Mechanical Performance of Reinforced Pultruded Columns for Curtain Walls

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Abstract. The present work is aimed at evaluating the mechanical performance of pultruded beams subjected to bending stresses through experimental tests. Such beams are intended to be used in a curtain wall construction system as a variant to a patent application (n.102020000025636) which includes wood columns. This variant wants to meet the need of smaller dimensions of the columns and keep guaranteeing the mechanical performance. The columns are made of pultruded I-beams, reinforced with glued metal plates and two prestressed threaded bars placed in the central axis of symmetry of the section. First, the materials (pultruded, steel plates, threaded bars and structural glue) are mechanically characterized; then, three types of columns are tested by means of a 3-point bending test and 3 loading/unloading cycles: (i) n. 1 beam with no reinforcement plates or pretension bars, (ii) no. 2 beams with reinforcement plates and no pretension bars, (iii) no. 2 beams with reinforcement plates and pretension bars. The maximum deformation in the elastic range for all reinforced beams (11.48 mm) is measured by applying a load of approximately 10 kN, corresponding to a wind pressure of more than double the requirement for windows (2000 Pa). The contribution of the threaded bars to the maximum applicable load is negligeable, which can be ascribed to their placement in the middle of the section. This first solution is chosen because of the small dimensions of the GFRP profile section.

Keywords: Pultruded columns · Mechanical performance · Curtain wall

Nomenclature

E_t	Young's modulus in tension
ε_t	Tensile strain
ε_y	Yielding strain
ε_{max}	Tensile strain at failure
σ_t	Tensile strength
σ_y	Yielding stress
σ_{ys}	Tensile yield strength
σ_{max}	Tensile strength at failure
τ	Shear strength
k	Stiffness
W_t	Working temperature

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A_t	Application temperature
T_g	Glass transition temperature
S_t	Service temperature

1 Introduction

Within the curtain wall market segment, the current demand is increasingly oriented towards large glazed surfaces and transparent casing supported by lean frames (typically stainless steel or aluminum), to which the load of the glass panels is transferred [1, 2]. This trend leads to the need, also confirmed by the latest regulatory developments, of ever-growing high-performance (mechanical, energetic and environmental) materials and components.

Glass Fiber Reinforced Polymer (GFRP) pultruded profiles are a good solution to satisfy these requirements, thanks to their light, strong and durable features. GFRP matrix also has low thermal and electrical conductivity. All these characteristics made GFRP profiles started being used in many branches of civil engineering by the end of last century. Significant applications have been made in the field of windows frames [3, 4] but also bridges and building structures [5]. Thanks to their increase in structural applications, GFRP pultruded profiles have been widely investigated in their mechanical properties. A number of studies have been carried out on samples [6–9], also under critical conditions [10, 11], as well as on full-scale elements such as joints [12, 13], profiles [14] or panels [15]. Some studies also focused on GFRP behaviour when coupled with other materials [16–19].

In this work the mechanical performance of pultruded GFRP beams subjected to bending stresses is evaluated through laboratory tests. These beams are included in the patent n. 102015000087569 “Sistema per la realizzazione di facciate per edifici”, concerning smaller-section columns for curtain wall systems, reinforced with pretended bars or strands. They are intended to be used in a curtain wall construction system as a variant to a patent application (n.102020000025636) which involves wood columns (Fig. 1). Such curtain wall system has been designed to be structurally simpler, more flexible and rapid to assemble compared to the solutions available on the market, allowing effective and robust support even in the case of very large glazed panels (i.e., 3.00 x 3.00 m). Supplementary features are: low environmental impact thanks to the lower number of components compared to analogous solutions available on the market, good thermal insulation, possibility of both industrial and handcrafted production. In addition to the mentioned characteristics, the variant with the pultruded columns tested in this piece of research wants to meet the need of smaller dimensions of the columns, guaranteeing a comparable mechanical performance.

Fig. 1. Curtain wall system prototype.

2 Materials and Methods

The tested columns are made of pultruded GFRP I-beams (section 15.5 x 7.5 cm), reinforced with 2 mm thick metal plates (covering the entire upper surface of the wing) and two prestressed threaded M16 bars (Fig. 2). The steel plates, bonded to the beams at the upper surface of the wings with structural epoxy glue in the transversal direction, have the dual purpose of limiting the deformation of the GFRP and facilitating the use of bolted joints to fix the glazed panels. This avoids the insertion of bolts directly in pultruded profiles, which interrupts the fibres of the material and reduces its mechanical performance.

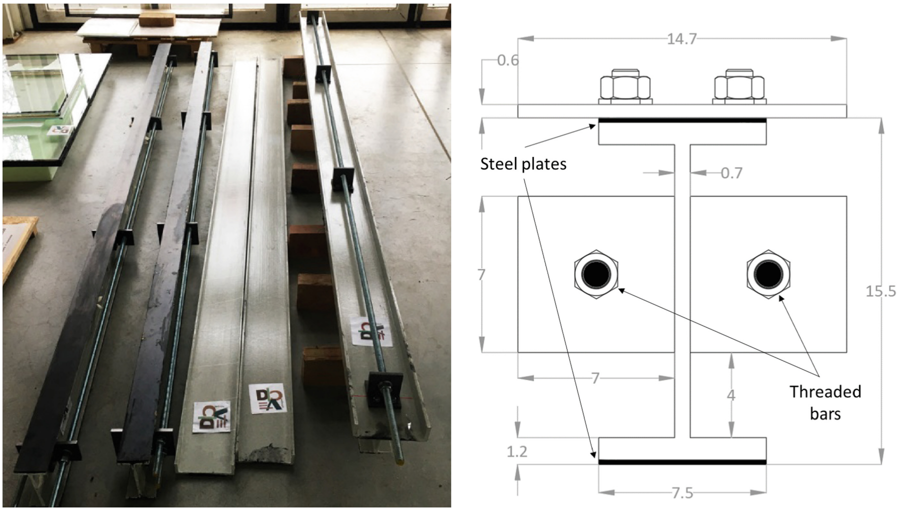

Fig. 2. Tested GFRP I-beams: picture (left) and sketch of the cross section (right)

The bars, bonded to the beam with two L-shaped steel profiles, have the purpose of to increasing the GFRP bearing capacity and limit its deformations in order to contain the dimensions and better respond to the market demand requiring almost seamless surfaces. Because of the small dimensions of the profile section, and to make the curtain wall structure resistant to both wind pressure and depression, as a first solution the bars have been placed in the central axis of symmetry of the section. This solution is easy-to-make, though placing the rods closer to the profile wings would improve the mechanical response.

2.1 Material Characterization

This section describes the mechanical characteristics of the materials used in the experimental campaign, i.e., GFRP beams, steel plates, threaded bars and structural glue. GFRP pultruded profiles are manufactured by Fibrolux (Germany), S275JR steel plates are manufactured by Termoforgia (Italy), the structural adhesive is a two-component epoxy (2K) EPX (3M™ Scotch-Weld™ Epoxy Adhesive 7260). The properties of the materials, as reported by the manufacturers in their technical sheets, are reported in Tables 1 and 2.

Table 1. Technical and mechanical parameters of the GFRP profiles and steel plates as reported by manufacturers.

GFRP profiles*			Steel plates**			
E_t (GPa)	σ_t (MPa)	ε_t (%)	E_t (GPa)	σ_{ys} (MPa)	σ_t (MPa)	ε_t (%)
26	400	1.5	210	326.7	385.5	29.1

* according to EN 755–2
**according to EN 10025–2:2004.

Table 2. Technical and mechanical parameters of the adhesive as reported by manufacturer.

Adhesive	EPX
Chemical base	Two-part epoxy
Viscosity	Thixotropic
W_t (min)	16
A_t (°C)	15 ÷ 25
T_g (°C)	66.87
S_t (°C)	-40 ÷ 80
τ*(MPa)	29.40*
E_t (MPa)	1500

(*continued*)

Table 2. (*continued*)

Adhesive	EPX
ε_t **(%)	-
Use	Semi-Structural

* On aluminium-steel adherends

** At failure.

The mechanical properties of the threaded rods (M16, CL 8.8) have been previously experimentally characterized [18, 20] using tensile tests according to UNI EN 10002-1. The tensile tests were performed with a Zwick-Roell ZMART.PRO universal tensile machine with a loading speed rate of 1.27 mm/min. Table 3 shows the mechanical parameters measured by the tensile tests.

Table 3. Mechanical characteristics for M8 rods (experimental) [20].

Material	E_t (GPa)	σ_{max} (MPa)	ε_{max} (%)	σ_y (MPa)	ε_y (%)
M16 rods	214 ± 14.24	663.17 ± 7.45	0.65 ± 0.00	600 ± 9.01	0.28 ± 0.02

2.2 Test Settings

A 3-point bending test simulating the wind load to which the structural parts of a facade or windows can be subject, is carried out according to UNI EN ISO 14125 [21] on three types of columns: (i) n. 1 beam with no reinforcement plates or pretension bars (N), (ii) no. 2 beams with reinforcement plates and no pretension bars (R1, R2), (iii) no. 2 beams with reinforcement plates and pretension bars (RB1, RB2). The vertical force is applied by means of a hydraulic jack (maximum load 500 kN). A settling load of about 4 kN is first applied on the middle axis and then, removed. Next the transversal displacements are measured with 3 LVDT devices (whose position is shown in Fig. 3 and detailed in Table 4) by applying a load until a maximum deflection of L1/250 is reached for each column, where L1 is the span of the beam. The beam is then unloaded. The loading/unloading cycle is repeated 3 times for each tested column. Figure 3 shows a sketch of the test setup and Table 4 reports the specifications of the tested columns.

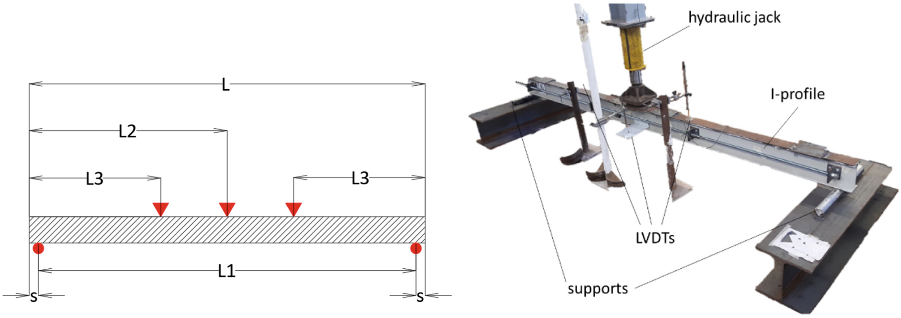

Fig. 3. Test setup: sketch (left) and picture /right). In the sketch, red triangles indicate the position pf the LVDTs, red circles stand for the supports.

Table 4. Characteristics of the tested columns.

Column type	L (cm)	S (cm)	L1 = L-2s (cm)	L2 (cm)	L3 (cm)	$\delta_{lim\_L/2}$ = L1/250 (mm)
GFRP with no reinf. plates or pretens. bars (N)	305	7	291	152.5	100	11.64
GFRP with reinf. plates with and without pretens. bars (R and RB)	301	7	287	150.5	100	11.48

3 Results

Figure 4 shows the results of the 3-point bending test on all tested GFRP pultruded columns. The blue lines indicate data acquired by the LVDT placed at L/3-left side, green lines are for L/3-right side, orange lines indicate LVDT in the central axis (L/2). Red bar stands for the limit deformation of L1/250 for each column. Results are also summarized in Table 5. For N type column, only the L/3-right side curve is displayed since, for a technical issue, the L/3-left side measurement is not acquired.

The curves show a global linear trend for both loading/unloading phases. A nonlinear behavior is locally registered after the load changes its direction. The maximum applied load is comparable for all reinforced configurations (R_i and RB_i), with a maximum difference of 0.53 kN (5.3%) recorded between the two configurations reinforced with steel rods (RB1 and RB2). The stiffness, calculated as the average on the three load cycles for each column, is comparable for all configuration (except the N type, for which the shape of the load/displacement diagram made useless its calculation). These observations seem to show that in this case the contribution in strength of the threaded bars is negligeable, which can be ascribed to the positioning of the rods in the central axis of the column. To improve the contribution of the bars, it is sufficient to move them

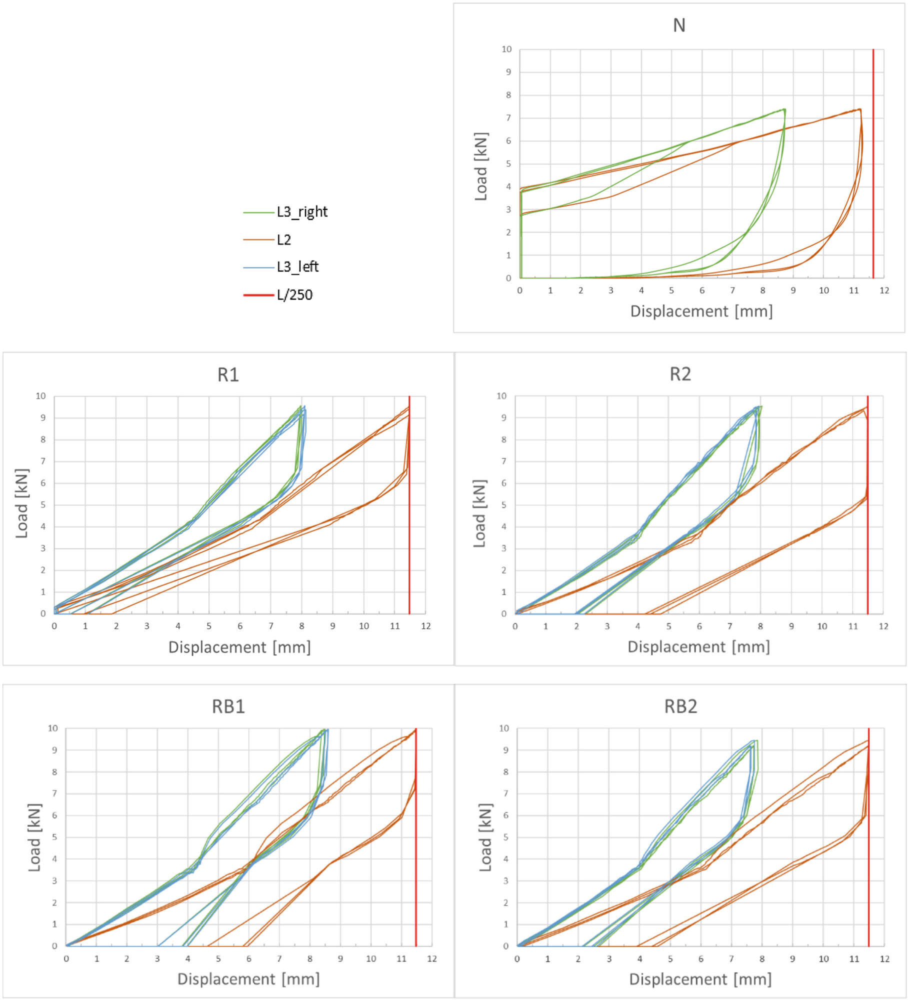

Fig. 4. Results of the 3-point bending test.

towards the section fibres under tension. This solution responds to the higher possibility that the structure is subject to pressure stress rather than depression; on the other hand, a double bar solution would satisfy both stress conditions, but requires larger dimensions of the profile.

In any case, no residual deformation is recorded, which confirms that all measurements are performed in the elastic range. Within the latter, the maximum deformation for all reinforced beams (11.48 mm) is measured by applying a load that settles around 10 kN, corresponding to a wind pressure of more than double the requirement for windows (2000 Pa).

Table 5. Main results of the 3-point bending test.

Column type	δ_{max} L/2	Max load	***k***
	(mm)	(kN)	(kN/mm)
N	11.24	7.40	-
R1	11.48	9.57	0.82 ± 0.017
R2		9.54	0.82 ± 0.009
Mean Values		**9.56**	**0.82**
RB1		9.97	0.86 ± 0.004
RB2		9.44	0.81 ± 0.013
Mean Values		**9.71**	**0.83**

4 Conclusions

In this study, an experimental campaign to analyze the mechanical performance of reinforced pultruded columns intended for curtain walls is carried out.

Three types of GFRP columns are subject to a 3-point bending test with 3 load/unload cycles.

GFRP columns are a valid alternative to obtain slender frames and may be an effective variant to wooden column used in the patent application n.102020000025636.

Results show that adding threaded bars to GFRP columns reinforced with steel plates placing them in the central axis of the beam has no influence on the maximum applicable load, being equal the ultimate deformation.

Possible future developments will focus on similar loading tests carried out on columns with the threaded bars placed in the area of the tensile fibres of the I-section. This will require the design of an appropriate technical-constructive solution in order to keep small the dimensions of the section and, at the same time, increase the contribution of pre-tensioned bars, (i.e., the configuration reported in Fig. 5). In addition, a variant having double pretension bars (in order to respond to both pressure and depression stress) and slightly greater dimension of the section is currently under development for a future experimental test campaign.

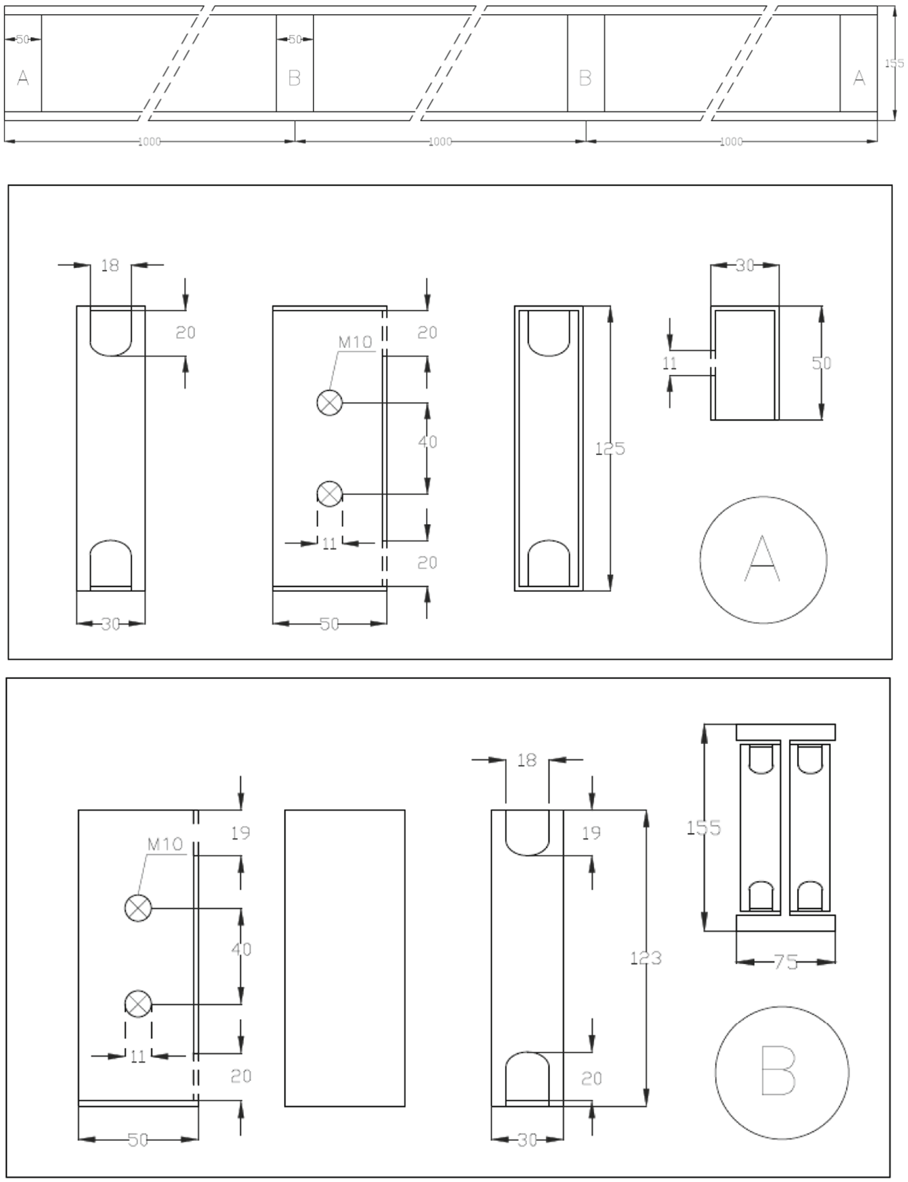

Fig. 5. Hypothesis for a double bar profile section

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