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Characterization of hybrid pultruded structural products based on preforms

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ABSTRACT

Pultrusion is a widely known technique for production of constant cross-section profiles, such as bars, L-shape or T-shape profiles, as well as structural tubes in polymer matrix composite materials. In some applications, requirements are demanding for profiles able to provide better thermal or sound insulation or needing a slightly higher moment of inertia without increasing the ratio between weight and strength. In such cases, hybrid pultruded profiles with core based on preforms are a possible solution.

After obtaining prototypes according to the methodologies described in a previous work, and as a complement to that work, it is necessary to verify if the properties of these hybrid profiles correspond to the initial expectations, by performing destructive and non-destructive tests. Thus, tensile, compression and bending tests were performed, in order to verify the mechanical benefits achieved through the core introduction into the hollow profile and to analyse the added value brought by these new products. These values, once properly validated, can be added to existing databases related to structural calculation programs, enabling to get the adequate values for calculations regarding this kind of profiles. In addition, thermal and acoustic insulation tests were performed, in order to quantify the physical improvements achieved regarding these properties, which are extremely important in specific applications linked to the civil construction and public works, among many others. The cored profiles showed a strong adhesion between the profile and any kind of core tested as well as improved properties in terms of thermal insulation and moment of inertia. However, the sound insulation did not present significant improvements, probably due to GFRP profile external rigidity and consequent reflection.

1. Introduction

Composite material applications are continuously increasing due to the flexibility on their properties and suitability for easy adaptability to the advanced requirements, difficult to achieve based on a single material or alloy [1–4]. The sub-group of composites based on polymeric matrix has experienced a considerable increase in sales volume and application fields due to its low specific weight, high strength, very good corrosion resistance, easy processing and colorization, as well as easy assembly using several joining processes [5,6]. One of the most common families of polymeric matrix composite materials is the GFRP (Glass-Fiber-Reinforced Plastics), used as the basis for this work [7].

Pultrusion is a manufacturing process usually connected to composites with a polymeric matrix, mainly focused on the production of products with a constant cross-section, both in massive and tubular shapes [8–11]. In this process, the fibres, previously embedded in resin, are pulled through a die where the profile is acquiring the desired shape, are later cured, which gives them stiffness and the final shape [12–14].

The need to put the pultruded products closer to the market requirements leads manufacturers to design hybrid pultruded products oriented to provide specific market requirements, such as improved thermal insulation or increased acoustic insulation, which enhances the moment of inertia as well and contributes to a higher global performance. These properties are particularly suitable for the market related to the construction engineering. However, other studies have been focused on raw materials such as cork or polyurethane regarding the study of their thermal, acoustic and mechanical properties [15–17]. Indeed, incorporating lightweight materials such as polyurethane with different densities, cork or other materials as core, the properties of the former hollow profiles acquire more attractive properties while keeping constant or even increasing the strength/weight ratio [18–22].

The manufacturing process used to obtain hybrid pultruded profiles is described in other paper of the same authors [23], but it can be briefly described in a few steps: the pultruded profile is generated around a preform continuously fed to the pultrusion machine, while the fibers are previously impregnated with resin and cured into the heated die and giving rise to a cross-section constituted of an external

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composite profile and a core of the material selected and fed as preform.

These novel products must be conveniently characterised in order to evaluate if the increase both in cost and weight is properly compensated by the improved achieved properties. Since the characterization of this kind of products is not regulated by specific standards, the tests should be carried out based on recommendations for regular materials.

In order to evaluate the physical and mechanical properties of the hybrid profiles, it is necessary to carry out tests, which are usually standardised. Because the constitution of composite materials is heterogeneous, test results usually show a great dispersion, forcing in some cases the use of a larger number of samples [24–26]. The tensile test is a destructive but essential test because it provides several important information about the mechanical behaviour of the material, providing crucial data for the design process. In fact, extremely important properties such as the ultimate strength, Young's modulus or elongation are provided directly from these tests. The adhesion between the core and the outer composite profile was also subject of analysis but this kind of test is not standardised. Thus, a new setup was designed, as described later in this paper. With regard to the physical properties, test procedures and setups were also designed leading to evaluate the profits achieved both in thermal and acoustic insulation by the inclusion of different core materials. Bending tests can be divided into two types: three points bending and four-point bending, depending on the number of loading points used in the test. Due to the novelty of the hybrid concept on pultruded products, there are no standards focused on the adhesion between the pultruded profile and the corresponding core. However, because this property is regarded as very important when the hybrid profile is subjected to bending loads, a novel test was devised in order to assess this parameter.

Regarding the desired applications for this kind of profiles, the ability to present better thermal and acoustic insulation is a key requirement. Thus, it will be necessary to evaluate the heat conduction resistance into the hybrid pultruded profile and compare it with the current profile. Indeed, there are available methods based on experimental procedures able to evaluate the transferred energy. These methods recognise two basic transfer mechanisms: thermal conduction and radiation [27].

Acoustic insulation refers to the material ability to resist to the sound waves' propagation. The larger is the resistance, the better will be the insulation ability. Sound can be considered as a mechanical compression front, which propagates in a circumferential way just in materials having mass and elasticity, such as solid, liquid and gases. The sound is characterised by the frequency in Hertz [Hz] and amplitude in decibels [dB]. The sound to the human ear is limited to the range of 20 Hz to 20 kHz frequency. Frequencies below 20 Hz are usually called infrasound and those above 20 kHz are ultrasonic [28]. Although ultrasonic frequencies are not audible by the human ear, they spread in the form of vibrations that can be detected and converted into electrical signals by adequate equipment, which allows the quantification of their intensity. In this way, acoustic insulation tests can be performed with ultrasound equipment, with the advantage of using a non-destructive method [28]. In order to evaluate the acoustic insulation, two different methods can be applied: Echoing Chamber or Stationary Waves, being the last one used in this work with adjusted dimensions as considered in other researches [29,30].

This study aimed at characterising a novel hybrid pultruded profile regarding the adhesion resistance between the pultruded profile and the core, its flexural resistance and both thermal and acoustic insulation properties.

2. Materials and methods

This section describes the tests undertaken in this work, corresponding setups, procedures and parameters. The core materials were

Table 1
Mechanical and physical properties of the core material - *Corecork*® NL20 [36].

Properties	Test Methods	Units	*Corecork*® NL20
Density	ASTM C271	kg/m³	200
Compressive Strength	ASTM C365	MPa	0.5
Compressive Modulus	ASTM C365	MPa	6.0
Tensile Strength	ASTM C297	MPa	0.7
Shear Strength	ASTM C273	MPa	0.9
Shear Modulus	ASTM C273	MPa	5.9
Thermal conductivity	ASTM E1530	W/m·K	0.034
Acoustic absorption coefficient at 500 Hz	_	Hz	0.33/0.35

Table 2
Properties of the polyurethane PUR60 [37,38].

Properties		Units	PUR60
Density		kg/m³	60
Compressive Strength	//	kg/cm²	3.6
	⊥	kg/cm²	1.9
Closed cell quantity		%	96
Thermal conductivity coefficient		W/m·K	0.023
Maximum temperature		°C	110
Modulus at 100% (ISO 37)		MPa	1
Acoustic absorption coefficient at 4 kHz		Hz	1

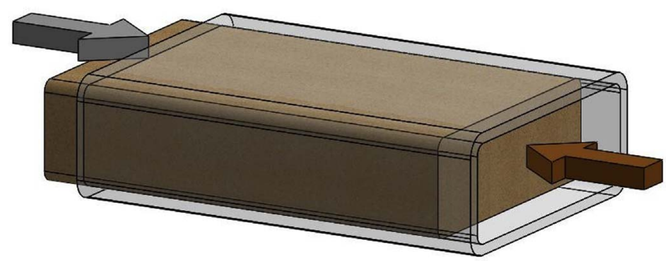

Fig. 1. Adhesion test by application of a compressive load applied between the core and the external pultruded profile.

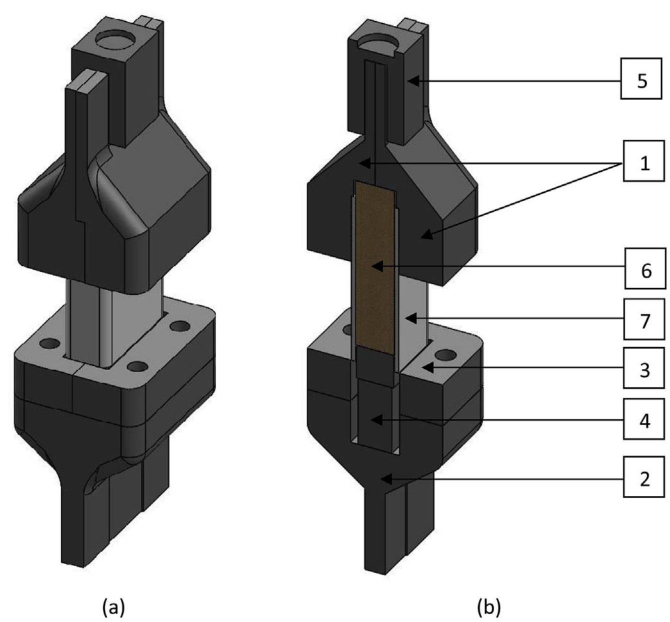

Fig. 2. (a) Schematic representation of the setup used to test the adhesion between the core and the external pultruded profile regarding the hybrid products tested (b) cross-section view.