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Bending behaviour of Textile Reinforced Concrete sandwich beams

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HIGHLIGHTS

- The large shear deformability of EPS governs the sandwich global response.
- The solution investigated behaves as a partially composite sandwich.
- Sandwich beam experiences large ductility thanks to EPS compressive plastic strain.
- Fabric position in the thickness of the TRC layer affects multicracking pattern.

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ABSTRACT

A prefabricated concrete sandwich panel, with insulating material acting as a structural layer able to transfer the shear stresses, is discussed. The use of an in-pressure casting technique allows to avoid the use of glue and to prevent the debonding between the layers thanks to the good bond obtained during the production. Sandwich beams characterized by a thick internal expanded polystyrene foam core and by two thin external Alkali-Resistant glass Textile Reinforced Concrete layers are experimentally investigated according to four point bending scheme. The significant role played by the tangential non linear behaviour of the EPS foam is shown.

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1. Introduction

Precast concrete sandwich panels are largely used worldwide, especially in Europe and North America, as structural and insulating walls in multi-unit residential, commercial and warehouse building [1]. These panels are generally made of two external reinforced concrete layers connected through the insulation layer by means of various type of shear connectors (e.g., concrete webs, metal connectors, plastic connectors or a combination of them).

Depending on the strength and stiffness of the shear connectors used, a sandwich behaves as fully-composite, partially-composite or non-composite panel [2]. In the first case, the connectors are able to transfer the shear forces between the two external layers, hence both of them carry the applied load acting as a compact section. When the connectors transfer a minimal part of the shear force from one external layer to the other, the system is considered non-composite: the amount of load carried by each layer, and hence the stress distribution, depends on the stiffness of the layer itself. As underlined by Einea et al. [1], in many non-composite panels the load is carried by just one concrete layer, that is considered as the structural one, while the other layer does not contribute to the strength of the panel and is used mainly for esthetic purposes, to enhance the panel durability and to encase the insulating material. Partially-composite panels lie in between these two extremes [3].

The thickness of each concrete layer depends on its structural function, the concrete cover required, the anchorage of the connectors and the finishing; however, in conventional sandwich panels, it is never smaller than 50 mm [1].

Some studies concerning the bending behaviour of sandwich panels were developed [4], paying particular attention to the relationship between the shear connectors used and the obtained composite action [5,6].

However, the high costs of full-scale testing, the difficulty in fabricating small-scale panels and the reluctance of the producers in sharing the information with their competitors lead to a lack of information on the mechanical performances of the precast concrete sandwich panels [5].

The main advantage of a sandwich solution, that is the integration between the thermal insulation and the wall structural

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element, has to be added to all the advantages related to the prefabrication such as quality control and fast mounting. The main disadvantages are related to the insufficient architectural design range, the clumsy appearance and the corrosion damages that, according to Hegger et al. [7], induce a decreasing in the acceptance of this technology for façade.

Moreover, the insulation efficiency of the sandwich panel depends on the thermal resistance of the insulation material, generally polystyrene or polyurethane, and this efficiency can be considerably reduced by the thermal bridges caused by the presence of the shear connectors, that can be significant especially in the fully-composite solution.

In order to exploit the advantages of a prefabricated sandwich solution while solving corrosion problems, improving the design possibility and obtaining the desired finishing, Hegger et al. [7] proposed sandwich panels with both the concrete layers made of Textile Reinforced Concrete (TRC) and pointed out the good mechanical behaviour of this solution. TRC is a composite cement-based material reinforced with glass, carbon or aramid fabrics that allows designers to obtain thin and lightweight structures thanks to the high tensile resistance [8,9]; this material can be also used in the retrofitting of existing structures as repair layer with not only a strengthening [10], but also a protective function [11,12]. Considering sandwich panels, the use of TRC guarantees to significantly reduce the thickness of the layers if compared to traditional panels. Furthermore, the fine-grained concrete used in TRC allows to obtain good durability and finishing, features that are very important for façade elements.

In this paper a prefabricated façade sandwich characterized by an internal insulation layer made of expanded polystyrene foam (EPS, 100 mm thick) and by two external layers of Textile Reinforced Concrete (TRC, 10 mm thick) is considered. This sandwich solution is adopted in the external façade panel proposed for energy retrofitting of existing buildings in the framework of a more extensive research project (EASEE [13]); the maximum dimension of this panel is $1.5 \times 3.3\ m^2$. The real panel is supposed to be placed on an existing wall by means of four punctual connectors placed near to the four corners of the panel on the short edges: the two upper connectors are aimed to resist only the wind pressure acting on the panel, while the two connectors placed at the bottom are loaded both by wind pressure and self weight of the panel. In order to prevent the thermal bridges caused by connectors, the insulating material is used to transfer the shear between the two external TRC layers; hence, in a full-scale panel designed with this technology, just few connecting devices, active only in extreme conditions (e.g., fire), must be provided to prevent the detachment between the two TRC layers. This approach to transfer the shear by means of the core material is commonly adopted for building sandwich panels characterized by polymeric or metallic external skins [14]; nevertheless, Ferrara et al. [15], Colombo et al. [16], di Prisco et al. [17], di Prisco et al. [18] and Muller et al. [19] proposed cement based sandwich elements in which advanced cementitious composites are used for the external layers and the connection between the layers is obtained only through the bond between the insulating material and the cementitious layer without any connector. The experimental campaign presented in this paper is aimed at identifying the behaviour of the sandwich composite investigated when a four point bending scheme is adopted. The results allow a deeper understanding of the failure mechanisms when different slenderness are considered and provide a reliable benchmark for future numerical modeling of structural elements characterized by this sandwich solution. In the paper two different geometries of the specimens are considered: the tests are carried out on $550 \times 150\ mm^2$ and $1200 \times 300\ mm^2$ sandwich beams, both characterized by a thickness of 120 mm and the stratigraphy described above.

2. Specimens and test description

The experimental campaign – whose results are presented in this paper – concerns the investigation on sandwich beams tested according to a four point bending scheme.

2.1. Cross-section and materials

The sandwich beams investigated are characterized by two external layers 10 mm thick made of Textile Reinforced Concrete (TRC) connected by an insulation layer of expanded polystyrene foam (EPS) 100 mm thick.

The expanded polystyrene foam used is commercially known as EPS250 and is characterized by a compressive strength of 0.25 MPa at a strain equal to 10% and by a low thermal conductivity (0.034 W/mK according to EN 13163 [20]). The elastic modulus is equal to 13.7 MPa: it was measured performing compressive tests on three $100 \times 100 \times 150\ mm^3$ nominally identical specimens (Fig. 1). According to uniaxial tensile tests performed on a similar EPS [16], the tensile behaviour is expected to be elastic–brittle, with an higher strength in tension rather than in compression. The shear modulus can vary between 4.14 and 4.41 MPa for this class of expanded polystyrene foam according to ASTM C 578-92 [21].

TRC is obtained reinforcing a high strength fine grain mortar with an Alkali-Resistant glass fabric, manufactured by means of a leno-weave technique and covered with an epoxy coating.

The fabric used as reinforcement, whose geometrical and mechanical characteristics are collected in Table 1, was selected after performing several investigations aimed at optimizing the performance in terms of TRC strength and ductility, the bond between matrix and fabric, and the internal filament slip. The variables considered in the preliminary study were fabric geometry (warp and weft spacing and their cross-section), fabric weaving and fabric coating. The nominal strength of the selected fabric obtained in the warp direction is equal to 820 MPa. Further information on the testing procedure and some considerations on the results can be found in Colombo et al. [22].

The cementitious matrix used is characterized by a water to binder ratio equal to 0.225 and by a superplasticizer to cement ratio equal to 9.3%. The maximum aggregate size selected is equal to 1 mm. These properties guarantee a high flow capability and, hence, a good bond between matrix and fabric and the possibility to cast the mortar in pressure.

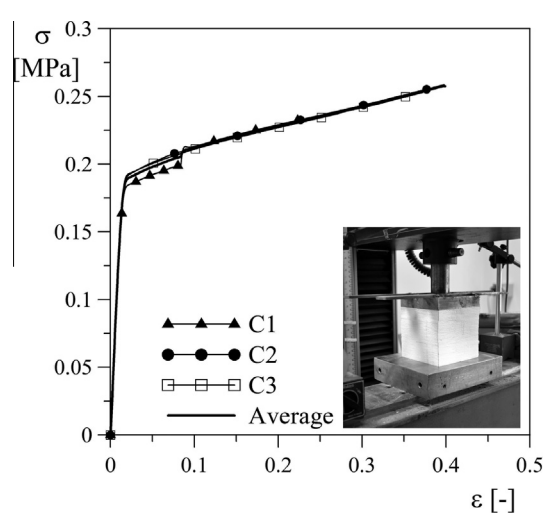

Fig. 1. EPS behaviour in compression.

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