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Adhesively bonded connections between composite sandwich floor panels for building rehabilitation

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ABSTRACT

A connection system between adjacent sandwich panels for use in building floor rehabilitation, consisting of an adhesively (epoxy) bonded Z-joint, is proposed and studied. Experimental and numerical investigations were carried out to assess the joints' behaviour under vertical loads, their effect on the overall mechanical response of the sandwich floor panels, and the stress distributions within the various panel components. Their behaviour along the transverse and longitudinal (main span) directions was studied for panels made of glass-fibre reinforced polymer (GFRP) faces and two types of cores: polyurethane (PUR) foam and balsa wood. The joints' failure along the transverse direction occurred in the GFRP elements due to excessive through-thickness tensile stresses – failure in the adhesive layer was not observed. In the longitudinal direction, joint failure did not occur. The developed FE models were able to simulate the behaviour of the connections and jointed panels, providing reasonably accurate predictions for the deformations and failure modes experimentally observed. The joints significantly increased the panels' shear stiffness, but showed limited influence on their bending stiffness. Although the flexural stiffness of the PUR foam and balsa wood cored panels was similar, the balsa wood core absorbed a significantly higher portion of shear force.

1. Introduction

In buildings preceding the use of reinforced concrete (RC) and structural steel in construction, floors were typically built from timber beams supported by load-bearing masonry walls [1]. However, such floors tend to exhibit high deformations over time (floor sagging), often face durability problems due to biological attacks, and frequently do not comply with current structural performance requirements [1]. When their replacement is necessary, typical rehabilitation solutions involve the construction of new timber floors (which will suffer from limited durability and require regular maintenance) or the adoption of different floor systems made of either RC, steel or composite (steel–concrete or timber–concrete) elements.

However, RC and steel solutions substantially increase the buildings' structural mass, which is particularly problematic in seismic regions where the horizontal design loads can be substantial [2]. Alternatively, lightweight floor systems have high potential for building rehabilitation by limiting the additional dead load transmitted to the existing structure [2–5], combining these advantages with high durability [6,7] and providing a viable lightweight solution for the rehabilitation of building floors [8,9].

Floor systems made of composite sandwich panels may be quickly assembled on site, potentially allowing for time savings within the construction planning [10–12]. However, sandwich panels must be adequately interconnected upon assembly, with the purpose of constituting a monolithic floor and providing diaphragm behaviour. Consequently, appropriate connection systems between composite sandwich panels need to be considered.

Different solutions for the connections between adjacent sandwich panels have been considered in the construction industry (*cf.* Section 2.1). A significant part of the current sandwich panel connection technology has been developed for non-structural or secondary structural sandwich panels (*e.g.*, [13]). Regarding connection systems for primary structural application in sandwich panels, the existing industrial experience is limited and the influence of such joints on the global behaviour of the sandwich slabs must be assessed, namely with respect to its effects on stiffness, stress distributions, and failure mechanisms.

This paper addresses this subject, with the objective of: (i) proposing a connection system between adjacent composite

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sandwich floor panels, (ii) assessing its behaviour under vertical loads, (iii) understanding how the connections affect the overall mechanical response of the sandwich floor panels under vertical loads, namely regarding their stiffness, failure loads and failure modes, and (iv) assessing the stress distributions within the panels and their components. To this end, sandwich panels comprising glass-fibre reinforced polymer (GFRP) faces and cores of polyurethane (PUR) foam and balsa wood were used. An adhesively bonded joint was adopted, comprising an epoxy-based adhesive and a specific connection system built-into the panels' cross-sectional geometry. The panels were thus bonded along their longitudinal edges, with the joints acting also as reinforcement ribs/webs of the floor panels. The behaviour of the connections along the longitudinal and transverse directions was experimentally and numerically investigated considering different loading configurations to obtain a comprehensive characterisation of their mechanical response.

2. Structural connections between sandwich panels

2.1. Current practice

Several connection systems make use of inserts and profiles that are fitted and in some cases adhesively bonded to the adjoining panels [14,15]. Connections between structural sandwich panels with steel faces using bolted or welded steel plates and profiles have also been proposed for the maritime industry [16,17]. However, using additional elements for the joints increases their cost and complexity, affecting the economic competitiveness of the floor system.

Adhesively bonded male–female connections have been proposed and used for joining pultruded bridge deck panels [18–21]. A noteworthy example is the *DuraSpan* pultruded deck, produced by *Martin-Marietta Composites*. However, this type of connection requires the adjoining panels to be horizontally slid into position with the help of hydraulic jacks, rendering this solution unpractical for building floors, especially in the rehabilitation context where spatial limitations are often encountered.

Other pultruded bridge deck panels, such as the *FBD 600* (*ASSET*) manufactured by *Fiberline Composites*, use a Z-shaped adhesive joint for the panel-to-panel connections [22,23]. This system has the advantage of allowing the adjoining panels to be lowered into position and it also does not require the use of any jacking system, which is more practical in confined spaces. An interlocking, adhesive free, connection has also been proposed for the *ASSET* decking system [24]. However, the interlock joint (produced by vacuum infusion) introduces a certain (significant) joint flexibility and in addition it is not designed to cope with horizontal tensile loads, making this connection inappropriate for building floors.

A Z-shaped adhesive joint has also been used in the connection of adjacent sandwich deck panels in the Avançon Bridge, in Bex, Switzerland [12]. The sandwich panels comprised GFRP faces and a laminated veneer lumber (LVL) balsa wood core. The Z-joint geometry at the panel's edges was built-into the detailing of the faces and core, thus eliminating the need for further connection elements other than the structural adhesive itself (a filled two-component epoxy). The joint's performance was assessed through flexural fatigue and failure tests, which validated its viability for use in the final structure.

2.2. Investigated connection system

During the development of the sandwich panel-to-panel connection system presented in this paper, an adhesively bonded Z-joint configuration was deemed as the most suitable for building floor applications, due to the following reasons: (i) as explained in the literature review described above, it guarantees an effective stress transfer and compatibility of deformations between the adjoining panels, (ii) it allows for an easy panel installation in confined spaces, (iii) it does not require additional connection components other than a structural adhesive, and (iv) it is easy to integrate into the sandwich panel production process.

Regarding the last point, the sandwich panels used in the current investigation were produced by vacuum infusion, with the joint geometry already included in their cross-section. The panels also include longitudinal GFRP ribs/webs, integrated in the connection system, which have been shown to substantially improve the flexural performance of composite sandwich panels [8,25]. The adopted Z-joint configuration is presented in Fig. 1-a, while Fig. 1-b and -c schematically present the cross-section of inner and end panels, and Fig. 1-d shows the adopted cross-sectional dimensions.

The geometry of the connection system is anti-symmetrical so that the panels may be simply lowered into position, *i.e.*, no horizontal movement is needed. At the bottom surface, a structural adhesive may be easily applied before lowering the next panel into place, allowing for a quick installation of large floor areas. At the floor's edges, the end panels allow the floor to be flush with the building's walls.

3. Experimental investigation

3.1. Programme overview and materials

End-type panels (*cf.* Fig. 1-c) were produced and adhesively bonded to each other (in pairs) to assess the behaviour of the

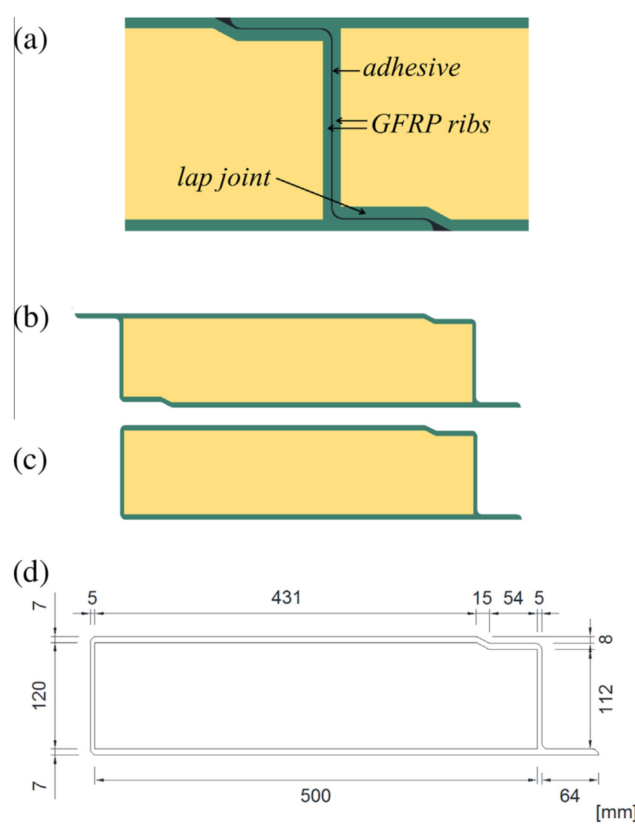

Fig. 1. Proposed panel-to-panel connection system: (a) joint components, (b) interior panel cross-section, (c) end panel cross-section, and (d) cross-sectional dimensions.