INVESTIGATION OF FILLIGREE (U)HPC-FACADES WITH AN INNOVATIVE EXPERIMENT SET-UP

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Abstract

With a new innovative experiment set-up it is possible to examine the multiaxial load bearing behaviour of whole facade systems made of (U)HPC under realistic conditions. The 3D-deformation-analysis delivers deformation data, which can be compared with FE-Models to check the plausibility. Few facades of artificial stone were tested. The failure load was used to recalculate the bending tensile strength with two different approaches. The results show that there are available reserves in the system and that the results deviate clearly from the results of uniaxial testing. The utilization of these reserves would lead to more economical facade systems and to a reduction of transmission heat losses, because the number of fastener and therefore thermal bridges would be reduced.

Streszczenie

Z nową innowacyjną konfiguracją stanowiska badawczego możliwe jest zbadanie wieloosiowego zachowania całych systemów elewacyjnych wykonanych z B(U)WW w rzeczywistych warunkach. Dane uzyskane z trójwymiarowych analiz deformacji można porównać z modelami ES, aby sprawdzić ich wiarygodność. Przetestowano kilka elewacji z kamienia sztucznego. Obciążenie niszczące było używane do przeliczenia wytrzymałości na rozciąganie przy zginaniu z dwóch różnych podejść. Wyniki pokazują, że w systemie istnieją rezerwy nośności i że wyniki odbiegają wyraźnie od wyników testów w stanie jednoosiowym. Wykorzystanie tych rezerw będzie prowadzić do bardziej ekonomicznych systemów elewacyjnych i zmniejszenia strat ciepła, ponieważ liczba elementów mocujących, a co za tym idzie mostków termicznych zostanie zmniejszona.

Keywords: **3D deformation analysis; Artificial stone; Bending tensile strength; Facades; GFRP; (U)HPC.**

1. INTRODUCTION

1.1. General

The dimensions of usual facade systems vary according to their application. They are used as thick curtain-wall facing with surfaces up to 30 m^2, but more as sandwich wall panels. Here they are used as facings. Another field of application is as curtain-wall artificial stone. The area of these artificial stone facades is mostly less than one square meter. That is why they can be produced without reinforcement. The different types are shown in Fig. 1.

New materials like (ultra)high-performance concrete and noncorrosive reinforcement allow to reduce the thickness of facades without reducing the size of the elements. So they can be used as curtain-wall facing or as facing for sandwich walls. To enable a wise and material-saving calculation of such filigree facades, it is necessary to check present approaches. Accordingly, an experimental setup was developed to test facades systems as whole system.

Facades are mostly punctual supported slabs with a multiaxial load bearing behaviour. They aren't load-bearing elements, because the main function is to pro-

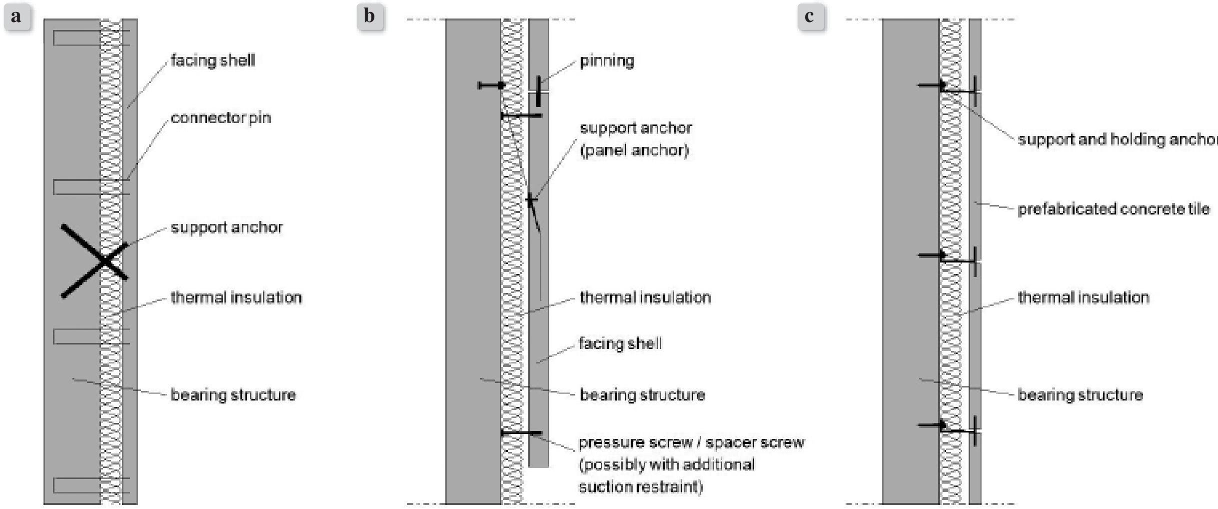

Figure 1.
a) sandwich wall, b) curtain-wall facing, c) curtain-wall artificial stone

tect the thermal insulation from external influences. The main design loads are wind suction, wind pressure and temperature.

Especially for artificial stone facades, the most important mechanical parameter is the bending tensile strength, which is the base for a calculation according to DIN EN 18516-5 [1].

1.2. Reason for multiaxial testing

Without the knowledge about the biaxial strength, the real bearing capacity is unknown. With uniaxial test methods and the thereon based structural design, the result of the bearing capacity can only be a rough estimation. This leads to high safety factors, which don't increase the reliability of the facade, if the real reserves are unknown. These high safety factors make facades uneconomical. A new developed, innovative experiment set-up allows the examination of the system behaviour of whole facade panels under a surface load. That opens new possibilities in the field of structural testing and the optimization of fastener.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Specimen

The specimen consists of the facade, a hollow space in the layer of thermal insulation and the carrying element. It is important that the specimen are without thermal insulation, because that is necessary to have a free space, where the air can be pulled out. The connection between carrying element and UHPC-facade is realized with GFRP fasteners.

All together four specimen were build and tested. The specimens, which are shown in Figure 2, have a size of 1.3 m x 1.3 m. The UHPC-facade has no reinforcement, a thickness of three centimetres and is connected with nine GFRP fasteners. One pair of specimen has a gap for the thermal insulation of 20 cm and the second pair of 6 cm. That is the usual maximum and minimum thermal insulation thickness in practice. In Table 1 the mechanical and geometric

Table 1.
Mechanical and geometric properties of the specimens

Position	geometric parameters [mm]					mechanical properties [MPa]		
	a/b	d_{VS}	d_D	d_{TS}	a_1/b_1	$f_{cm,cube}$	E_{cm}	R_f
V1_60	500	30	60	150	150	139.41	54000	9.34
V2_60	500	30	60	150	150	128.60	54000	13.37
V1_200	500	30	200	150	150	125.56	54000	9.14
V2_200	500	30	200	150	150	137.63	54000	10.58

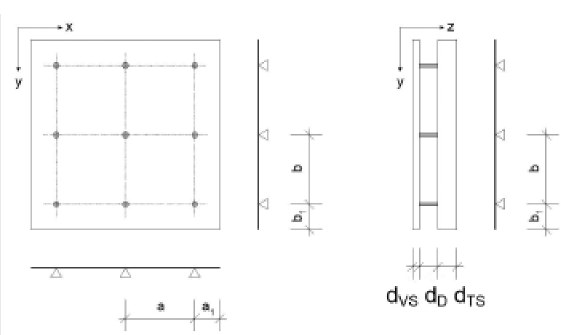

Figure 2.
Dimensions and static system of the specimens [3]

properties of all specimens are shown. The bending tensile strength, which is also shown in the table, is tested on prism according to DIN EN 196-1 [2].The average of two prisms R_f is shown in the table.

2.2. Experiment Set-up

To enable an airproof hollow space, the specimen is jacked with a steel frame on all sides. The airproof case has openings to connect a vacuum pump, measure the air pressure and for cables of conventional measurement equipment. For the load application, a high-performance vacuum pump is used to add wind pressure. With a control unit the valves can be regulated.

The internal and external atmospheric pressure is measured permanently with calibrated manometers. Behind a safety glass, the optical measurement system is placed. The system consists of a high-speed camera to analyse the failure mechanism and two cameras for optical 3D deformation measurement. The full experimental set-up is shown in Figure 3.

The 3D measurement is used with a resolution of 2448 x 2050 pixels, which works with stereo correlation technique with a measuring speed of 5 fps. The loading is performed in 2.5 kPa steps. To analyse the failure mechanism of the facade a high-speed camera is used. The camera features a resolution of 1024 x 1024 pixels and a maximum measuring speed of 120.000 fps.

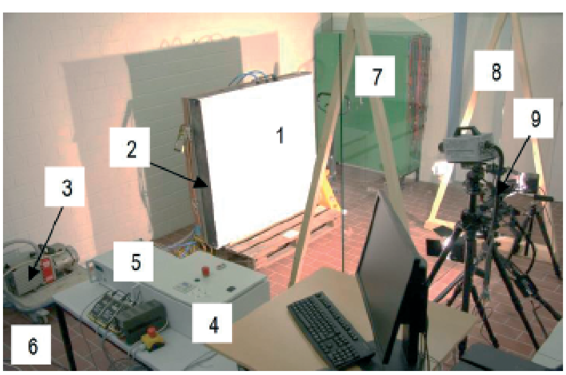

Figure 3.
Experiment set-up: 1 specimen, 2 steel frame, 3 vacuum pump, 4 control unit, 5 measurement amplifier, 6 manometer, 7 safety glass, 8 high-speed camera, 9 3D measurement system

3. RESULTS

3.1. Failure load and mechanism

The specimens reached the ultimate limit state between under-pressure loads of 53.6 to 65.8 kPa. All results are shown in Tab. 2.

Table 2.
Failure load

specimen	standard wind load	V1_60	V2_60	V1_200	V2_200
load [kPa]	1.1	65.8	58.8	53.6	56.0

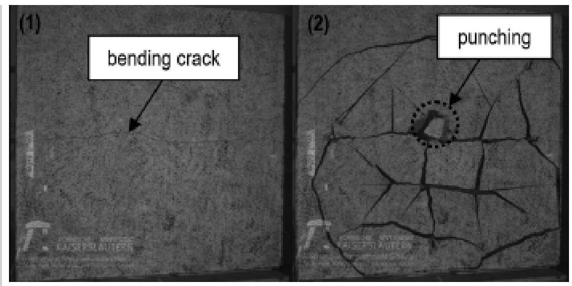

Figure 4.
Cuttings from the high speed video before (1) and after (2) the system failure (V2_200)

All specimens failed through a bending failure. Figure 3 (1) shows clearly that the failure starts with a bending crack and ends with punching (2). The failure mechanism of specimen V2_200, the time between (1) and (2), last 5.4 msec.

3.2. Recalculation of the flexural bending strength

According to DAfStB Heft 240 [4]

Following the bending tensile strength of the specimens is recalculated indirectly using the failure load from the experiment. With the static system of a spare continuous beam, the calculation of the maximum bending moment is executed. The equations in (1) and (2) show that the material parameters aren't considered. The moment $M_{s,w}$ is the maximum moment at support and d_{vs} the facade thickness.

$$M_{S,w} = -\,2.1 \times w \times \frac{A_A}{12} \tag{1}$$

$$\sigma = \frac{6 \times M_{S,w}}{d_{vs}^2} \tag{2}$$

Finite element model

The finite element model is a punctual supported slab with linear elastic material behaviour under the respect of the material parameters of the used UHPC and GFRP fastener, which is simulated with RFEM. The plausibility is checked with the results of the 3D deformation measurement, which are shown in Figure 5. It shows that the z deformation fits together and the maximum field deformation of 0.4 mm in the measurement is equal to the simulation. For each specimen a model is created with its failure load. The result is the maximum, recalculated bending tensile strength.

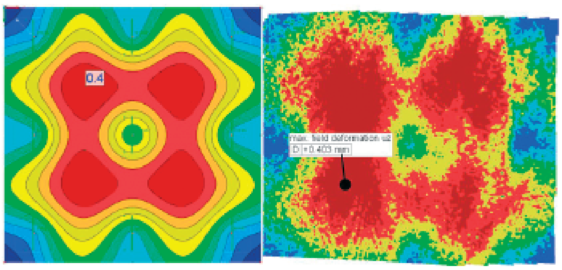

Figure 5.
Comparison of the deformation in z between FE-model (1) and 3D-deformation measurement (2) from specimen V2_60

3.3. Comparison between tested and recalculated bending tensile strength

Following the tested bending strengths according to DIN EN 196-5 [2], which are shown in table 1, are compared with the results of the recalculations.

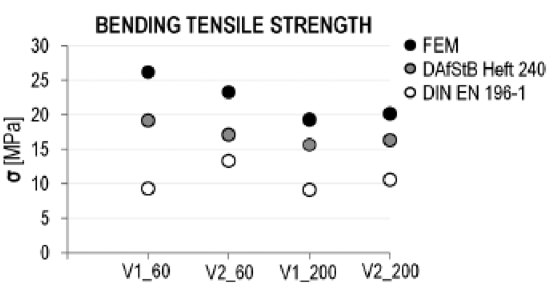

Figure 6.
Comparison between recalculated and tested bending tensile strength

Figure 6 shows that the recalculation with the real failure load leads to higher bending tensile strength values, than the uniaxial tested bending tensile strength. It stands out that the highest bending tensile strength is recalculated with the finite element model.

4. DISCUSSION AND CONCLUSIONS

Though the 3D measurement and the finite element model match well together, it can be proved that the results of the finite element model are close to reality. The higher values of bending tensile strength from the finite element model are plausible, because it respects the material parameters and has to be more accurate in comparison to the calculation according to DAfStB Heft 240 [4]. The results of both recalculations show that there are huge reserves compared to DIN EN 196-1 [2]. That can be attributed to the multiaxial load bearing behaviour, which leads to higher results and cannot be determined with an uniaxial testing method.

In conclusion the investigations showed that there are system reserves which are not used in existent calculation approaches. These reserves would lead to more economical facade systems. The facades could be constructed with bigger dimensions or the facade thickness and the amount of fastener could be reduced. That would reduce transmission heat losses through thermal bridges.

In the future, the experiment set-up will be advanced to add an extra temperature effect. It will be possible to combine temperature with the simulation of a wind load to examine the load bearing behaviour under different combinations. Furthermore, different facade systems will be tested.

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