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Structural behavior of multifunctional GFRP joints for concrete structures

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ABSTRACT

A multifunctional all-FRP joint has been developed for the transfer of bending moments and shear forces in thermal insulation sections of concrete slab structures used in building construction. Tensile forces from moments are transferred by horizontal GFRP bars, while a pultruded cellular GFRP element transfers the compression forces. The shear forces are transferred by inclined GFRP bars and the webs of the GFRP element. The new joint considerably increases energy savings for buildings due to the low thermal conductivity of GFRP materials. The quasi-static behavior of the joint at the fixed support of cantilever beams was investigated. Two parameters were studied: shear- or moment-dominated loading mode and concrete strength. Results show that the all-FRP joint does not play a critical role at the ultimate limit state. Ductile failure occurs through concrete crushing. The GFRP bars lead to a significant improvement in joint performance compared with similar joints comprising steel bars. Higher concrete strength does not, however, significantly improve the ultimate load.

1. Introduction

In the context of the sustainable use of non-renewable raw materials and energy, a significant trend towards energy saving construction concepts and methods can be observed in building construction. There is an ongoing movement towards construction methods with high thermal insulation and new standards requiring very low energy consumption are being defined. In this respect, thermal bridges in insulating facades created by penetrations of structural components (e.g., cantilever balcony structures) and built from materials with high thermal conductivity (concrete or steel) are a major concern. New codes comprising stringent requirements regarding thermal insulation have, therefore, been implemented, e.g., the new Swiss Code SIA 380/1 [1], prescribing decreased values for linear thermal bridge allowance limits in facade constructions.

As a result of the new requirements, efforts are being made by the construction industry to develop new structural components for facade penetrations offering improved thermal behavior. The use of new high strength GFRP materials (Glass Fiber-Reinforced Polymers) is being explored – GFRP composites present a thermal conductivity approximately 200 times lower than that of steel [2] and in addition provide load-bearing functions. Two examples of load-bearing and insulating GFRP components were presented by Keller et al.: a hybrid-FRP/steel joint [2,3] and an all-FRP joint [4] for thermal insulation and load transfer in concrete slabs. The hybrid FRP/steel joint, shown in Fig. 1, is inserted in cantilever slabs at the location of the facade penetration, providing a transfer of shear forces and bending moments as well as thermal insulation [5].

The present paper describes the further development of the hybrid-FRP/steel joint presented in [2] to an all-FRP joint, shown in Fig. 2, through the replacement of the steel bars of the hybrid joint with GFRP bars. The all-FRP joint provides a reduction of approximately 50% of the linear thermal bridge allowance of the hybrid joint (value obtained from testing and FE simulation). To verify the load-bearing behavior of the new all-FRP joint in detail, quasi-static full-scale experiments on concrete cantilever beams with integrated insulating joints were performed. The experimental results for the beams with all-FRP joints are presented in the following and their load-bearing performance is compared with that of similar beams with hybrid-FRP joints.

2. Insulating joint composed of GFRP bars and GFRP element

The design of the all-FRP joint was based on the previously developed hybrid FRP/steel joint described in [2]. The compression forces from the bending moment and a part of the shear forces are transferred through the hybrid joint by the CS-element (CS stands for compression–shear), a custom-made pultruded GFRP element covered with two adhesively bonded GFRP cap plates, as shown in Figs. 1–3 and described in detail in [2] and [3]. The compression forces are transferred in the lower thicker flange and the shear forces in the four element webs. The cap plates protect the cut surfaces of the element from alkaline moisture ingression and ensure a smooth introduction of the concentrated compression forces

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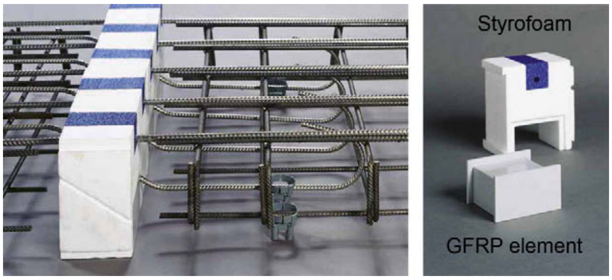

Fig. 1. Prefabricated hybrid FRP/steel insulating joint with GFRP elements embedded in styrofoam insulation and stainless steel bars (isolan plus joint [5]).

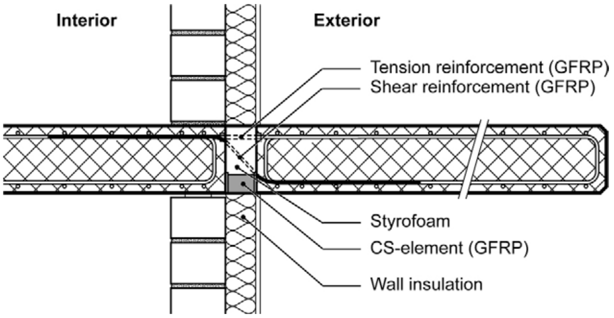

Fig. 2. All-FRP thermal insulating joint composed of GFRP bars (tension, shear) and GFRP CS-element (compression, shear).

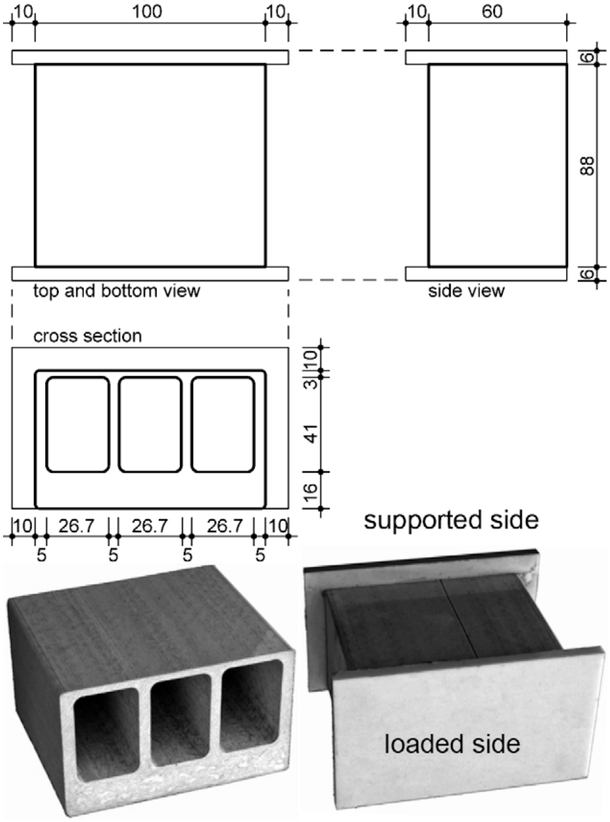

Fig. 3. GFRP CS-element (photo without and with cap plates, units in mm, from [2]).

Table 1
Material properties GFRP-bars (from supplier) and system properties CS-element (mean and standard deviation from 14 tests)

Component	Strength (MPa)	E-Modulus (GPa)
GFRP-bars, ϕ 12.7 mm, shear bar (Pultrall, V-ROD½)	708 (tension)	43.9 (tension)
GFRP-bars, ϕ 25.4 mm, tension bar (Pultrall, V-ROD 1)	597 (tension)	41.9 (tension)
Stainless steel bars hybrid joints, from [2]	900 (tension) 800 (yielding)	195 (tension)
GFRP CS-element (Fiberline, custom-made)	−265 ± 23 (compression)	16.0 ± 0.5 (compression)

from the lower GFRP flange into the concrete. The same CS-element, consisting of E-glass fibers (67% by weight) and isophthalic polyester, is used for the new all-FRP joint. The element is pultruded by Fiberline A/S [6]; Table 1 gives its compressive system strength and stiffness [2,3].

The stainless steel bars of the hybrid joint, the straight upper "tension bars" (that transfer the tensile forces from the moment) and the curved "shear bars" were replaced by GFRP bars, supplied by Pultrall (V-Rod [7]). The bars are pultruded and sanded and consist of E-glass fibers (75% by volume) and vinylester. The curvature of the shear bars, shown in Fig. 4, was obtained by bending the partially cured bars after the pultrusion process. The GFRP bar diameters were designed to provide the same stiffness as the steel bars, that is, the product $\phi^2 \cdot E$ is the same (with ϕ = bar diameter and E = Young's modulus of bar, both according to Table 1). Table 1 also shows the tensile strength and stiffness of the bars as given by the supplier. The overall strength of the shear bars is reduced through the bending to approximately 50% according to the supplier. In addition to the GFRP bar properties, the properties of the stainless steel bars used for the hybrid joints are also listed in this Table 1.

3. Experimental investigation

3.1. Experimental beam description

The experimental set-up and program was similar to that of the hybrid FRP/steel joint experiments, detailed information can be found in [2]. Four beams with integrated all-FRP joints were poured. Fig. 4 shows the dimensions and the arrangement of the GFRP components in the joint and the remaining steel reinforcement in the concrete parts. The beam cross section was 270 mm wide and 200 mm deep. The total beam length was 1800 mm and consisted of three parts: the left (building interior) supported 1000 mm long part, the 100 mm insulating joint, and the right (building exterior) 700 mm long cantilevered part, which was loaded. Two GFRP tension bars of ϕ = 25.4 mm and two shear bars of ϕ = 12.7 mm were used for each beam. The remaining steel reinforcement was of normal steel quality B500 according to Swisscode SIA 262 [8]. Two different concrete strengths were used in order to investigate their influence on load-bearing behavior: concretes C25/30 and C40/50 according to [8]. The average uni-axial prism strengths after 28 days, f_{cm}, were determined according to [8] as 32.3 ± 1.1 MPa for the lower and 52.5 ± 3.5 MPa for the higher strength concretes (see also Table 2).

3.2. Set-up, instrumentation and experimental program

The supported beam part was fixed against uplift at the left end, as schematically shown in Fig. 5. The right end was supported on a steel tube 100 × 100 × 10 mm. The support was placed 100 mm behind the concrete edge to prevent concrete confinement. The right concrete section was loaded by a hydraulic jack with a maximum load of 300 kN and a travel of 200 mm. Two different loading positions were applied: a moment mode was obtained with a lever arm of 660 mm, while, to obtain a shear mode, the lever arm was