# Broad development potential for SCC: Carbon Fibre Prestressed high performance SCC

*Dr. DI ETH Giovanni Pietro Terrasi*
*Head laboratory for Materials and Engineering, Empa, Swiss Federal Laboratories for Material Testing and Research, Dübendorf, Switzerland*

*Georges BÄTTIG, Director, SACAC Schleuderbetonwerk AG, Lenzburg, Switzerland*

## 1 Introduction

This paper describes selected architectural projects realized by using thin-walled structural elements made of carbon fibre reinforced plastic (CFRP) prestressed high performance self compacting concrete (HPSCC) and gives information about design and field implementation work.

## 2 Constituent materials: CFRP and HPC

The prestressing reinforcements chosen for this work are thin Ø 3 mm to 6 mm pultruded and sand-coated CFRP profiles with round cross-section. Their design tensile strength is remarkable with values in the region of 2’000-2’700 MPa. In addition to that rolltruded CFRP tapes can be used as shear reinforcements in combination with the pultruded tendons. The low density and the excellent stress corrosion resistance of CFRP are well known [1]. Other favourable properties of CFRP tendons are the superior fatigue behaviour and the absence of creep and relaxation [1]. The above properties make the still expensive unidirectionally CFRP profiles particularly suitable as prestressing reinforcements for concrete elements [2]. The high quality and the cost of CFRP tendons require a correspondingly high quality of the concrete matrix: HPC of strength class C90 to C100 is a suitable partner for this advanced composite reinforcement class. The compaction of HPC can be achieved by centrifugal casting, vibration or – in a very rational way – by the self compacting method (High Performance Self Compacting Concrete [HPSCC][3]). The advantageous characteristics of CFRP and HPC and an appropriate bond between them (over sand-coating of the CFRP) make it possible to minimise the weight of the planned pretensioned bending element by reducing its wall thickness while guaranteeing an excellent serviceability (no susceptibility to corrosion, high bending stiffness and high fatigue strength). The key advantage in manufacturing slender prestressed concrete elements is the durability of the CFRP prestressing material. Steel corrodes and a significant concrete cover (45-65 mm) is required to protect the prestressing steel from aggressive internal and/or external environments. On the contrary, when durable CFRP tendons are used, only a relatively small concrete cover (e.g. 15-20 mm for CFRP tendons of diameter 4-5 mm when embedded in HPC) is required. Prefabrication using HPSCC, precise formwork and accurate positioning of the prestressing tendons makes it possible to pretension filigree bending elements with very small dimensional imperfections, the deviations from nominal values being lower than +/- 5 mm.

## 3 Field applications

### filigree building facade elements made of CFRP prestressed self compacting concrete

The architectural field seems to be a promising market nice for this novel material combination. In the past two years the prefabrication company SACAC AG could manufacture several hundred thin-walled, load-bearing CFRP prestressed HPSCC elements (strength class C90) for two building facades in the city of Zurich.

A first glass-concrete facade of a 6-storey office building in Zurich was realised in 2005 using 250 thin-walled elements of length up to 8.8 m for totally 1’600 m facade beams. The architects Kaufmann, van der Meer and Partner chose CFRP prestressed HPSCC elements with an L-cross-section of 267 mm x 385 mm and a wall thickness of 40-70 mm (figure 1). Their intention was to install continuous horizontal concrete bands around the entire concrete-glass building facade (figure 2) by anchoring the slender concrete beams at the height of the floor slabs. The static system selected was an asymmet-

*Fig. 1: CFRP prestressed HPSCC facade beams with L-cross section 267 x 385 mm and length 8.38 m*

rically supported continuous girder under a combination of self weight, temperature gradients, snow load, wind loads and 2 maintenance personnel of variable position. The beams were fully prestressed for maximum service loads in order to avoid bending cracks and limit short-term and long-term deformations. All beams were prestressed by 14 CFRP tendons of Ø 5.4 mm, at a total prestress of 260 kN at release. Hence the CFRP prestressing ratio was rather low, being 40% of the design tensile strength of 2'000 MPa. Stainless steel inlays were cast in the HPSCC for the anchorage of the facade beams to the building's slabs. On their lower flange the beams are supporting the rotation axes of a glass lamellas front in which 3.5 m long x 0.5 m wide vertical glass lamellas assume the function of sun-blinds that can be electrically controlled by the office occupants (Figure 2). Besides that the L-beams are acting as casing for a steel-superstructure carrying the electric control units of the glass lamellas axes.

The extension of the college "Falletsche" in the city of Zurich with a new 3-storey classroom-building was designed by architect Rolf Mühlethaler of Berne. A glass-concrete facade with very slender concrete border elements was planned. This project required the production of 905 m slender rectangular concrete beams with very low geometrical tolerances, that were produced by SACAC in CFRP prestressed HPSCC. The main reason for the choice of CFRP prestressed concrete elements was the high slenderness ratio of the beams imposed by the customer under fulfilment of high durability requirements: Again aesthetic

*Fig. 2 CFRP prestressed HPSCC L-beams as structural facade elements*

criteria were decisive for the materials' choice. 157 vertical facade beams with a length varying between 0.5 m and 11.1 m and a cross section of 100 mm x 300 mm (figure 3) were designed and manufactured in the winter 2005-2006. The elements are supporting glass-windows.

*Fig. 3 cross section of a three-storey rectangular HPSCC façade element (12 CFRP tendons, window connection over stainless steel 'cup' inlays at the inner short edge)*

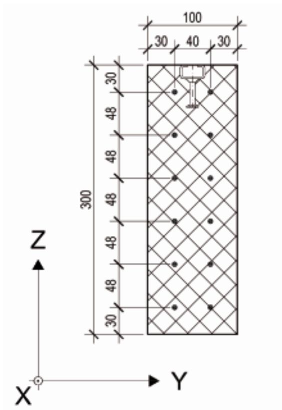


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*Fig. 4 11.1 m long (first two from the left) and 7.6 m long CFRP prestressed HPSCC facade beams*

Figure 4 shows two three-storey (11.1 m) and one two-storey (7.6 m) facade beams during quality assurance operations in the SACAC production plant.

The beams were prestressed with 8, 10 or 12 pultruded and sand coated CFRP tendons of diameter 5.4 mm at a total prestress of 146 kN, 183 kN, 220 kN respectively: The CFRP prestressing ratio was again 40% of the design tensile strength of 2'000 MPa. The minimum concrete cover of the CFRP tendons was 25 mm (figure 3). Design of the elements was performed considering a simply supported beam under self weight (determining load case: transport and installation). The deflection criteria to be fulfilled by the beams under maximum service load was field (l) deflection < l / 300, with l = 0.5 to 11.1 m. In order to avoid cracks and limit deflections the beams were fully prestressed for maximum service loads.

Relevant cross-sectional data of the rectangular facade beams prestressed with 12 CFRP tendons are the cracking moments
$M_{crack}^{y\,+/-} = \pm 18.8$ kN·m,
$M_{crack}^{z\,+/-} = \pm 6.2$ kN·m
and the moments of resistance
$M_R^{y\,+/-} = \pm 48.5$ kN·m and
$M_R^{z\,+/-} = \pm 14.6$ kN·m.

The vertical facade beams were fixed to the building's structure/windows by standard inlays in the HPSCC (stainless steel Halfen-railsTM with nail anchors for connecting the windows, see figure 3 and hanging tensile anchors for the anchorage of the beams). Besides this 326 thin-walled (thickness 50 mm) CFRP HPSCC screen-panels with L-profile and length 1-1.5 m were manufactured and serve as horizontal joining elements in the facade, that were fixed to the sides of the vertical facade beams at the height of the slabs of the building. The building facade was installed in spring 2006 (figure 5).

*Fig. 5 college Zurich Falletsche: a slender CFRP prestressed HPSCC facade beam is highlighted.*

## 4 Conclusion

The innovative combination of materials CFRP and HPSCC opens up promising possibilities in the design of structural elements (beams). The full prestressing of HPSCC beams for maximum service loads makes it possible to manufacture thin-walled, lightweight, filigree, fatigue resistant and very durable concrete elements with a low raw-material consumption for use throughout the infrastructure engineering and the architectural industry.

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