WRAPPING PROCESS FOR BUILDING COMPONENTS MADE OF GLASSFIBER- AND TEXTILE-REINFORCED CONCRETE

FABIAN KUFNER, PETRA RUCKER-GRAMM, and MICHAEL HORSTMANN

Dept of Architecture, Civil Engineering and Geomatics, Frankfurt Univ of Applied Sciences, Frankfurt, Germany

In the research project WiFaPu (wrapping process for highly fiber-reinforced concrete using the example of a pump sump) a wrapping process has been developed that combines the advantages of glassfiber-reinforced concrete and textile-reinforced concrete in terms of manufacturing processes and composite load-bearing behavior. In this process, a fine-grained concrete is sprayed with chopped-in short fibers on a carrier sheet and the textile reinforcement to produce a thin glassfiber- and textile-reinforced concrete layer with a defined thickness. This layer is continuously wrapped up onto a formwork to obtain a pump sump with an arbitrary cross-sectional thickness. The paper reports on the challenges in the development of the wrapping process and the associated coordination of the material components to produce durable members with monolithic blow-hole cross sections, acceptable surfaces and a reduced CO\textsubscript{2} footprint. Pump sumps are produced as demonstrator components of the process. Their load-bearing capacity as well as their suitability for use are investigated in component tests. According to the experimental load tests, components with a high load-bearing capacity are produced. Filling tests show the overall high-water impermeability of the thin-walled components. This is made possible by fine-grained concrete with low water penetration depth and very small crack widths.

Keywords: Spray process, Casting process, Short fibers, Pump sump.

1 INTRODUCTION

Glassfiber-reinforced concrete (Meyer 1973) components are manufactured either by spraying or extrusion (Fig. 1a and b) (Bartos 2008). Components made of textile-reinforced concrete are often produced by casting (Fig. 1c) in pre-reinforced formworks (Tomoscheit et al. 2011) or concrete and textiles are inserted in layers using a lamination process (Scholzen et al. 2007, Hegger et al. 2011, Hegger et al. 2012). In both methods, the precise positioning of the textiles within the thin-walled component cross-sections and the introduction of high reinforcement contents are challenging. For the casting method, textiles with spacers securing a sufficient concrete cover to the surface of the component and spacer textiles, in which the distance between the reinforcement layers is ensured (Fig. 1c), were developed. However, high reinforcement contents cannot be realized with spacer textiles using the casting process and so far required the lamination process (Fig. 1d) (Curbach and Ortlepp 2011), in which the accuracy of positioning the textiles in the cross-section depends on the layer accuracy and the concrete consistency.
The wrapping process (see Fig. 1) for short-fiber-reinforced textile concrete components addresses the deficits of the aforementioned methods and extends them to the extent that three-dimensional, preferably rotationally symmetrical components with high reinforcement content, any thickness and a smooth surface next to the inner formwork can be produced, while no smooth outer surface is required for the components, e.g., for pump sumps, small sewage treatment plants, cisterns, recess bodies, etc. The same inner formwork core can be used for components with different cross-sectional thicknesses, e.g., to be able to react to different load situations. The width of the wrapped layer can correspond to the outer dimensions of the wrapped body. However, stripes of smaller widths can also be wrapped, for example to apply stripe-shaped reinforcements or structurally required thickenings such as buoyancy protection in partial areas. Casting premixed short-fiber concrete in members with a thin cross-section results in lower fiber contents on the one hand and less controllable alignment on the other. By spraying thin, textile-reinforced concrete layers with a total thickness of just a few millimeters, reinforcement can be placed precisely and in large quantities in the cross-section if needed. By spraying, the short fibers are also aligned in the layer plane and thus optimally aligned with the direction of stresses (2D). The glassfiber- and textile-reinforced concrete layer is continuously wrapped up onto a formwork.

2 DEVELOPMENT OF THE WRAPPING PROCESS AND PRODUCTION OF PROTOTYPES

2.1 Properties of the Materials Used

2.1.1 Fine-grained concrete

The fine-grained concrete meeting the requirements of the wrapping process was developed based on an existing mixture from the project partner eFBe. The concrete with a maximum grain size of 2 mm is characterized by a flexural strength of $f_{cm,fl} = 9.8 \text{ N/mm}^2$ and a compressive strength of $f_{cm} = 73.6 \text{ N/mm}^2$. A suitable stiffness and sufficient cohesion of the concrete are required. This was adjusted iteratively via the type/dosage of superplasticizer and the spraying of setting accelerators.
2.1.2 Textile reinforcement, short fibers and carrier material

An uncoated AR glass textile (Fig. 2a) was designed based on structural designs of the sumps. Although promising better tensile strength an epoxy resin coating was deliberately not considered due to better sustainability and better wrappability. Short fibers with lengths of 15 and 30 mm were chopped-in at the spray head using an integral AR glass fiber roving (Fig. 2b) to reduce cracking. An alkali-resistant (AR) glass short-fiber fleece (Fig. 2c) consisting of approx. 50 mm long short fibers and a water-insoluble bond were selected as the carrier material for the short-fiber-reinforced textile concrete layer.

Fig. 2. a) Textile reinforcement, b) short fibers made of AR glass roving and c) AR glass fleece.

2.2 Process for Producing the Wrapped Layer

The suitability of the developed concrete for the wrapping process first has been investigated and evaluated on a laboratory scale using a simple wrapping model (Fig. 3a). The concrete was applied in a casting process. The penetration through and the bond to textile were depending on concrete consistency and fiber content. For the practical scale concrete casting of the wrapped layer was not pursued any further since it was not possible to achieve an economical, continuous production process. Therefore, the spraying process was preferred. The fine-grained concrete is pumped to a spraying head where chopped fibers are blown into the concrete spray. The prototype production line (Fig. 3b) is a combination of a conveyer belt and a spray booth in which a spray head moves on a portal perpendicular to the conveyer belt. The speeds of both conveyer belt and spray head, the pump feed of the concrete to the spray head and the feed of the endless roving for cutting and blowing the short fibers into the spray jet can be varied. To produce the wrapped layer, an a few meters long short-fiber concrete layer is sprayed onto the AR glass short-fiber fleece carrier layer, the belt is retracted, the textile reinforcement is inserted and another short-fiber concrete layer is sprayed on top. Good experiences in the wrapping process have been made with overall thicknesses of the wrapped layer of 6-8 mm. The accuracy of placing of the textile reinforcement within the concrete section has met the expectations.

Fig. 3. a) Laboratory-scale test setup and b) prototypical production line with wrapping station.
2.3 Development of Formwork and Wrapping Mechanism

The wrapping tests were carried out for rectangular and cylindrical pump sumps. As it was initially planned to produce the pump sump floor in advance, a cradle in the form of a reeling device (usually for wrapping up cables) was used as a wrapping station, which was connected to a forklift and equipped with a manual drive (Fig. 4a). The formwork for the rectangular pump sump consisted of a rigid wooden inner core an external polyurethane (PUR) jacket. The wrapping tests onto the rectangular form were not successful since the short-fiber-reinforced textile concrete layer was difficult to wrap around the corners due to the non-synchronization of conveyor belt and wrapping station. Wrapping the layer from above (Fig. 1) or with more tensile prestressing on the carrier material did not solve the issue sufficiently. Thus, the majority of the production tests were carried out with a cylindrical formwork that was easier to wrap. With the manual drive, a synchronization of conveyor belt and wrapping station still was not satisfyingly achieved. In addition, the cantilever construction of the wrapping station was not stiff enough and resulted in large deformations of the formwork. To enhance wrapping results, a pinned through axis with supports on both sides was used, which lost the advantage of adding the floor slab directly before or after production of the sump walls. By placing the collar of the PUR jacket on the conveyor belt with lifting hydraulics located on top of the supports finally a sufficient synchronization could be achieved. As the materials and above-described processes were fine-tuned, the wrapping results of the pump sumps continuously improved (see Fig. 4b). The layer thicknesses, the bond between the wrapping layers and the inner and outer surfaces achieved satisfying qualities. The at last produced pump sumps provided also a wrapped buoyancy protection. The pump sump floor slabs were cast in a second work step after the concrete of wrapped walls has hardened.

![Fig. 4. a) Wrapping station and b) the wrapping results.](image)

3 THEORETICAL STUDIES ON THE PUMP SUMP DEMONSTRATOR

The evaluation of an extensive parameter study using finite element calculations on the structural design of thin-walled pump sumps for different intended uses has shown that in the case of cylindrical pump sumps, due to the rotational symmetry and the favorable membrane load-bearing action in the walls, even low wall thicknesses of 2 cm and lower textile reinforcement levels are sufficient. Significant bending moments only occur near the floor slab. Besides the structural performance also aspects of sustainability are important to the project team. A theoretical comparison with common systems on the market revealed the following properties for the wrapped pump sumps: Plastic pump sumps with low dead weights (approx. 58 kg with a thickness of < 1 cm) tend to shift when the adjacent base slab is concreted and to float in the event of pressing groundwater. A powerful crane is required for the installation of prefabricated pump sumps made of reinforced concrete (approx. 910 kg with a wall thickness of 12 cm). The demonstrator pump sump weighs around 149 kg with a wall thickness of 2.8 cm and represents an excellent compromise between the weight and material advantages of concrete. Production using short-fiber-reinforced...
textile concrete with the developed fine-grained concrete used can save around 32% primary energy and 35% Global Warming Potential compared to the steel-reinforced concrete variant.

4 EXPERIMENTAL LOAD-BEARING CAPACITY TESTS

The load-bearing capacity of the pump sumps was mainly investigated by load tests on the floor slab (Fig. 5a). The bigger the slab height and the static effective height (Fig. 5b), the larger the bending load-bearing capacity of the floor slab. Due to the centric loading, rotationally symmetrical, finely distributed crack patterns were obtained in floor slabs with at least two textile fabrics (Fig. 5c). As expected, the load-bearing capacity was increased by adding additional textile layers. In saw cuts the reinforcement in the area of the wall supports was found to be lifted up to the upper surface close due to the production method of the floor slab. Thus and because of the reinforcement lap in Fig. 5b) low clamping moments were transferred. This results in a larger stiffness and load-bearing capacity (Fig. 5c, PS3). The load-bearing capacity of the wrapped buoyancy protection was not achieved in a field test (Fig. 5d).

![Fig. 5. Experimental load-bearing capacity tests on pump sumps.](image)

5 EXPERIMENTAL USABILITY TESTS

The water impermeability of the thin-walled uncracked cross-section and the water penetration through possible cracks are of key importance for the serviceability of pump sumps. Fig. 6 displays the results of filling tests on four specimens. Each specimen has been filled with 300 liters of water for three days. In contrast to small concrete samples for standardized water absorption tests, where water absorption only occurs through the uncracked concrete, the water loss in the pump sumps is also influenced by the effects of the wrapping process like cavities within the wrapped wall cross-section, by possible cracking as a result of shrinkage and water pressure as well as by the subsequent connection of the sump floor slab (see Fig. 5b). The latter leads to a non-monolithic joint that is weak part of the demonstrator (see Fig. 6). The most recently produced pump sump PS4 with the highest execution quality but still including some cavities within the wall section is very close and almost parallel to the theoretical water absorption curve (see Fig. 6). Cavities significantly occur at the area of the first overlay. In the PS2 test specimen, a significant larger water loss is measurable, but still less than 2% of the filling volume. Overall, the filling tests show satisfactory water impermeability despite the low wall thickness and due to the self-sealing potential of the observed very fine cracks.
CONCLUSIONS

The article proofs that the wrapping process is a manufacturing method that on the one hand has a high potential for the production of rotationally symmetrical components with high reinforcement ratios and accurate reinforcement placement in the cross-section, but on the other hand formulates high requirements on the capability of the applied materials in accordance with the process. The following points should be addressed in further investigations:

- Reducing the CO₂ footprint of the fine-grained concrete and adapting the pumping/spraying technology to cement-reduced formulations,
- integrating the floor slab production into the wrapping process to obtain a monolithic member without joints,
- synchronization of wrapping station with prototypical production line and tightening tension for the carrier layer in order to further minimize cavities within the section during wrapping – especially in the first overlay.

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