, and material savings of up to 40% can be achieved with the help of
this production of carbon reinforcements compared to the conventional variant (externally produced semi-finished products in the form of rolls or layers). The production of reinforcement yarn impregnated at an instantaneous speed of 0.5m/s allows a production speed of ~ 0.8m²/min for mesh sizes of 5 cm. Compared to the production speed of multiaxial warp knitting machines depending on parameters such as the textile construction or the coating agent with ~ 2.5m²/min to 7.5m²/min (1-3m/min), the production speed of the new manufacturing technology is far below that of multiaxial warp knitting machines. Nevertheless, it must be distinguished that in the process described in the article, the production of the jelly in its geometry and the impregnation with 2K resin systems are carried out in one operation. Products of multiaxial warp knitting machines are only coated with aqueous dispersions and must be impregnated in the downstream process. Accordingly, production speeds must be reduced again. The investment costs for the machines are also much higher, which ultimately affects the price of the product. In sum, it is necessary to consider the variety of geometries of the facade elements and which way is the most economical and ecological for one's own requirements. If the duration of the production of own reinforcements can be well integrated into the factory's own cycle times, economic and ecological improvements can certainly be achieved in the overall process of facade production.

References