TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

**Institute of Concrete Structures
and Structural Engineering
Prof. Dr.-Ing. Jürgen Schnell**

Erwin-Schrödinger-Straße
67663 Kaiserslautern
Gebäude 14, Zimmer 515
Telefon (0631) 2 05 - 21 57
Telefax (0631) 2 05 - 35 55
e-mail: jschnell@rhrk.uni-kl.de

Outline Report: „Lightweight Construction with Concrete - Innovative Adhesive Joining Technology for Filigree Facade Panels made of Ultra High Performance Concrete"

Client: Federal authority for building and regional planning
Referat II 2
Deichmanns Aue 31-37
53179 Bonn

Project Engineers: Dipl.-Chem. Vitalijus Kohl , Tel. 0631/205-4485
Ake Chopradub (M.Eng.) , Tel. 0631/205-3823
Dipl.-Ing. Catherina Thiele , Tel. 0631/205-2010

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Prof. Dr.-Ing. Jürgen Schnell

Prof. Dr.-Ing. Paul Ludwig Geiß

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Abstract

In this project a new type of lightweight facade system was developed using Ultra High Performance Concrete (UHPC) facade panels and Glass-Fibre Reinforced Polymer (GFRP) anchors instead of using conventional concrete and metal anchors. Furthermore, the innovative technique, using adhesives to join anchors and facade panels, was developed. The project objective is to establish a design method for this innovative pre-cast lightweight rear-ventilated facade system. The results of computational investigations and mechanical testings as well as corresponding design methods are discussed in this paper.

1. Introduction

The Project "Lightweight Construction with Concrete - Innovative adhesive jointing technique for filigree facade panels made of Ultra High Performance Concrete" is part of the overall research work "Future in Construction". This project was supported by the Federal Authority for Building and Regional Planning (BBR) by means of a fund originated from the German Federal Ministry for Transport, Building and Urban Development and was managed by the Institute of Concrete Structures and Structural Engineering, University of Kaiserslautern, in cooperation with the department for Joining Technologies/Working group for materials and surface technologies (AWOK), which was supplementarily sponsored by Schöck Bauteile GmbH, Novacret Faserbaustofftechnik GmbH, Sika Deutschland GmbH and Heidelberger Betonelemente GmbH & Co. KG.

1.1. Background

In pre-cast concrete facade construction, a number of new technologies and related questions have been addressed in this project. GFRP anchors seem to be an attractive alternative to metal anchors [1]. Due to their lightweight properties GFRP anchors facilitate assembly and provide low material costs, superior corrosion resistance and the opportunity to reduce energy consumption due to a low thermal conductivity. Additionally, the setting of conventional expansion- or undercut-anchors requires thicker facade panels than adhesively bonded surface fasteners [2, 3]. Furthermore, recent researches enable to create attractive surface finishings of thin concrete plates by using fine-grain concrete reinforced with glass fibre and textile [4], short fibre [5] or micro-reinforcement [6]. Therefore a structural adhesive technology [7] has been applied in this project to join such lightweight facade panels with supporting GFRP anchors. Regarding to the mentioned aspects, this project was initiated within the context of the "Future in Construction" research framework at TU Kaiserslautern. This project emphasizes on developing a lightweight facade system, illustrated in Fig. 1.1, using UHPC and GFRP anchors instead of using conventional concrete and metal anchors. Furthermore, the innovative technique, using adhesives to attach anchors to facade slabs, has been developed. The project objectives are to develop such a lightweight facade system and to find a design method for it.

The idea, how such a facade system will be assembled, is illustrated in Fig. 1.2. One end of an anchor will be embedded in the load-bearing wall for wind during casting of concrete. Subsequently the other end of the anchor will be bonded to the lightweight facade panel using adhesives. Eventually, the entire assembled system will be lifted up and attached to the host structure.

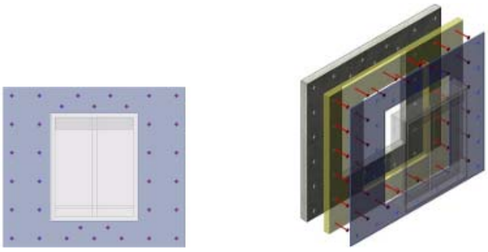


Figure 1.1: The facade system comprises a load bearing wall, thermal insulation, glass-fibre reinforced plastic (GFRP) anchors and a ultra high performance concrete (UHPC) façade panel.

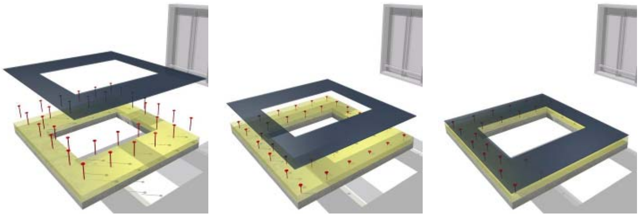


Figure 1.2: Anchors and slab and facade panel will be bonded together during assembly by adhesives

The advantages of the innovative facade system are:

- no sub-frame required,
- dead load and space reduction,
- better quality through factory manufacturing,
- corrosion resistance of GFRP anchors,
- no temperature restraint through low E-Modulus of GFRP,
- manifold design options,
- enabling the substitution of expensive façade cladding made of natural stone or metal panels.

1.2. Objectives

The objectives of the research project is to develop the innovative pre-cast ventilated facade system by using approximately 15 mm thick UHPC as a façade panel and GFRP as an anchor instead of using conventional concrete or natural stone as a facade and metal as an anchor. Furthermore another objective is to develop an innovative technique using adhesives to bond anchors and facade panels together.

1.3. Materials

An overview of the materials used in this project is given in Tab. 1.1 and 1.2.

Constituent	Weight [kg]
Cement "CEM I 42,5"	800
Water	71
Plasticizer "Glenium ACE 30"	34.5
Steel fibre ϕ15 μm x 6 mm	144
Suspension "Silicoll SL"	240
Fe_2O_3 Pigment	24
Superabsorbent Polymer (SAP)	3.2
Silica fume	194.80
Fine sand 0.125 – 0.5 mm	216.75
Rhine sand 0 – 2 mm	173.42
Coarse aggregate 2 – 5 mm	493.35

Table 1.1: Composition of UHPC per 1 m^3

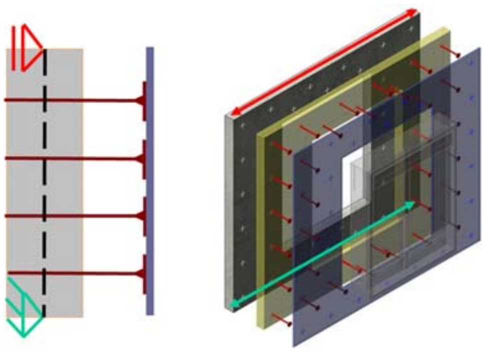
		Constructional Elements		
		Wind load shear wall	Facade	Anchor
		Material – Reinforced concrete C40/50	Material – Ultra High Performance Concrete with steel fibre reinforcement	Material – GFRP [8]
Properties	**Unit**			
Self-weight	kN/m^3	25	25	22
E-Modulus	kN/mm^2	31.4	39.6	60
Design value of bending stress	N/mm^2	-	4.95	-
Design value of tensile stress	N/mm^2	-	-	435
Poisson´s ratio, μ	-	0.2	0.2	-
Coefficient of thermal expansion	1/K	1×10^{-5}	1×10^{-5}	-
Thickness	m	0.15	0.015	-
Length	m	10.0	< 2.7	0.16
Height	m	3.5	3.5	-
Diameter	mm	-	-	12

Table 1.2: Materials properties

2. Loading and computational investigations

One hinge support at the top and one roller support at the bottom of the facade (Fig. 2.1) were modelled for the facade system. Due to the manufacturing condition, the facade width is limited to 2.7 m (Fig. 2.2). Codified actions including dead load, thermal stress due to differential temperature in a facade [9] and in a load bearing wall as well as thermal expansion of the facade panel, wind load from the wind zone 1 [10] for buildings not higher than 25 m, restraint, residual stress in facade, shrinkage and eccentricity were taken into consideration. To calculate the design value of actions, all load cases are factored and combined with regard to EC2 [11].

At first, the model in Fig. 2.1 and Fig. 2.2 was calculated assuming the anchors without hinge. The second calculation was carried out using anchors with hinged ends. The results showed that the bending stress was about 15 N/mm^2 at the surface of the facade modelled without hinge. Therefore a hinged connection is necessary to avoid excessive bending stress in the facade panel. The governing forces of the facade system with hinged anchors are shown in Fig. 2.3, which explains why the facade system can only be implemented with hinges at the end of anchor.



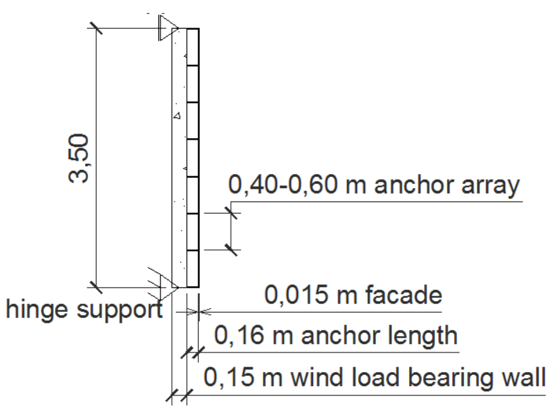


Figure 2.1: Structural system

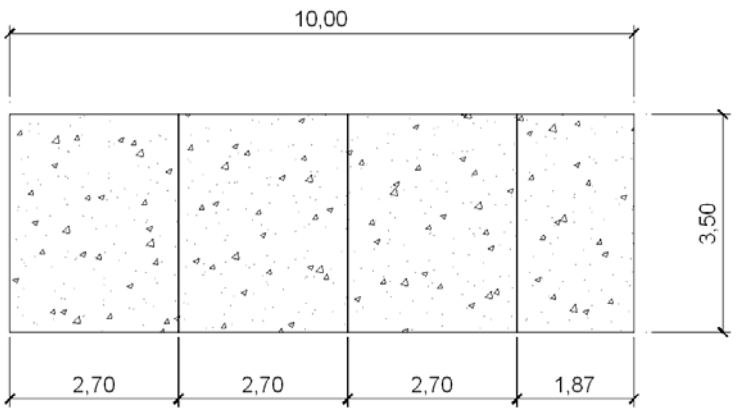


Figure 2.2: Maximum dimensions of facade panel (2,7 x 3,5 m) and wind load bearing wall (10,0 x 3,5 m)

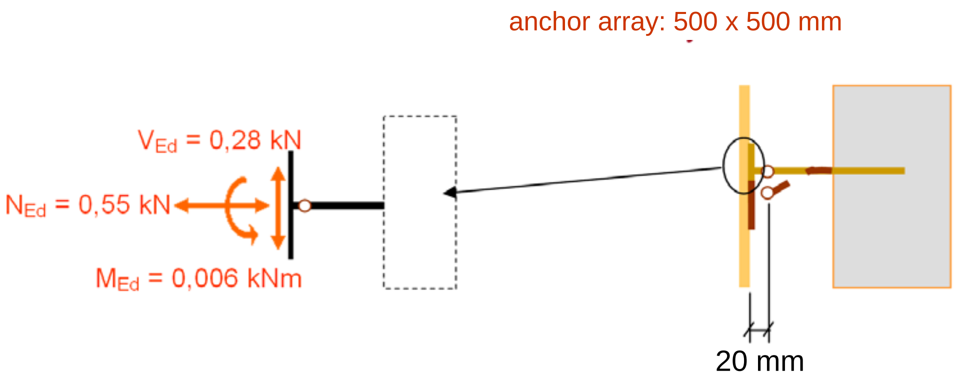


Figure 2.3: Design values of actions at the glued inner surface of the façade panel

At the adhesively bonded inner surface of the façade panel, the design values of actions are:

shear force V_{Ed} = 0.28 kN,

normal force N_{Ed} = 0.55 kN,

bending moment M_{Ed} = 0.006 kNm.

At the outer surface of the façade: bending tensile stress $f_{ct,fl}$ = 4.15 N/mm^2.

In GFRP anchor, the design values of actions are:

bending moment M_{Ed} = 0.039 kN·m,→ bending stress $f_{t,fl}$ = 229 N/mm^2.

3. Adhesive tensile strength testing

3.1. Primer selection for the UHPC surface

Testing for adhesive tensile strength between steel and UHPC surfaces (Fig. 3.1) were conducted to find the optimal pre-treatment for UHPC surfaces prior to bonding. To ensure a high load capacity of the adhesive bond to the UHPC surface, the UHPC surface has to be previously prepared by sand blasting using aluminium oxide. Five adhesives and five primers were combined in these tests. The primer "DP 490/Aceton 1:1" gave the best results.

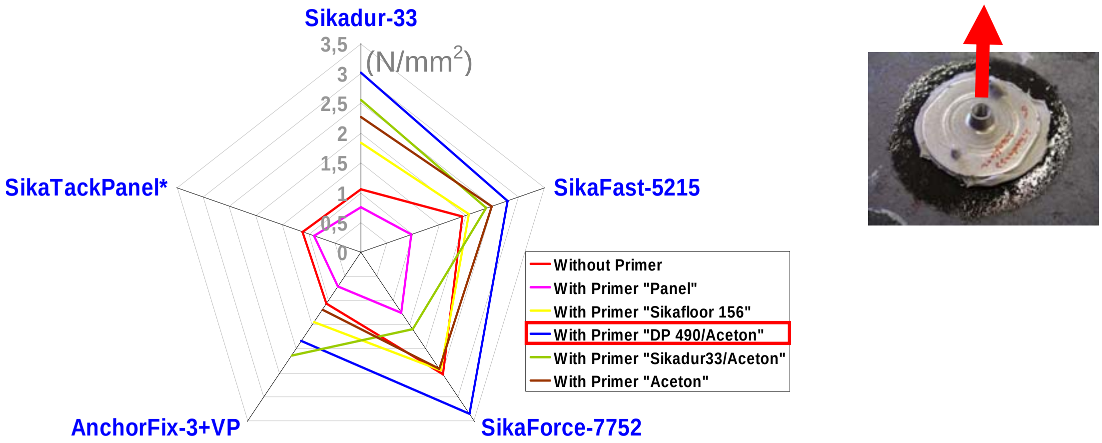


Figure 3.1: Testing for adhesive tensile strength between UHPC surface and steel

3.2. Selection of surface preparation for the UHPC surfaces

Adhesive tensile tests between GFRP end plates (Fig. 3.2) were carried out in order to find the optimal surface preparation method for the surface of GFRP end plate. The "atmospheric plasma" surface treatment gave the best results.

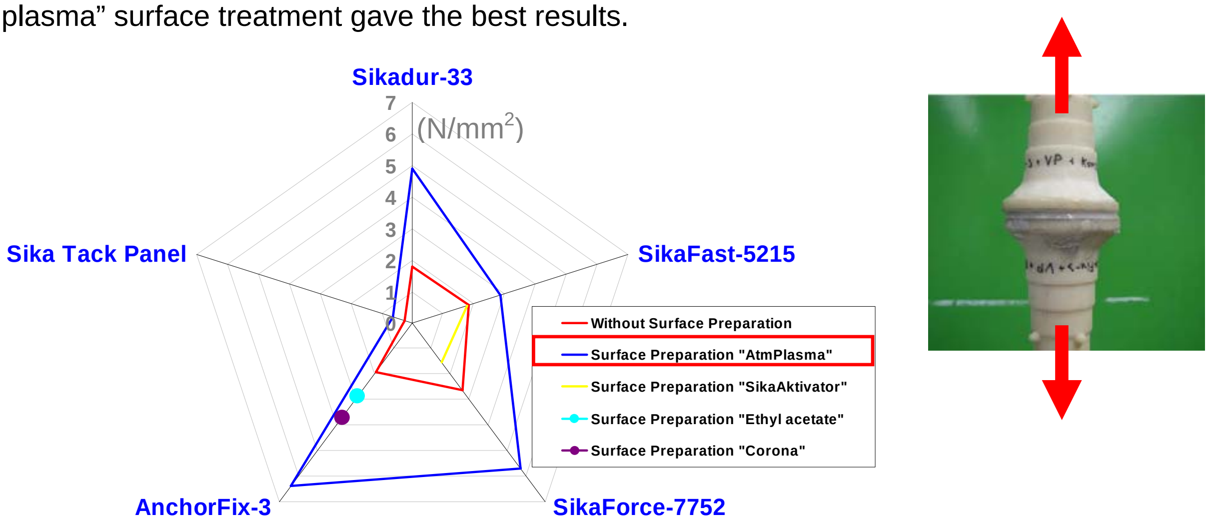
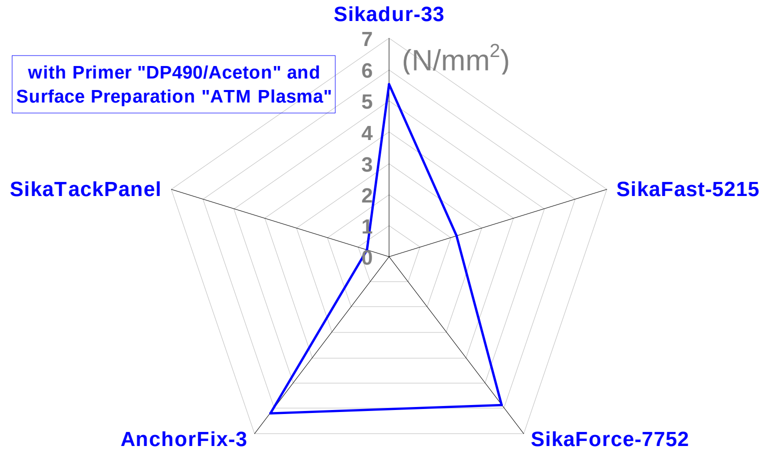


Figure 3.2: Testing for adhesive tensile strength between GFRP end plates

3.3. Selection of adhesive for the GFRP end plate and UHPC surface

The surface preparation for UHPC by sand blasting and primer "DP 490/Aceton 1:1" were taken from chapter 3.1. The "Atmospheric Plasma" surface preparation for the GFRP end plate was taken from chapter 3.2. Five adhesives were tested in short-term adhesive tensile strength testings (Fig. 3.3)



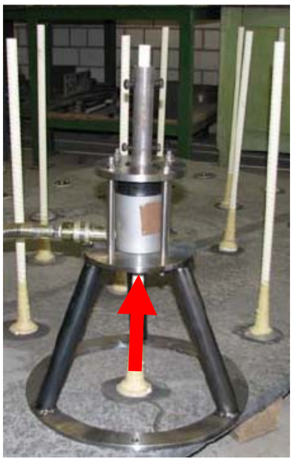


Figure 3.3: Testing for adhesive tensile strength between GFRP end plates and UHPC surface

3.4. Safety factors for adhesives

To estimate the safety factor for the adhesive connection, three adhesive tensile strength tests (Fig. 3.3) as described in Tab. 3.1 No.1 - No.3 were conducted. The test No. 2 and test No. 3 focused on detrimental climate conditions after the installation of the facade system. From these results, the adhesive "Sika AnchorFix" was selected as the best adhesive because of its optimum cost and performance ratio. The results from test No.1 – 3 were compared with the result of the short-term test in chapter 3.3 to calculate the reduction factors. The reduction factor for the quality of installation was estimated to be 0.8. By multiplication of all reduction factors and inversion of this result, the safety factor of adhesive was found to be 6.8 for the adhesive "AnchorFix".

	η	Condition	Reduction Factor
1.	η_1	new concrete surface	0.7
2.	η_2	freeze-thaw-cycle action (-40°C to +60°C , 60 cycles)	0.5
3.	η_3	thermal action (+80°C, 1 hour)	0.6
4.	η_4	quality of installation	0.8

Table 3.1: Reduction factors for adhesive "AnchorFix"

4. Mechanical experiments

4.1. Tension-shear interaction testing

Testing of tension-shear interaction between UHPC surface and GFRP end plate (Fig. 4.1) were carried out. Its result, depicted in Fig. 4.1, shows that the design limit should be a straight line as shown in Fig. 4.2.

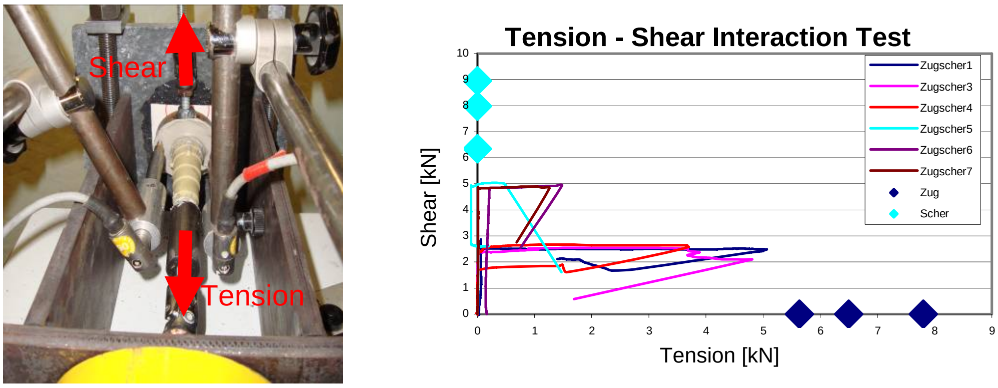


Figure 4.1: Testing for tension-shear interaction

The safety factor of 6.8 to be concluded from chapter 3.4 was used to calculate the necessary bond area of the GFRP end plate to govern the design values of actions from Fig. 2.3. From the diagram in Fig. 4.2, the required GFRP end plate area of 4,488 mm^2 was chosen.

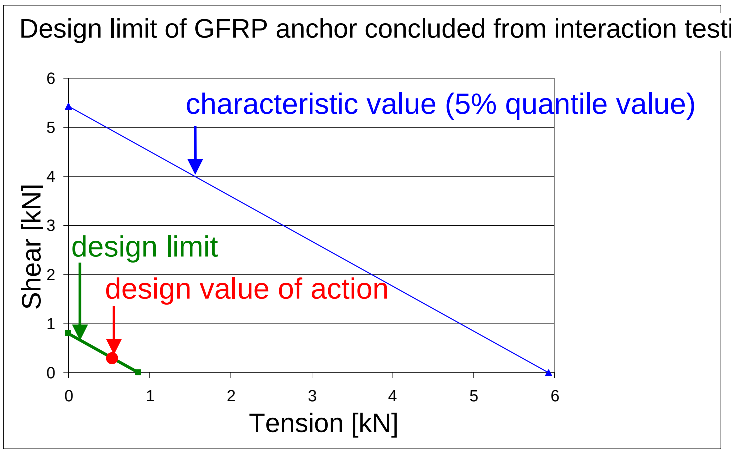


Fig. 4.2: Design limit of GFRP end plate provided with a contact area of 4.488 mm^2

4.2. Windload testing

Using a small facade panel 0.816 x 0.816 m, which was designed to yield the same bending stress level as the actual size façade panel, wind load testings were performed. Wind pressure was simulated by suction pressure from a vacuum pump. The pressure in system measured in relation to the room air pressure.

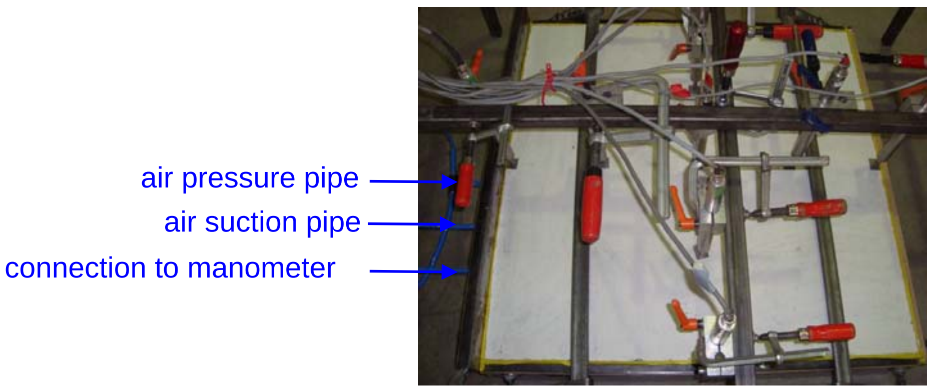


Figure 4.3: Wind load testings by suction tests

	maximum suction pressure [kN/m²]			mean value of pressure [kN/m²]	standard deviation [kN/m²]	variation coefficient [%]
	1.	2.	3.			
Short-term suction test	32.97	26.36	26.10	28.48	3.89	13.66
Suction test after dynamic pressure ±2 kN/m², 20,000 cycles with 0.2 Hz	26.99	23.61	19.03	23.21	3.99	17.20
Suction test after permanent pressure 10 kN/m², 24 hours	25.43	26.83	26.83	26.36	0.81	3.07

Table 4.1: Results of wind load testings

The results from Tab. 4.1 show that the maximum recorded pressures during the test exceeded the characteristic wind load of 1.275 kN/m^2. Consequently, the 15 mm thick UHPC façade panel should be safe for applications in buildings not higher than 25 m located in the exposed wind zone 1 [10].

5. Conclusions

The experimental testings as well as the computational investigations reveal that an adhesively bonded surface fastener will require a hinged connection to prevent damage form excessive bending forces to the bond and the panel. The anchor array of 0,50 x 0,50 m is optimal in terms of vertical deformation and efficiency. The UHPC can be used in lightweight façade panels because of its sufficient design value of bending strength.

Adhesive tests show that surface preparations prior to bonding are necessary. The best surface preparation of the UHSC facade can be provided by sand blasting prior to the application of a laboratory primer formulation "Scotch Weld DP 490 and Aceton 1:1". The "Atmospheric Plasma" surface treatment could achieve the best surface preparation of the GFRP end plate. The results of the durability test showed that the adhesive "Sika AnchorFix-3+" is favourable with to cost effectiveness and long-term durability.

The testings related to the influence of setting conditions showed that, the thickness of adhesive can be varied from 1 – 5 mm without significant loss of load-bearing capacity. Short-term and long-term as well as dynamic experiments showed that the load bearing capacity of the facade system is sufficient to be installed at buildings up to 25 m high.

In practice the size of facade system can be varied up to 3.5 m height and 10.0 m width using the same installation parameters. The manufacturing process of facade system is explained in Fig. 1.2. Although any Ultra High Strength Concrete (UHPC) with its design value of bending strength higher than 4.15 N/mm^2 could basically be used for manufacturing such facade panel, the suitability of the adhesive, the bonding process and the durability of the adhesive bond will need to be explicitly tested for each individual type of application. The advantages of the innovative facade system are conclusively explained in chapter 1.1.

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