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A Mechanical and Rheology Development of a Fiber-Reinforced Architectural Concrete for the Poseidon Building in Frankfurt am Main

Henrik L. Funke[1]

Abstract

In the course of revitalizing the Poseidon Building in Frankfurt, an energetically optimized façade, made of architectural concrete was developed. The development of a fiber-reinforced architectural concrete had to consider the necessary mechanical strength, design technology and surface quality. The fiber-reinforced architectural concrete has a compressive strength of 104.1 MPa and a 3-point bending tensile strength of 19.5 MPa. Beyond that, it was ensured that the fiber-reinforced high-performance concrete had a high durability, which has been shown by the capillary suction of de-icing solution and freeze thaw test with a weathering of abrasion of 113 g/m² after 28 freeze-thaw cycles and a mean water penetration depth of 11 mm.

Keywords: fiber-reinforced concrete, durability, CDF-Test, high-performance concrete

1. Introduction

Apart from designing claddings, the focus in civil engineering increasingly moves to sustainability and resource efficiency, because future-oriented living and building is hardly viable without a significant increase of resource efficiency. With respect to resource efficiency, optimized building with low input (material, energy, area) during the complete lifecycle of a building means to meet the requirements of the residents regarding indoor environment quality and home comforts.

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[1] Technische Universität Chemnitz, Professur Strukturleichtbau und Kunststoffverarbeitung, Reichenhainer Straße 70, 09126 Chemnitz. E-Mail: Henrik.Funke@mb.tu-chemnitz.de, Telefon: +49 (0) 371/531 38995

A truly sustainable building has to meet individual design requirements. It is to be built in the desired location within a very short time and with little effort. It also has to be possible to rebuild and remove the building easily at a future date (Lemken, 2008). Using the material and technologies that are currently available, the practical implementation of these innovative ideas is rather expensive and therefore reaches its limits easily. The application of new high-performance materials which are inorganic-non-metallic offers more freedom for construction. Fiber-reinforced concrete facilitates the production of thin-walled, single- and double-curved free-form elements which are highly suitable for lightweight construction and comply with design requirements regarding surface quality (Brameshuber, 2006; Funke et al., 2013a, Mumenya, 2012; Rafi et al., 2006; Funke et al., 2013b; Schneider et al., 2004).

The Poseidon Building, a multistory building in Frankfurt which was built in the 1970s and 1980s, is an example for construction in existing contexts. In 2008, the Poseidon Building was planned to be replaced by a newly built skyscraper (Wirtschaft & Architektur, 2013), but a revitalization was preferred instead by reason of resource efficiency and sustainability. In the course of revitalization, an energetically optimized façade was going to be implemented to get the Green Building “Gold” certification after LEED (Leadership in Energy and Environmental Design).

The 13800 m² three-dimensional façade consists of more than 11500 elements. Of special importance in the course of redesigning the façade was the replacement of the aluminum elements with high-strength architectural concrete. That architectural concrete was to be pure white, with perfect surface quality. This means, it had to have a homogeneous coloring and be absolutely non-porous.

This paper reports the devolpment of the architectural concrete and an appropriate process technology for the production of prefabricated façade elements. An important part of this work is the testing of long-term behaviour and durability aspects of the fiber-reinforced architectural concrete.

2. Method

2.1 Components of Architectural Concrete

The composition of the used concrete was dependent on the requirements it had to meet respecting statics, color, surface quality and element design. Based on these requirements, the fine concrete in Table 1 was developed.

Except from white Portland cement CEM I 52.5 N (according to EN 197) it contained amorphous aluminosilicate as pozzolan. Dolomite sand with a grain size of 0 to 1 mm and dolomite powder with an average grain size of 70 µm were used as aggregate and filler. The short alkali-resistant (AR) glass-fibers (16 mass percent of ZrO_2) was 12 mm long and had a length weight of 45 g/km. A super plasticizer based on polycarboxylate ether (PCE) was used with a solid content of 30 mass percent. The water binder ratio was 0.35.

Table 1: Qualitative Composition of the Architectural Concrete

Component	Explanation
white cement CEM I 52.5 N	• white cement with high early strength
amorphous aluminosilicate	• pozzolan to increase mechanical strength and durability, and as optical brightener
dolomite sand 0/1	• white aggregate
dolomite powder ($x_{50} = 70$ µm)	• filler to improve processability of fresh concrete and as white pigment
integral AR-glass fibers (12 mm)	• armoring for the fine-aggregate concrete matrix
water	• for mixing the concrete
high-performance plasticizer (30 M.-% PCE)	• electrosteric stabilizer

The fine grained concrete was mixed with the intensive mixer Eirich R05T. The mixing parameters are shown in Table 2. The mixing time was 5 min in total. The fresh concrete was tested according to DIN EN 12350. Air content and bulk density of the fresh concrete were determined by means of an air content testing device, following DIN 18555-2.

Table 2: Mixing Parameters for the Production of Fine Concrete

	component	mixing principle	mixing power in %	mixing time in s
1.	binders + aggregates	counter rotation	15	60
2.	75 % of water	co-rotation	50	90
3.	super plasticizer	co-rotation	50	60
4.	residual water	co-rotation	50	30
5.	ar-glass fibres	co-rotation	60	60

2.2 Rheological Optimization by Superplasticizer Content

The optimization of the superplasticizer content was carried out by rheological measurements of the fresh concrete of Table 2. For this, flow curves of the fresh concrete were measured with various superplasticizers content using the rheometer Thermo Scientific HAAKE MARS III (Figure 1). The measurements were carried out with the so-called material box. As a comparing measurement variable, the torque was used at a shear rate of 10 s^{-1} in response to the superplasticizer content.

Figure 1: Rheometer HAAKE MARS For Rheological Measurements (Origin: Thermo Scientific)

2.3 Determination of the Hardened Concrete Characteristics

The samples for the tests to be performed on the hardened concrete were stored dry, according to DIN EN 12390-2.

The compressive strength was determined by means of the Toni Technik ToniNorm (load frame 3000 kN) following DIN EN 12390-3, with cubes having an edge length of 150 mm (Figure 2a). The pre-load was 18 kN. The span width set was 200 mm and the load speed 100 N/s constant.

The 3-point bending tensile strength (Figure 2b) was determined with samples which measured 225 x 50 x 15 mm³ (length x width x height), based on DIN EN 12390-5 and ToniNorm (test frame 20 kN).

Figure 2. Determination of Compressive Strength and 3-Point Bending Tensile Strength

To validate the durability of the architectural concrete, the capillary suction of de-icing solution and freeze thaw test (CDF-test) was measured by the Schleibinger Freeze-Thaw-Tester (Figure 3) with standard agent solution according to the recommendations of RILEM TC 117-FDC. Beyond this, the water penetration depth was determined.

Figure 3. Determination of the Capillary Suction of De-Icing Solution and Freeze Thaw Test

3. Results

3.1 Optimization of superplasticizer content

Figure 4 shows the torque as a function of the superplasticizer content at a shear rate of $10s^{-1}$. The torque decreases up to a superplasticizer content of 3.5 mass percent due to the increasing electrosteric stabilization of finely dispersed particles, such as cement particles and silica fume. The point of saturation S_P, i.e. the complete stabilization of the finely dispersed particles, is about 3.5 mass percent of the superplasticizer content. Over the saturation point (> 3.5 mass percent) added superplasticizer contents results in an increasing torque. The increasing of the torque, and thus indirectly increases the dynamic viscosity, is due to the viscosity of the plasticizer itself. Beyond this, the increased entanglement of the steric PCE main and side chains results in an increasing of the torque.

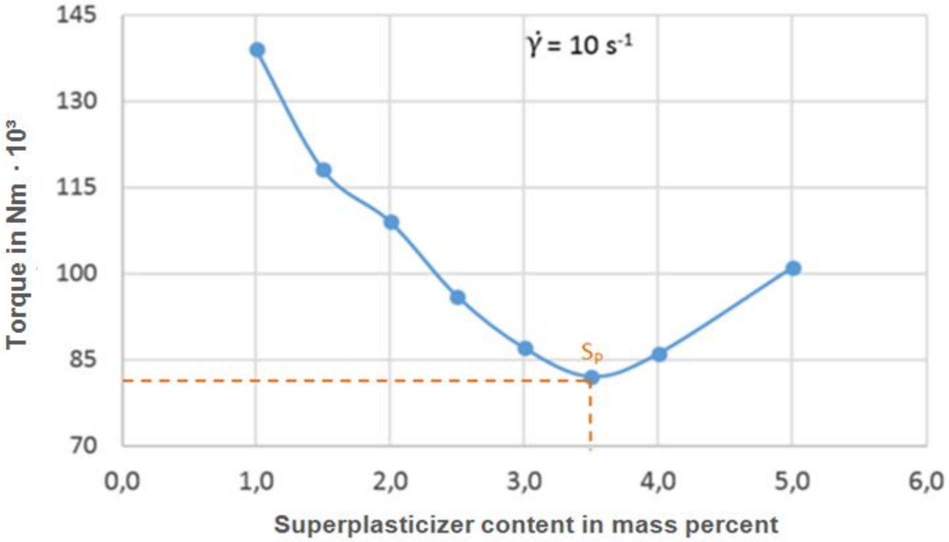

Figure 4. Torque as a Function opf Superplasticizer Content

3.2 Fresh and Hardened Concrete Characteristics

Table 3 shows the fresh and hardened concrete characteristics after 28 days. With a high flow capacity (diameter of the resulting flow table test: 650 mm) the fresh concrete complies with the flow class F6. The air content tester showed an air volume content of 2.0% and a geometric bulk density of 2.28 g/cm³ in the fresh concrete. The total shrinkage deformation, determined with a shrinkage channel, was 0.91 mm/m. The reasons for this were first the high binder content, and the high chemical shrinkage resulting from that. Second, autogenously shrinkage increased due to the low water-binder ratio. Drying shrinkage could be practically eliminated due to a two days aftertreatment including humidifying and protection against draft. The high total shrinkage deformation did not lead to shrinkage cracking and was therefore not harmful.

The compressive strength was 104.1 MPa after 28 days and already 38 MPa after 24 hours. Thus, the façade elements were ready to be demolded after one day. The small variation coefficient of 1.1% implied a homogenous microstructure of the hardened concrete. The 3-point bending tensile strength was 19.5 MPa, so the static requirements were met.

Table 3: Fresh and Hardened Concrete Characteristics of Fiberglass-Modified Fine Concrete after 28 Days

characteristic	fresh concrete	hardened concrete
geometric bulk density	2.28 g/cm³	2.21 g/cm³
flow spread	650 mm	-
air content	2.0 Vol.-%	-
linear shrinkage	0.91 mm/m	
compressive strength	-	104.1 MPa
3-point bending tensile strength	-	19.5 MPa

3.3 Durability and Recyclability

The results of the durability tests are listed in Table 4. The developed architectural concrete displays a high durability, which was validated in the CDF test (m_{28} = 113 g/m² and $R_{u,28}$ = 100%) after 28 freeze-thaw cycles and a water penetration depth of 11 mm. Thus, the architectural concrete meets the requirements respecting building regulations and usability over a long period.

Table. 4: Examinations of the Durability of Architectural Concrete

test method	*test value*
CDF test	m_{28} = 113 g/m² $R_{u,28}$ = 100%
water penetration depth	11 mm

Due to its composition, the architectural concrete is completely recyclable and can be used as aggregate or admixture in the production of fresh concrete. Not using a steel reinforcement facilitates and shortens recycling, including shredding, cleaning and classifying. This ensures that the quality of the recycled concrete is comparable to that of the original concrete.

3.4 Constructional Implementation

Fifty out of the 11500 façade elements were produced per day. The concrete elements were fixed to pedestals to ensure their safe transport to the building site, where they were mounted (Figure. 5).

Figure. 5: Mounted Façade Elements on the Multistory Building "Leo"

4. Conclusions

This practical research work was concerned with an applicable method to develop fiber-reinforced architectural concrete for the redevelopment of the façade of the Poseidon Building, in the course of its revitalization. It was demonstrated that the developed fiber-reinforced architectural concrete combines high strength with high surface quality, durability and recyclability.

In building construction that requires lightweight construction, the increasing use of innovative high-performance materials which are fiber-reinforced and inorganic-non-metallic facilitates the production of thin-walled, single- and double-curved free-form surfaces. This entails a larger design potential for architects and planners, especially with regard to organically formed buildings.

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