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# STRUCTURAL RESPONSE OF COMPOSITE PULTRUDED ELEMENTS SUBJECTED TO SHEAR

BY

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**Abstract.** The shear properties of pultruded composite plates are especially needed for the structural design of composite load bearing elements when one considers the shear capacity, the local buckling of plate type elements and some types of joints.

The paper presents experimental results obtained on Iosipescu type samples cut from glass fibre reinforced polyester (GFRP) composite strips fabricated by pultrusion.

It has been found out that the pultrusion process leads to composite products with uniform and controllable properties, and the fibre orientation is decisive in establishing the shear structural response.

**Key words:** glass fibres; isophthalic polyesteric resins; shear stress; shear modulus.

## 1. Introduction

Fibre reinforced polymer (FRP) composite materials are engineering materials consisting of a polymeric resin (matrix) and fibres (reinforcement). In

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the pultrusion manufacturing process, unidirectional filaments and other continuous strand mats (CSM) are impregnated with the polymeric resin and pulled through a heated die to produce constant cross-section shapes of any length.

There are many advantages of the pultruded glass fibre reinforced polymer (GFRP) structural shapes: high tensile and flexural strength, lightweight, fine tolerances manufacturing, custom colours, non-conductive behaviour, as well as corrosion/chemical resistance (Barbero, 2011).

The design with GFRP pultruded load bearing elements, subjected to bending and shear, involves the knowledge of the shear strength values needed to check the ultimate limit states and the shear modulus of elasticity required to check the serviceability limit states. In particular, the shear characteristics of the pultruded GFRP elements are needed in the design process, especially in case of local buckling, web crippling and connection details (Bank, 1990).

The most utilized shear test methods for the GFRP pultruded products use standard sizes and shapes of the specimens to achieve well controlled testing conditions. The Arcan shear test (Arcan *et al.*, 1978), the two- and three-rail shear test (Adams *et al.*, 1994), the tension of ±45° laminate (ASTM D 3518/D3518M-13, 2013), the Iosipescu shear test (Iosipescu, 1967; ASTM D5379/D5379M-12, 2012), the asymmetric four point bending (AFB) of the *v*-notched Iosipescu test specimen are among the most frequently utilized shear test methods (Sleptz, 1978).

In this paper the authors present an experimental test and the results concerning the shear properties of pultruded GFRP materials with different orientation of the fibres using the standard Iosipescu device. The shear tests have been conducted for 0°, 45° and 90° fibre orientation degrees aiming to evaluate the shear stresses and the shear modulus.

## 2. Experimental Program

### 2.1. Materials

Three series consisting of five specimens for each direction, 0°, 45° and 90°, respectively, have been prepared for the experimental program. The specimen coupons have been sawn from composite pultruded plates made of isophthalic polyester resin and glass fibres having a thickness equal to 6 mm. The specimen sawing has been performed with diamond tools (a circular saw and a milling machine) to cut the notches. The geometric characteristics of the GFRP notched specimens are presented in Fig. 1. The shear mechanical characteristics of the pultruded GFRP specimens supplied by the manufacturer are given in Table 1 (Fiberline Design Manual, 2002).

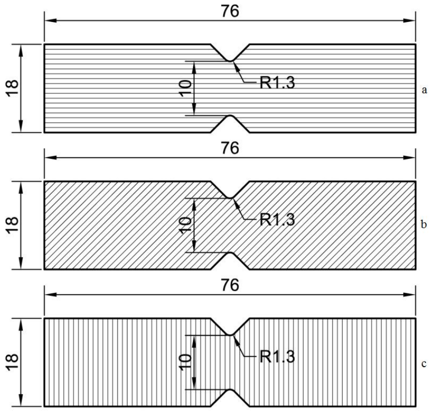



Fig.1 – GFRP specimens with different orientation of fibres: 0°, 45°, 90°.

**Table 1**
*Shear Mechanical Characteristics of the Pultruded GFRP Plates* (Fiberline Design Manual, 2012)

| Characteristics | GFRP plates |
|---|---|
| Shear modulus, [GPa] | 3 |
| Shear strength, [MPa] | 25 |

The shear tests of the specimens have been performed using a 600 kN universal testing machine (Fig. 2) equipped with integrated load cell and transducers for monitoring the force and displacement during the experiment.

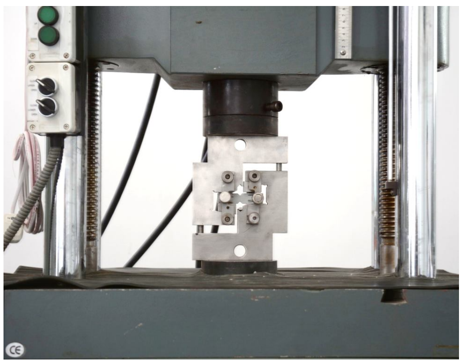


Fig.2 – The universal testing machine and the Iosipescu shear device with the GFRP specimen installed for testing.

The speed of the tests has been 2 mm/min provided by a constant crosshead movement according to ASTM D5379/D5379M-12.

The force *vs*. displacement average curves for each group of five specimens are plotted in Fig. 3 and the average values of the failure forces, the shear stresses and the fixture vertical displacements of specimens are given in Table 2.

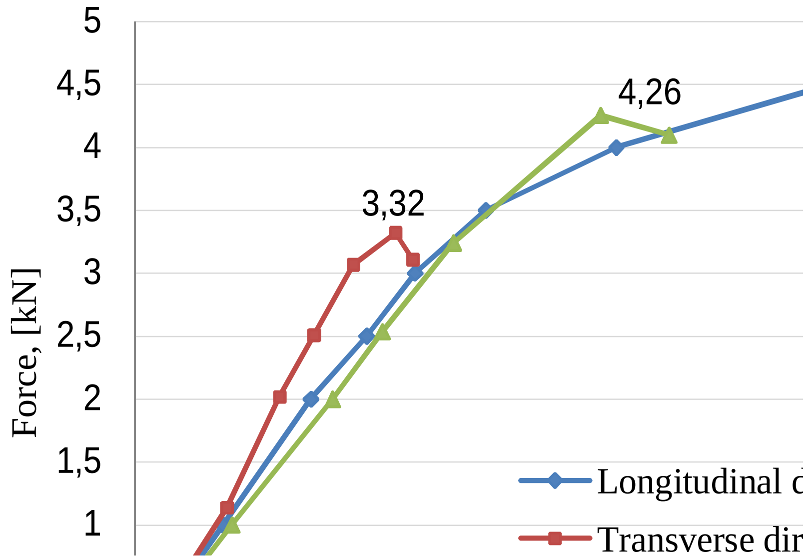



Fig. 3 – Shear force vs shear displacement (average).

The following main results can be observed from the analysis of the response curves:

a) the behaviour of the specimens is bilinear, with the initial values of the *P*-force relative to a constant area $A$ = 60 mm$^2$ (the net area of the notched specimen) which corresponds to the shear stress, $\tau$. In this phase the slope of the response curve is constant and the curve is linear;

b) the progressive deterioration of the polymeric polyester resin results in a change of the slope followed by reaching the ultimate strength, $\tau_{ult} = P_{ult}/A$;

c) the force *vs*. displacement curves illustrated in Fig. 3 reveal the difference in structural behaviour with respect to the fibre orientation: the maximum load bearing shear capacity was recorded in case of samples typ*e* a (longitudinal direction), while the minimum shear capacity was obtained for samples type *c* (transverse direction) for which the interlamelar shear failure was observed.

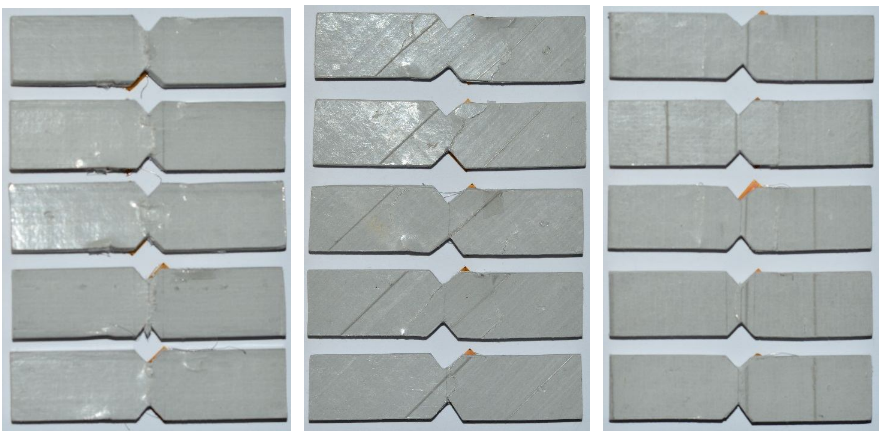
As expected the samples with fibre direction oriented at 45° showed an intermediate load bearing capacity.

Compared to specimens with 0° angle orientation of fibres in terms of shear stress, the values for the 45° samples are 9.4% smaller, and 40% for the transverse direction, respectively (Table 2).

**Table 2**
*Experimental Results – Average Values*

| Specimens | $F^{max}$, [kN] | $\tau^{max}$, [MPa] | $\delta^{max}$, [mm] |
|---|---|---|---|
| Longitudinal direction 0° | 4.66 | 77.66 | 5.81 |
| Angle direction 45° | 4.26 | 71.00 | 3.55 |
| Transversal direction 90° | 3.32 | 55.33 | 1.99 |

The failure mode of the samples is in good agreement with the ASTM D5379/D5379M-12 (Fig. 4). The fracture occurs in the middle part of the samples where the net area is minimum. The occurrence of cracks in the central area is perpendicular to the direction of the fibres and of the crushing attachment areas, where there are metallic wedges. This failure mode has been identified in all the samples tested with the arrangement of fibres perpendicular to the direction of testing. According to ASTM D5379/D5379M-12, the failure mode code for samples with fibre orientation $\theta$ = 0° is VGN (V is the abbreviation for vertical cracking, G is the gage section and N is the notch region) (Fig. 4 *a*).



*a* *b* *c*

Fig. 4 – Failure modes of the specimens: *a* – longitudinal; *b* – angular; *c* – transverse.

The failure mode code for samples with fibre orientation $\theta$ = 45° are various such as: VGN (2 samples), angled cracking gage section adjacent notches–AGA (2 samples) and multimode gage section adjacent notches–MGA (1 sample) (Fig. 4 *b*).

Failure mode codes identified for samples with fibre orientation $\theta$ = 90° are: VGN (2 samples), and vertical cracking in the notched regions adjacent to notches-VNA (3 samples) (Fig. 4 *c*).

## 3. Conclusions

The pultruded specimens have been tested according to the Iosipescu shear test.

The four point loading generates a high shear stress at the centre of the GFRP specimen, nearly zero moment. The first vertical shear crack (Fig. 3), appears in the notch area as follows: a force of over 3 kN leads to the appearance of cracks in the specimen with fibre orientation at 90º and a force of over 4 kN for the other two cases, 45 and 0 fibre orientation degree, respectively.

The fiber orientation in the analysed cases may substantially influence the shear characteristics of the composite material reinforced with glass fibres.

The values given by the producer (Fiberline A/S, Denmark) cover the shear strength design values regardless of the test direction.

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# COMPORTAREA STRUCTURALĂ A MATERIALELOR COMPOZITE PULTRUDATE SUPUSE LA FORFECARE

(Rezumat)

Proprietățile la forfecare ale plăcilor compozite pultrudate sunt necesare pentru proiectarea elementelor structurale atunci când se ia în considerare capacitatea portantă la această solicitare sau se analizează flambajul local al elementelor compozite de tip placă şi unele tipuri de îmbinări.

Se prezintă rezultatele experimentale obținute pe probe încercate pe dispozitivul Iosipescu, tăiate din plăci compozite polimerice armate cu fibră de sticlă (CPAFS), fabricate prin pultrudere.

S-a constatat faptul că procedeul de pultrudere conduce la obținerea unor produse compozite cu proprietăți uniforme şi controlabile, iar orientarea fibrelor este decisivă în stabilirea răspunsului structural la solicitările de forfecare.