FRP SANDWICH STRUCTURES IN BRIDGE AND BUILDING CONSTRUCTION

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ABSTRACT

Selected applications of fiber-reinforced polymer (FRP) sandwich structural elements in building and bridge construction are discussed. It is shown how in building construction this technology enables the integration of functions such as load-bearing capacity, thermal insulation, daylight entry and energy production, into single, large-scale and lightweight roof or façade panels. In bridge construction, the high resistance against environmental impact enables conceiving much simpler construction details because no sealing layer is required, and lightweight deck panels enable the widening of existing bridges without addionally loading the substructure.

KEYWORDS

Sandwich structures, bridge construction, building construction, function integration

INTRODUCTION

Fiber-reinforced polymer (FRP) sandwich structures offer high structural efficiency and are lightweight – the reasons why successful applications in aerospace, naval, automotive and rail industries are widespread. Due to their advantageous properties, load-bearing FRP sandwich structures are also arousing increasing interest in civil infrastructure, i.e. bridge and building construction; a growing number of pilot projects have been built in recent years.

In building construction, the potential multifunctionality provided by FRP sandwiches, i.e. the possible integration of structural, architectural, building physics and energy supply functions, is of great interest. The sandwich concept basically allows the integration of structural and building physics functions, i.e. the merging of building envelope (thermal insulation) and load-bearing structure. The flexibility and transparency of optically optimized glass-FRP (GFRP) materials further enables the integration of architectural functions (complex shapes, light, color) and energy supply functions (encapsulation of photovoltaic cells in transparent skins). Function integration results in a significant reduction in the number of building components, which can be prefabricated under controlled conditions, and thus improves quality compared to cumbersome multilayered on-site production using traditional materials such as concrete or steel.

In bridge construction, lightweight FRP sandwich decks are corrosion-free and thus allow construction details to be simplified and maintenance costs reduced. The replacement of heavy concrete decks may also allow the widening of existing bridges without increasing the total load on the substructure. In both building and bridge construction, lightweight components can be large scale but nevertheless easily transported to the construction site and rapidly installed, thus shortening construction time and compensating for higher material cost. Selected projects in Switzerland, already built or in the realization stage, demonstrate these advantages of FRP sandwich structures in civil infrastructure in the following.

FRP SANDWICH STRUCTURES IN BUILDING CONSTRUCTION

Eyecatcher Building, Basel, 1998

The five-story Eyecatcher Building in Basel, still the tallest FRP building in the world, was conceived as a reusable temporary building. After a first year of being used for a building fair at one location in Basel in 1999,

it was dismantled and reinstalled at another location in Basel where it still remains and is used as an office building, see Figure 1. The primary load-bearing structure is composed of three parallel multilayer GFRP frames connected by timber slabs. Translucent sandwich panels are used for the side-facades and were also made of GFRP. They consist of two thin face sheets separated by a sheet with trapezoidal corrugations. A fibre content of approximately 30% results in a translucency of approximately 70%. To provide thermal insulation, the panels are filled with aerogels, which can be either opaque or translucent. With a panel thickness of only 50 mm it was possible to obtain a U-value of 0.27 W/m^{2}K (Keller *et al.* 2004).

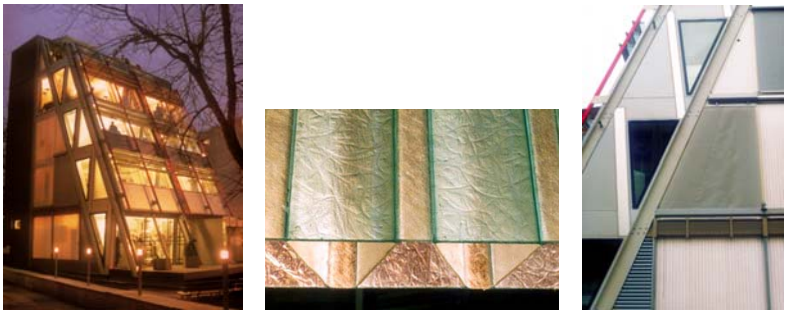

Figure 1 Eyecatcher Building, Basel: translucent aerogel-filled GFRP facade sandwich panels (architect F. Knobel, Basel)

Novartis Main Gate Building, Basel, 2006

The lightweight 400-m^2 GFRP web-core sandwich roof of the Novartis Main Gate Building is supported by only four glass walls, giving the building maximum transparency, see Figure 2. The sandwich construction integrates static functions (vertical load transfer and bracing of the glass walls), building physics functions (thermal insulation and integration of an acoustic ceiling) and architectural functions (double-curved wing shape), which allowed the prefabrication of the entire roof in only four panels that were easily transported to the site and rapidly installed. CNC cutting of 460 PU foam blocks up to 600-mm-thick, each of a different geometry, and adhesive bonding proved to be advantageous procedures for the fabrication of the complex shape, without the use of expensive molds (Keller *et al.* 2008).

Figure 2 Novartis Main Gate Building, Basel: GFRP web-core sandwich roof on glass walls (architect M. Serra, Basel): panel installation, completed building, CNC-cut foam blocks

CLP Building, Montreux (Project)

The 1000-m^2 GFRP web-core sandwich roof of the CLP Building, replaces a timber roof over an indoor swimming pool. It provides the inside space with architectural spatial effects thanks to double-curved enclosure shapes that bring daylight through the roof, see Figure 3. The impact of the complex shapes on the manufacturing cost is decreased by the repeated use of one (expensive) double-curved mold. The lightweight GFRP sandwich construction was selected for two main reasons: to allow the use of the existing vertical structural members as supports within their limited load-bearing capacity, and to meet demanding serviceability and durability requirements, particularly concerning performance under high temperature and relative humidity service conditions (up to approximately 34ºC and 80%, respectively). The prefabrication of the roof, envisaged in the form of 5-m-wide panels transportable by road to the site, is expected to speed up the installation process (which could be done almost simultaneously with the dismantling of the existing timber roof) and thus reduce the swimming pool closure time.

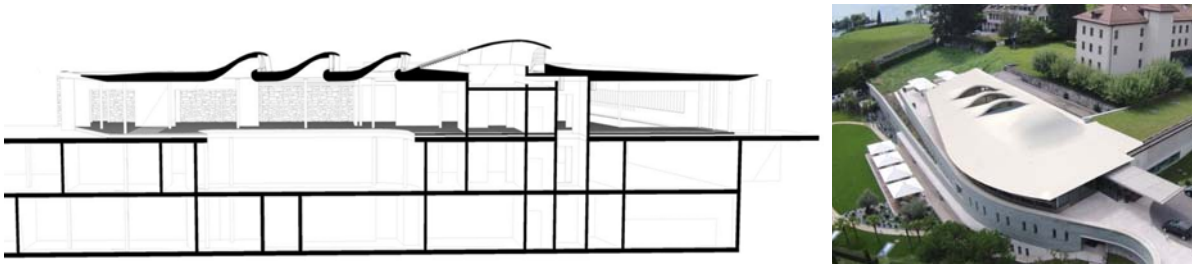

Figure 3 CLP Building, Montreux – GFRP sandwich roof (architects J. Brönnimann & P. Gottreux, Vevey): longitudinal section, architectural rendering of the roof

A/GFRP Thermal Break Element, 2016

A multifunctional highly-insulating aramid/glass-FRP (A/GFRP) thermal break element has been developed for the transfer of moment and shear forces from an outside balcony concrete slab through the thermal insulation layer of a building envelope to the inner concrete slab. The new connector considerably improves the energy savings of buildings due to its low thermal conductivity which is 115 (20) times smaller for AFRP (GFRP) compared to the currently used stainless steel bars in such connectors. The moment-tensile force of the balcony cantilever is transferred by an AFRP loop, the compression force by a short pultruded GFRP element. The latter is connected to a hexagonal AFRP or GFRP sandwich element with polyurethane core, which transfers the shear force through an inclined compression diagonal. This combined compression-shear element is industrially fabricated by filament winding. The 55mm insulation gap, located in the insulation layer, is filled with highly insulating aerogel granulate (Goulouti *et al.* 2016).

Figure 4 A/GFRP thermal break for balcony connections: thermal break element, hexagonal A/GFRP sandwich element, installation between two concrete beams (before casting)

FRP SANDWICH STRUCTURES IN BUILDING CONSTRUCTION

Avançon Road Bridge, Bex, 2012

The GFRP-balsa-steel bridge over the Avançon River is designed for 40 tons truck loads. The new two-lane lightweight bridge replaced a deteriorated one-lane concrete bridge without increasing the total load on the old stone abutments and foundations below the riverbanks, which could thus both be maintained despite the widening and doubling of the traffic loads, see Figure 5. The GFRP-balsa sandwich deck – of 11.45-m length, 7.50-m width, 285-mm thickness, including a skew angle of 65° and longitudinal slope of 8% – was prefabricated by vacuum-infusion in three panels. The deck consists of two 22-mm thick GFRP face sheets and a 241-mm thick balsa core, the latter composed of a laminated veneer lumber with fibers oriented perpendicularly to the face sheets. The deck panels were adhesively bonded onto two steel girders adjacent to the existing bridge. The transverse deck joints were subsequently manufactured using on-site adhesive vacuum infusion. After removal of the concrete bridge, the new bridge was installed in one day and the bridge closure was thus reduced from 50 days (required for a conventional replacement) to 10 days. The semi-integral bridge concept, without expansion joints and separate sealing (required on concrete decks), and thus entailing much simpler construction details, significantly reduces the maintenance required (Keller *et al.* 2014).

Figure 5 Avançon Road Bridge, Bex – GFRP-balsa sandwich deck: panel composition, panel with skew angle and asphalt adhesion layer, installation with pre-cast concrete end-beams

TSCB Pedestrian Bridge, Bissone

The 18-m-span pedestrian bridge is designed as a spatial frame composed of six identical combined modules – of 3-m length, 2.4-m height and up to 4.2-m width each – made of carbon-FRP (CFRP) sandwich sections, see Figure 6. Each combined module comprises two half pieces (basic modules) with the same geometrical shape – except for an additional opening in the roof – and different thicknesses, ranging from 30 to 40 mm, for the roof, wall and deck sandwich elements, which can therefore be fabricated using the same mold. The modules will be assembled at the production site, allowing the manufacturing of the vacuum-infused module-to-module joints, the project's most challenging construction elements, under controlled conditions. The fully prefabricated, one-piece bridge will be transported to the site ready for installation on the previously built foundations and abutments. The proposed modular system also enables the construction of footbridges of different span lengths using the same mold, thus offsetting the costs associated with their complex geometry by tailoring the sandwich material properties and/or thickness for an optimized design.

Figure 6 TSCB Pedestrian Bridge, Bissone – CFRP sandwich space frame (architect F. Broggini, Bellinzona): architectural model, prototype module, architectural rendering

FRP SANDWICH STRUCTURES - OUTLOOK

Photovoltaic Cell Encapsulation

GFRP materials may be translucent or transparent if the optical refraction indices of glass fibers and matrix match. The potential transparency allows the encapsulation of photovoltaic cells in load-bearing GFRP sandwich skins and may thus add an energy supply function, see Figure 7. Replacing the traditional polycrystalline silicon cells, which are opaque, with transparent dye solar cells enables the integration of translucent energy production zones (with transparent aerogel insulation) into GFRP sandwich structures in building construction (Keller *et al.* 2010, Agullo 2014).

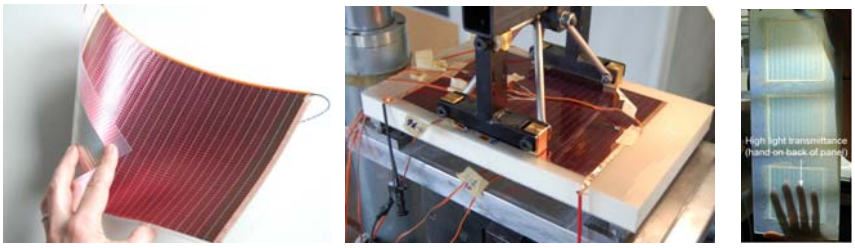

Fig. 7 Encapsulation of photovoltaic cells into translucent GFRP sandwich skins: flexible thin-film silicone cells, sandwich with encapsulated cell under loading, translucent DSC cells encapsulated in GFRP laminate

Multifunctional Fire Resistant Components

Multifunctional components in building construction, as described above, can further include a cellular structure with cells containing slowly circulating water, as in existing underfloor heating or cooling ceiling systems, see Figure 8. The water serves as heat transfer medium for several purposes: fire resistance through storage and removal of heat, interior room heating during winter and cooling during summer, thermal mass, but also as potential absorber for integrated thermal solar systems or cooling of photovoltaic cells. Furthermore, the extension of the water system to capture geothermal energy may extend the above-mentioned energy supply function. Fire performance experiments have confirmed the efficiency of water cooling systems: fire endurances of up to two hours were obtained for cellular GFRP floor systems (Tracy 2005).

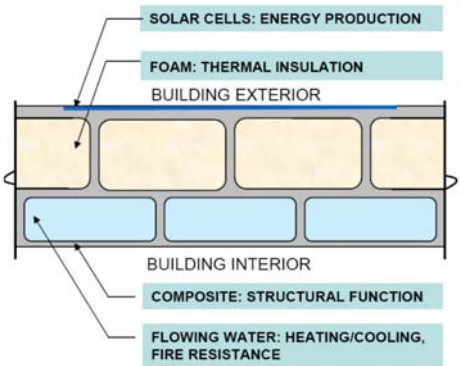

Figure 8 Multifunctional wall or roof component

Complex Core Assemblies

The load-bearing performance of FRP sandwich structures may be significantly improved by optimizing the core material selection and composition. Combining balsa wood of different densities for example and inserting a thin CFRP arch into a slab of (maximum) 800-mm thickness enables the span of GFRP sandwich slab (road) bridges to be increased by up to 19 m, see Figure 9. Combining further GFRP sandwich decks with steel main girders and adding timber and steel inserts above the (adhesively-bonded) deck-to-girder joints to improve composite action allows the span of such lightweight hybrid GFRP-steel bridges to be increased by up to 30 m, see Figure 10 (Osei-Antwi *et al.* 2013, 2014).

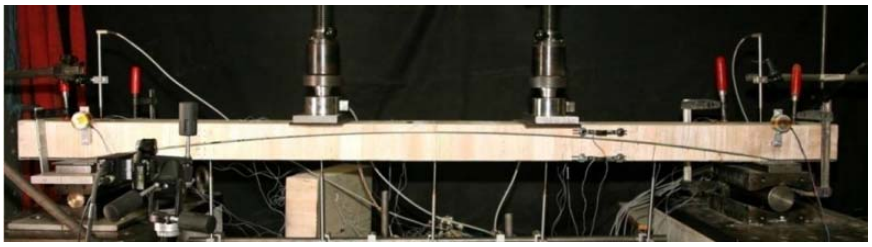

Figure 9 Concept for slab bridges of up to 19m span, complex core system consisting of balsa with integrated CFRP arch

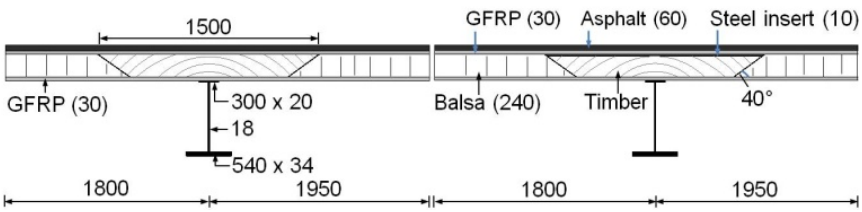

Figure 10 Concept for girder bridges up to 30m span, complex core consisting of balsa with timber and steel inserts (dimensions in mm)

CONCLUSIONS

Requirements regarding length of the design working life, live load level, construction within the built environment and building physics differentiate GFRP sandwich applications in bridge and building construction from other fields.

In building construction, the integration of structural, building physics and architectural functions into large-scale, prefabricated and lightweight FRP sandwiches, which can be rapidly installed, may lead to efficient and sustainable solutions of high quality.

In particular, the potential transparency of GFRP laminates and free formability may contribute to architecturally attractive freeform structures with integrated energy production through solar cells.

In bridge construction, the use of FRP sandwich decks with complex core assemblies may result in durable and economic solutions which can minimize traffic interruptions and increase the load-carrying capacity or enable the widening of existing bridges without overloading the substructure.

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