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Pull-out behaviour of Glass-Fibre Reinforced Polymer perforated plate connectors embedded in concrete. Part I: Experimental program

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HIGHLIGHTS

- An innovative Glass Fibre Reinforced Polymer (GFRP) connector is proposed.
- The pull-out behaviour of the proposed GFRP connector is experimentally accessed.
- The influence of type of GFRP, number of holes and type of concrete is investigated.
- The contributions of the resisting mechanisms is evaluated.

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ABSTRACT

The Glass Fibre Reinforced Polymer (GFRP) connectors studied in this work were previously proposed by the authors for connecting the outer Steel Fibre Reinforced Self-Compacting Concrete (SFRSCC) layers of sandwich panels for prefabricated modular housing. In this building system, SFRSCC was used to totally eliminate the need for conventional reinforcement and to decrease the thickness of the panel's outer layers, with consequent reduction of the global self-weigh of the panels, while GFRP connectors aimed to significantly decrease thermal bridging effects. For a reliable design of the structural elements that make use of these connectors, the mechanical behaviour of this connection should be known and taken into account. The present paper summarizes the results obtained in an experimental research devoted to the assessment of the behaviour of GFRP-SFRSCC connection by performing pullout tests with specimens representative of the developed sandwich panel. The specimens were designed to examine the influence of the number and geometry of holes executed in the GFRP connector that assure the connection between these two materials.

1. Introduction

In the technology of precast concrete sandwich panels, composite action between the two outer concrete layers is most usually provided by shear connectors [1–8]. In a previous work the authors of the present paper proposed an innovative solution for precast sandwich panels comprising outer layers made with Steel Fibre Reinforced Self-Compacting Concrete (SFRSCC) and connectors of Glass Fibre Reinforced Polymer (GFRP) [9,10]. These panels consist on two outer concrete layers, a thermal insulation material in the core, and GFRP connectors that are used to tie the SFRSCC layers together and keep the panel intact during the stripping, transporting, erecting and under service conditions (Fig. 1). Based on the results of numerical analyses of panels under ultimate limit state, Lameiras et al. [10] suggested that, for housing façade panels, the SFRSCC layers could be as thin as 30 mm. Considering that for economic and practical purposes there is a strong interest of the constructor on keeping the thickness of the sandwich panel concrete layers as small as possible, and also taking into account the constraints for assuring proper embedment conditions for the connector, the authors indicated a thickness of 60 mm for the thickness of the SFRSCC layer. In these previous studies, different solutions to connect the SFRSCC outer layers were also investigated, and their effectiveness was compared by executing preliminary pull-out tests. Amongst the investigated alternatives, the ones that consisted on perforated GFRP plates (hereafter called PERFOFRP) presented a remarkable performance during the preliminary pull-out tests [9].

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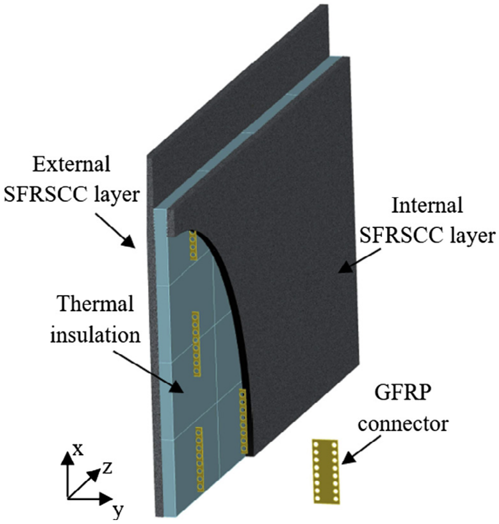

Fig. 1. Sandwich panel comprising GFRP connectors.

The development of the PERFOFRP connector was inspired on the steel Perfobond rib shear connector, but taking advantage of the inherent properties of the GFRP (i.e., reduced thermal conductivity and immunity to corrosion). The steel Perfobond technology was originally developed for railway bridges [11], and since then several studies have been carried out to check its applicability in composite floor systems [12–18]. More recently Cho et al. [19] proposed perforated shear connectors in Fibre Reinforced Polymer (FRP) for a FRP-concrete composite deck. The connector investigated herein has similarities with the proposal by Cho et al. [19], with the main differences between them being related to the restraint imposed by the quite limited embedment depth available for the connectors in the sandwich panels (i.e., concrete cover and geometry of the connector).

The performance of the composite panel is highly influenced by the mechanical behaviour of these connections in the longitudinal and transversal directions of the panel. The longitudinal stiffness of the shear connection affects the flexural rigidity of the composite section and defines its degree of composite action. In fact, the full composite action is practically attained when the longitudinal stiffness is high and, consequently, the corresponding transversal deflections in the sandwich panel are smaller. Therefore, the longitudinal stiffness of the connection should be considered in the evaluation of the serviceability requirements (i.e., deflection limits) when the connectors longitudinal stiffness is low. In addition, the longitudinal strength of these connections is especially important to the case of precast panels that are generally transported in the vertical position, as shown in Fig. 2a, since the panels are generally transported by suspending one of the layers, therefore the deadweight of the other layer is transferred through the connectors. On the other hand, the transversal behaviour is related to how the connection resists the forces that tend to separate both concrete layers. Such type of transversal tensile stresses arises mainly during stripping and erection operations of panels (Fig. 2b). The magnitude of these tensile stresses is difficult to estimate due to dynamic effects that are involved during these operations. During the panels service life, these connections also experience continuous variation of transversal tensile stress due to thermal cycles and wind action. Thus, the panel should have a performance in the transversal direction that assures the required resisting tensile capacity.

Numerous studies have been devoted to the parametric study of steel Perfobond connectors based on tests and numerical simulations [20,21]. Moreover, formulations have been proposed to estimate the shear strength of this type of connection [18,20,22–24].

The geometry of the PERFOFRP connector is similar to the Perfobond connector, but the overall design and mechanical behaviour of this connection differs from the steel Perfobond due to the lower strength and elastic modulus of GFRP comparatively to steel. According to tests carried out by Lameiras et al. [9], the main concern of connections made with PERFOFRP connectors is their shear failure. It is expected, therefore, that in addition to the failure modes resulting from the rupture of the concrete itself (Fig. 3a–c), the possible failure modes of the PERFOFRP connector must be also considered (Fig. 3d–f).

The present paper aims to deeply investigate the behaviour of the PERFOFRP connectors when subjected to tensile stresses. For this purpose, pull-out tests were conducted with PERFOFRP connectors by using specimen and loading configurations capable of reproducing, as much as possible, the conditions found in a sandwich panel.

The variables investigated included the type of GFRP, the number of holes of connector, and the type of concrete (conventional and fibre reinforced self-compacting concrete). The contributions of the resisting mechanisms (i.e., SFRSCC dowel effect and frictional resistance, schematically represented in Fig. 4) were evaluated by comparing the results of tests on connectors with and without holes.

2. Experimental program

The experimental program, carried out at the Laboratory of the Structural Division of the University of Minho, included a total of 24 pull-out tests on GFRP connectors embedded in bulk concrete blocks.

2.1. Material properties

2.1.1. GFRP laminate

All the composites used in this research consisted of polyester resin matrix and E-glass fibre reinforcement. The polyester resin used to prepare the composites is characterized by the following cured properties given by the manufacturer [25]: 45 MPa for the tensile strength, 3100 MPa for the tensile modulus and 1.6% for the elongation at break.

Four types of GFRP were used: 1) CSM; 2) BIA; 3) MU2 and 4) MU4. The first laminate was made of a Chopped Strand Mat (CSM) reinforcement. This solution had already demonstrated satisfactory behaviour when employed as a constituent material for connectors [9]. The CSM composite comprised short length fibres randomly oriented in its plane, as shown in Fig. 5a. The laminate was obtained by stacking 5 mat layers of 450 g/m^2 each, resulting 2250 g/m^2 of glass fibre reinforcement. Its final thickness is about 2.0 mm, and a fibre content by volume of 41%, determined by the resin burn-off method ASTM D2584 [26].

The BIA laminate comprised long fibres arranged on ±45° directions (see a schematic representation of the material in Fig. 5b). The reinforcement used in this solution was supplied in bi-axial Stitched Roving Fabrics (SRF) containing 8 mat layers of 400 g/m^2 each. It is characterized by an average thickness of 2.2 mm, and a fibre content by volume of 51%. Considering that in simply supported panels subjected to transversal loading the maximum shear stress planes occur at 45° to the longitudinal direction, the BIA laminate may be the most effective one to transmit the shear forces that occur in the sandwich panel. However, the absence of fibres at 0° and 90° can lead to unsatisfactory behaviour of the connection, resulting in premature failures localized on the proximity of holes.

The third and fourth laminates were produced using the same manufacturing process, the same constituent materials and the same fibre volumetric proportion. They differed only on the number of layers and, consequently, on the total thickness of the laminates. The laminate of the third material alternative (MU2) was obtained by stacking 6 layers of 400 g/m^2 ±45° stitched-bonded mats and one layer of 0°/90° containing 300 g/m^2 in each direction, positioned in the symmetry plane (see Fig. 5c). On the other hand, the fourth material alternative (MU4) included 12 layers of 400 g/m^2 ±45° stitched-bonded mats and one layer of 0°/90° containing approximately 600 g/m^2 in each direction (see Fig. 5d). The average total thicknesses of third and fourth laminates is, respectively, 2.2 mm and 4.0 mm. The fibre volume fraction of these laminates is 49%.

All the materials were produced in the installations of PIEP – Innovation in Polymer Engineering. The manufacture process adopted is the Vacuum Assisted Resin Transfer Moulding (VARTM). Details about the composite layup and the thickness of laminates are grouped in Table 1 and the total amount of fibres per direction is given in Table 2.