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A HYBRID CEMENTITIOUS BASED-G/CFRP SANDWICH PANEL: CONCEPT, DESIGN AND INITIAL OUTCOMES

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1. INTRODUCTION

Nowadays, the advantages of using fibre-reinforced polymers (FRP) in Civil Engineering structures are very well-known. In comparison to other materials, the FRPs show high strength-to-weight and stiffness-to-weight ratios, as well as high corrosion resistance [1]. Moreover, they can be easily moulded into complex shapes during the manufacturing process. Due to the slenderness of the cross section components and systems [2], and their significant initial cost [3], the FRPs are typically used along with other materials in composite structural elements. In the recent years, the FRPs have been increasingly used in composite sandwich panels designed for the building and housing industry [4]. However, in terms of flooring solutions, the sandwich panels still reveal some limitations for the most typical values of spans and loads in buildings [5].

In order to overcome the aforementioned drawbacks, the EasyFloor project was launched to develop enhanced composite sandwich panels for rehabilitation of floors in buildings. One of the important innovations included in the project relies on the use of both glass and carbon fibre roving (G/CFRP). This hybrid solution aims at improving significantly both the strength and stiffness. Furthermore, the top face of the panel is made of steel fibre reinforced self-compacting micro concrete (SFRSCMC), instead of the usual FRP compressive face, aiming to overcome face wrinkling issues. Additionally, this solution can provide higher ductility, fire endurance and impact resistance [6]. Furthermore, polycianurate (PIR) closed-cell foam is used as core material of the panel. Proper adhesion between G/CFRP and SFRSCMC is developed in order to obtain the full bending capacity of the composite solution. Finally, the FRP component is produced by pultrusion, taking all the advantages of this manufacturing process.

The final proposal for the hybrid sandwich panel was obtained through the use of genetic algorithms in the design, which consisted in optimizing the geometric and the mechanical properties of the panel, taking into account the following features: (i) structural and energy efficiency; (ii) durability, versatility of use, ease of handling, quick assembly and production; (iii) low maintenance needs and aesthetics.

The present work describes the design solution that resulted from the optimization procedure and subsequently presents initial experimental results regarding the mechanical characterization of the different materials, as well as the FRP/SFRSCMC interface. The experimental program comprised: (i) tensile and flexural tests on both the bottom and external ribs of the C/GFRP laminate skins; (ii) tensile, compressive and direct shear tests on both foam core materials (PIR); (iii) compressive and flexural tests on the SFRSCMC top face, and; (iv) pull-off tests for the characterization of the connection between the SFRSCMC and FRP using different types of adhesives.

2. CONCEPTION AND DESIGN

The design of the EasyFloor hybrid sandwich panels was addressed using Genetic Algorithms (GA). With this approach, a multi-objective function was defined with the target of minimizing (i) self-weight, (ii) total price and (iii) carbon-footprint of the solution. Taking into account the current needs in terms of rehabilitation market, a span of 5.0 m was considered for the panel, assuming simple supported conditions at the extremities. Values of 1.5 kN/m^2 and 2.0 kN/m^2 were used for other permanent and live loads, respectively. Additionally, due to technical limitations of the pultrusion equipment, a width of 500 mm was set. In order to create the random population and to continuously exclude the individuals outside the boundaries of the problem statement with GA, a set of boundary conditions (BC) were initially defined for avoiding "cripple" solutions. Some of the BC were set according to the requirements of the manufacturer (e.g. the width), while others were established to guarantee the fulfilment of the Structural Eurocodes 0 (EN 1990:2002) and 1 (EN 1991-1-1:2002) and the Italian recommendation CNR DT 205/2007 in terms of Ultimate Limit States (ULS) and Serviceability Limit States (SLS). Additionally, some building physics aspects were also considered, mainly thermal and acoustics. Further details about these aspects can be found in [7]. Moreover, a snap-fit type of connection between the panels was designed and studied by means of numerical and analytical models, where the structural behaviour of the panels, force required for assembly, and load distribution among the floor's principal axes were taken into account in the joint's detailing and geometry [8].

Fig. 1 depicts the final solution for the hybrid sandwich panel with a total height of 140 mm, a width of 500 mm and a self-weight equal to 59.8 kg/m^2. The solution consisted on the following components: (i) a top face of SFRSCMC with a constant thickness of 20 mm in the middle of the cross-section and 36.5 mm at the extremities in order to improve the connection between the SFRSCMC and the remaining parts; (ii) face FRP sheets made of hybrid carbon fibre roving strands and glass fibre plies (G/CFRP) of 5 mm and 4 mm of thickness, for the case of bottom face and lateral ribs respectively; (iii) a foam core material made of polycianurate (PIR) closed-cell foam with a density of 40 kg/m^3; and, (iv) a GFRP skin between the PIR and the SFRSCMC with 3 mm of thickness, in order to prevent the damage of the PIR during the manufacturing production of the FRP component by pultrusion. In turn, the snap-fit joint (see Detail D1 and Detail D2 of Fig. 1) is 5 mm thick and has: (i) a latch 30 mm long, (ii) an overhang overlap of 1 mm, (iii) an overhang entrance angle of 4º, (iv) faces inclined at 2º and (v) a clearance of 0.25 mm.

Finally, the estimated thermal conductivity (U-value) for the hybrid sandwich panel is 0.19 W/m^2·K, which satisfies the legal requirements for thermal insulation in buildings for a heating flux below 0.30 W/m^2. Considering a room volume of 3.56×3.56×2.7 m^3, the estimated airborne and impact sound insulations are, respectively, 35.7 dB and 87.1 dB. These estimated values also fulfil 65% of Portuguese legal requirements, which are in agreement with the defined goals for the EasyFloor project.

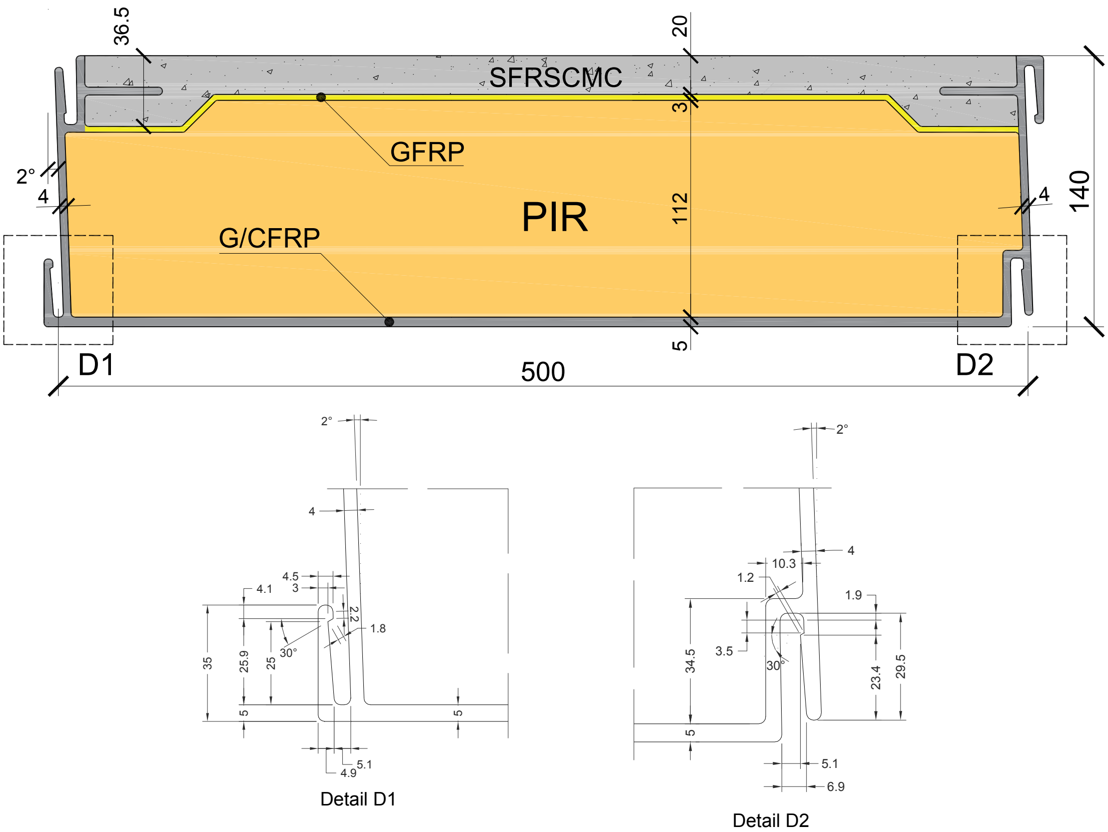

Fig. 1: Final geometry of the hybrid sandwich panel. Units in [mm].

3. MATERIAL CHARACTERIZATION TESTS

In the scope of the present paper the results of the material characterization carried out on the G/CFRP faces, foam and SFRSCMC are introduced, as well as the characterization of the interface between the GFRP skin and SFRSCMC face.

The direct tensile tests on the G/CFRP sheets comprised the longitudinal (0º), transverse (90º) and inclined (30º) directions, according to the ASTM standards D3039/D3039M-00. From the tests carried out, *E*-modulus of 50.2 GPa with a coefficient of variation (CoV) of 7.2%, of 13.9 GPa (6.5%) and of 8.87 GPa (11.8 %) were obtained for the specimens at, respectively, 0º, 30º and 90º directions, while the ultimate strength was, respectively, 545.0 MPa (8.2%), 115.8 MPa (3.6%) and 71.54 MPa (7.0%), with an ultimate strain of 0.982% (2.1%), 1.07% (8.2%) and 0.99% (12.4%), respectively.

Direct tensile, compressive and shear tests on PIR were executed according to the ASTM C297/C297M, C365/C365M and ASTM C273 standards, respectively. From these tests the following results were obtained: i) tension - *E*-modulus of 5.81 MPa (11.5%), ultimate strength of 0.22 MPa (10.7%), ultimate strain of 0.22 (2.9%); ii) compression - *E*-modulus of 4.79 MPa (10.0%), ultimate strength of 0.22 MPa (15.5%), ultimate strain of 0.054 (22.0%); iii) shear - *G*-modulus of 2.73 GPa (2.3%), ultimate strength of 0.19 MPa (6.5%), ultimate strain of 0.151 (13.0%).

The material characterization of the SFRSCMC was carried out at 7 and 28 days of age and comprised compression and flexural tests, according to the EN 12390-3:2001 and RILEM TC 162-TDF/2000, respectively. The rheological properties of the SFRSCMC were also assessed at fresh state. All the mixtures did not show any sign of segregation. From the compression tests at 28 days an E-modulus of 23.8 GPa (2.1%) and a compressive strength of 39.3 MPa (1.3%) were obtained. In terms of the flexural tensile properties, tested at 28 days, the following values were obtained: limit of proportionality of 4.16 MPa (5.2%); equivalent flexural strengths of $f_{eq,2}$=7.28 MPa (15.0%) and $f_{eq,3}$=6.69 MPa (15.4%); and, residual strengths of f_1=7.02 MPa (15.0%), f_2=7.47 MPa (13.7%), f_3=6.06 MPa (15.7%), and f_4=4.95 MPa (14.5%).

In general, all the results obtained for the material characterization of the G/CFRP sheets, PIR foam and SFRSCMC were in agreement with the required values at the design stage.

With the aim of studying the bond behaviour between the GFRP skin and SFRSCMC face, by using different surface treatments (without treatment, sandpaper with coarse aggregate size of 80 and 20) and adhesives (SikaTop® Armatec® 110 EpoCem, Sikadur® 32 EF, Mapei Eporip, Kerabuild® Eco Epoprimer) applied on the surface after the corresponding treatment and before casting the SFRSCMC, pull-off tests following the ASTM D 4541 standard were carried out. The best bond behaviour was observed in the series where the adhesives Sikadur® 32 EF and Mapei Eporip were used, independently of the roughness treatment applied. Moreover, in those series failure was cohesive and occurred always at the SFRSCMC substrate. This fact indicates that a complete composite action for the corresponding sandwich panel can be assumed in the design context.

4. CONCLUSIONS

The present work describes the design of a new hybrid sandwich panel for flooring applications in building industry. An hybrid sandwich panel was developed having a cross section of 500 mm of width and 140 mm height, with a span length of 5 m and a weight of 59.8 kg/m^2, able of supporting 1.5 kN/m^2 (other permanent loads) and 2.0 kN/m^2 (live loads) and fulfilling the design guidelines. The components of the hybrid sandwich panel, which resulted from the optimization procedure, are: (i) a top layer in SFRSCMC with 20 mm of thickness, (ii) bottom face and ribs on G/CFRP with thickness of 5 mm and 4 mm, respectively, (iii) PIR closed-cell foam as core, (iv) a GFRP skin between SFRSCMC and PIR, and (v) snap-fit connection between the panels.

An experimental program was carried out for material mechanical characterization. The results revealed that the required mechanical properties at the design stage were achieved by the adopted solutions. Finally, to improve the bond between the top face (SFRSCMC) and the core (PIR), adhesive Sikadur® 32 EF or Mapei Eporip should be used before casting the cementitious-based material.

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REFERENCES

[1] S. Ahmed, K. Galal., “Effectiveness of FRP sandwich panels for blast resistance”, *Composite Structures*, 2017; 163: 454-464.

[2] B. D. Manshadi, et al., “Post-wrinkling behavior of webs in GFRP cell-core sandwich structures”, Composite Structures, 2016; 138: 276-284.

[3] J. R. Correia, F. A. Branco, J. Ferreira (2009). “GFRP-concrete hybrid cross-sections for floors of buildings”, Engineering Structures, 31, 1331-1343.

[4] S. Satasivam, Y. Bai, Y. Yang, L. Zhu, X. Zhao (2018). “Mechanical performance of two-way modular FRP sandwich slabs”, Composite Structures, 184, 904-916.

[5] H. Abdolpour, J. Garzón-Roca, G. Escusa, J. M. Sena-Cruz, J. A. O. Barros, I. B. Valente (2016). “Development of a composite prototype with GFRP profiles and sandwich panels used as a floor module of an emergency house”, Composite Structures, 153, 81-95.

[6] L. Zhang, Y. Bai, W. Chen, F. Ding, H. Fang (2017). “Thermal performance of modular GFRP multicellular structures assembled with fire resistant panels”, Composite Structures, 172, 22-33.

[7] G. Escusa, J. Sena-Cruz, F. Cruz, E. Pereira, I. Valente, J. Barros (2017). “The use of genetic algorithms for structural optimization of hybrid sandwich panels”. APFIS2017 – 6th Asia-Pacific Conference in FRP Structures, Singapore, 4 p.

[8] M. Proença, M. Garrido, J.R. Correia (2017) “Development of the panel-to-panel snap-fit joint” Project EasyFloor, Technical report no. CERIS DTC 11/2017.